Measuring Tackle and Ruck Technique in Rugby Union

by

Stefanus den Hollander

Thesis presented for the Degree of

DOCTOR OF PHILOSOPHY

In the Department of Human Biology

Faculty of Health Sciences

Division of Exercise Science and Sports Medicine

University of Cape Town

South Africa

February 2020

Table of Contents

Acknowledgments

Dr Sharief Hendricks

Thank you for everything, I would not be where I am today without your wisdom, guidance and input. Thank you for getting me to the top of this mountain and encouraging and supporting me along the way. Your perspective on life has kept me grounded, and you have been an incredible mentor throughout this journey. I look forward to continuing to work with you.

Professors Mike Lambert & Ben Jones

What a privilege it has been to have the two of you in my corner. Mike, thank you for your pearls of wisdom throughout the years. I admire your integrity, humility and passion towards your work and life. Ben, even though your support has been from a distance, the impact has been large. Thank you for taking a genuine interest.

Financial Support

UCT Benfara Scholarship, UCT Frank Foreman Grant, NRF Free-standing Scholarship, NRF International Travel Grant and UCT International Travel Grant. Thank you for your support. This thesis would not have been possible without you.

Special Mentions

To the ESSM staff and students; Ayesha Hendricks, Trevino Larry, thank you for all the assistance and support throughout the years. To the rugby research group; Nic Burger, James Brown, Wayne Viljoen, Clint Readhead, Lindsay Starling, Demi Davidow and Jason Wulfson, thank you for all the input. To the Western Province Rugby Academy; Anton Moolman, Alastair Theys, Angelo Nelson, Gareth Dunn and Greg Hunt, thank you for giving me the opportunity to do research in an applied setting. Your input has and experience has shaped my

understanding of the game. Lastly, thank you to all the players from SK Walmers and WPRA, this thesis would not have been possible without you.

Friends & Family

To my friends and family, thank you for all the encouragement every step of the way. To my parents, Welly and Daan, you are an inspiration to me. Thank you for giving me an opportunity to follow this path. To my wife, Desi, you are the bomb. Thank you for all the love, support and encouragement. This would have been a lot harder without you. To my Father, thank you for your provision, love and giving me an eternal perspective.

Declaration

I, Stefanus den Hollander, hereby declare that the work on which this thesis is based is my own original work (except where acknowledgments indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university. I authorise the University to reproduce for the purpose of research either the whole or any other portion of the contents in any manner whatsoever.

Signed by candidate

Signature: Date: 24 January 2020

Academic Outputs

Peer-reviewed publications

1. den Hollander S, Jones B, Lambert M & Hendricks, S. **The what and how of video analysis research in rugby union: a critical review.** *Sports Medicine Open* 2018; 4 (1): 1-14.
2. den Hollander S, Lambert M, Jones B, & Hendricks, S. **Tackle and ruck technique proficiency within academy and senior club rugby union.** *Journal of Sports Science* 2019; 1-10.
3. den Hollander S, Ponce C, Lambert M, Jones B, & Hendricks, S. **Tackle and Ruck Technical Proficiency in Rugby Union and Rugby League: A Review.** *Science and Medicine in Football* (in review).

Other publications

1. **Match and collision characteristics and exposures across world rugby union.** Preliminary Report: World Rugby Project 17031 *(August 2019)*
2. **What makes a safe and effective tackle.** rugbyscientists.com *(https://rugbyscientists.com/2018/02/01/what-makes-a-safe-and-effective-tackle-10-contact-techniques-to-focus-on-during-training/).*
3. **Safe and effective contact technique part 2: The ball-carrier**. rugbyscientists.com *(https://rugbyscientists.com/2018/03/29/safe-and-effective-contact-technique-part-2-the-ball-carrier/).*
4. **Our quest to review all the skills in rugby**. rugbyscientists.com *(https://rugbyscientists.com/2015/04/16/our-quest-to-review-all-the-skills-in-rugby/).*

Conference outputs

1. **The contact skill characteristics of an academy rugby union team**. 17th Biennial Congress of the South African Sports Medicine Association (SASMA). *Cape Town, South Africa (October, 2017).*
2. **The what & how of video analysis in rugby union: A critical review.** 23rd Annual Congress of the European College of Sport Science (ECSS). Dublin, Ireland (July 2018).
3. **Tackle & ruck technique proficiency within academy and senior club rugby.** 2nd BRICS Conference of Exercise and Sports Science (BRICSES). *Cape Town, South Africa (October, 2019).*
4. **Tackle and ruck technical proficiency in rugby union & rugby league: a review.** 18th Biennial Congress of the South African Sports Medicine Association (SASMA). *Cape Town, South Africa (October, 2019).*

Other presentations

1. **Effective tackle and ruck technique.** Western Province Rugby Academy. *Cape Town, South Africa (February, 2019).*

List of Tables

List of Figures

Thesis Abstract

Background: Developing tackle and ruck technique is important to improve performance in matches and reduce the risk of injury. Little is known regarding valid tools to assess tackle and ruck technique in rugby union. The aims of this thesis were (1) to assess the validity and representativeness of the contact assessment tool, and (2) to identify factors which may affect the degree to which contact technique developed in training transfers to matches.

Methods: Tackle, ball-carry and ruck technique of players competing at different levels of play were assessed in a two-on-two training drill using standardised technical criteria. Technique scores between levels of play were compared to assess the validity of the contact assessment tool, and contact technique scores assessed in training and matches were compared to assess the representativeness of the tool. Physical qualities and questionnaire data on the importance of technique to improve performance and reduce injuries were compared to contact technique scores assessed in training, to determine the effect of physical conditioning and player's knowledge on contact technique proficiency. Finally, tackle and ruck technique scores assessed in training and matches were compared to measures of match performance and contact related injuries.

Results: Senior players scored significantly higher in the tackle, ball-carrier and ruck assessment than academy 1st and 2nd level players, demonstrating the good construct validity of the assessment tool. Contact technique scores were associated with performance outcomes in training and in matches, although technique scores in matches were lower than technique scores in training. There were no significant relationships between player's knowledge of the importance of contact technique and their contact technique proficiency. There were moderate to large associations between various physical qualities and tackle, ball-carry and ruck technique scores assessed in training. Players with better contact technique in matches

performed better in matches, however, there were no meaningful correlations between contact technique in training and match performance or match related contact injuries.

Conclusions: These findings demonstrate the validity of a tool to assess contact technique in rugby union with good representative learning design, however progressing the drill into less structured environments is recommended to further improve the representativeness of the assessment environment. Furthermore, the findings highlight the importance of contact skill training and physical conditioning to ensure skills developed in training are transferred to match performance.

Roadmap of Thesis

In this thesis we assessed the validity and representativeness of a tackle and ruck technique assessment tool and identified factors which may affect the degree to which contact technique developed in training transfers to matches.

Chapters 1 and 2 reviewed provide the background and rationale of the thesis. Chapter one gives a critical review of video analysis research in rugby union and highlights the need for valid skill assessment tools in rugby union. Chapter 2 provides a scoping review of tackle and ruck technique in rugby union and league. The primary purpose of this chapter is to present the current research investigating tackle and ruck technique and highlight areas yet to be examined. Chapter 3 to 7 are the study chapters of the thesis. Chapter 3 examined the validity of a contact technique assessment tool, and chapter 4 examined the representative design of the tool. In chapters 5 and 6 we described the relationship between tackle and ruck technique, and physical qualities and knowledge, respectively. Chapter 7 investigated the relationship between technique assessed in training and matches, and measures of match performance and injury outcomes. An outline of the aims and objectives of the thesis, and the specific research questions for each study chapter, are provided after the review chapters (1 and 2). Chapter 8 concludes the thesis, providing answers to each research question, the practical applications and limitations of the thesis, and recommendations for future research. Practical applications and limitations for each study can also be found in the discussion sections of the relevant chapter.

Chapter 1: Literature review of video analysis research in rugby union

A version of this chapter has been published as:

den Hollander S, Jones B, Lambert M & Hendricks, S. **The what and how of video analysis research in rugby union: a critical review.** *Sports Medicine Open* 2018; 4 (1): 1-14.

Introduction

Rugby union is a high-intensity collision-based sport (119). It is played by over 9.6 million players, in over 120 countries, which makes it one of the most played sports in world (222). The sport is also associated with a higher risk of injury, compared to other sports like Association Football (14). The higher injury risk is due to the dynamic environment in which physical contact occurs between players, with the tackle accounting for more than 50% of all match-related injuries (158).

The drive to reduce the risk of injury and improve performance in rugby has set in motion a high volume of scientific research including the analysis of match video footage to identify and describe player and team actions (12, 130), usually in relation to performance or injury outcomes (206). Arguably, a strength of video analysis is that it allows for dynamic and complex situations in sports to be quantified in an objective, reliable and valid manner (53).

Video analysis research in rugby union frequently includes *what* studies that identify key events (for example, number of tackles in a match) to *how* studies that describe key events (for example, tackle technique relates to injury). Furthermore, the scope of these studies ranges from the description of in-depth case studies (27, 100, 120) to the broad analysis of commercial databases (160, 195, 203); and from studies that apply sophisticated statistical modelling that accounts for context (13, 85, 88) to studies that only report on the frequencies of events (40, 115, 196). The sizes and types of samples used in these studies also vary considerably, a similar finding to that in Association Football (for a review: see Mackenzie and Cushion, 2013 (121)).

Due to the many different types of studies using video analyses in rugby, it is difficult to standardise the techniques. This makes it difficult to compare studies and translate the findings

to a real-world setting. In response to this, a critical review of the literature on video analysis research in rugby union was performed. The aim was to critically appraise the studies to determine how the findings can be used to inform practise.

Methods

The purpose of a critical review is to show an extensive overview of the literature, as well as a critical evaluation of the quality of the literature (75). It exceeds a narrative review of the studies by including a degree of analyses (75). The methods of a systematic review were used in the literature search (49, 96). This was done to ensure that all the available relevant literature was included in the review (75). The critical evaluation of the literature was performed through the use of a series of polar questions (Table 1.1). In line with the purpose of the review, these questions were related to the methodology of the studies, namely, how the researchers used video analysis methods to collect data and answer specific research questions. Polar questions were used to attempt to provide a level of objectivity to the evaluation.

Systematic literature search

Specific search terms were used to identify peer-reviewed articles in three electronic databases, SCOPUS, PubMed and Web of Science. The search terms were 'rugby union' in the title, keywords or abstract linked with either 'performance analysis', 'video analysis,' 'tackle performance', 'video', 'notational analysis', 'match performance', 'match analysis', 'time motion analysis', 'attacking strategies', 'defensive strategies', 'performance indicators', 'injury risk', 'injury mechanisms' or 'injury rates' anywhere in the text. The time frame for the literature search was any study published before 2017. The search results from the three databases were merged, and any duplicates were removed.

Table 1.1 Polar questions used to review literature

Sample Type
Was a complete season/tournament analysed?
Was the research from a one-off tournament (example, World Cup)?
Did the research include data from multiple seasons or tournaments?
Were differentiations made between competition stages?
Operational Definitions
Were the variables analysed fully defined?
Were the variables partially defined?
Was reference made to a previous publication, or the development of definitions, but not provided in the article?
Were definitions provided insufficient?
Match Related Context
Was the relative strength of the opposition considered in the analysis?
Was there a reference made to the match location?
Were environmental factors considered? (Weather, field condition)
Event Related Context
Was there a comparison between different outcomes?
Was the playing position included in the analysis and differentiated in the results?
Was the field position taken into consideration?
Was there specific information relating to the playing situation of the assessed variables? (Formation or movement of the attacking and defensive lines, the number of support players, the type of pass/kick etc.)
Was technique assessed? (Injury studies only)
Practical Applications
Was there a reference to the practical application of the findings?

The inclusion criteria were as follows: the article needed to use video analysis to quantitatively study rugby union match footage and needed to be published, in English, in a peer-reviewed journal. Inclusion criteria were applied at the title, abstract and full-text level, and any article not meeting the criteria was omitted from the review. A second author applied the inclusion criteria to the merged database at the title, abstract and full-text level, to assess the inter-rater reliability of this process of the literature search. Where there were any disparities between the two databases, the reasons for including or excluding the relevant papers were discussed and the studies were either included or excluded from the final database.

The reference lists of the papers that met the inclusion criteria were checked, and any relevant papers were added to a separate database. Inclusion criteria were applied to this database, at abstract and full-text levels. The papers that met the criteria were merged into the original database. The outcome of this process was a total of 92 papers (Figure 1.1).

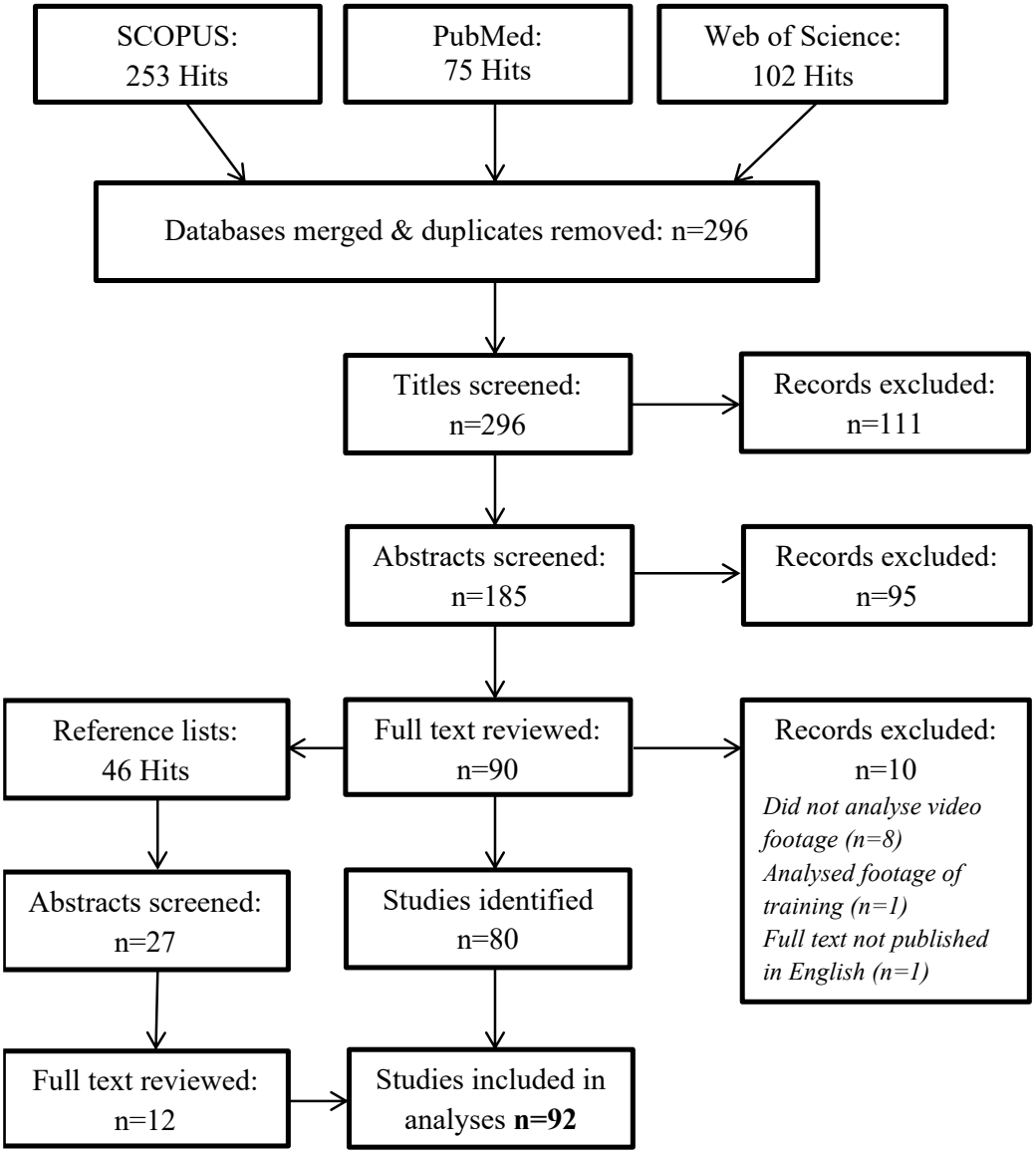

Figure 1.1 PRISMA flow diagram of literature search.

Critical evaluation

Data related to the aims, outcomes, variables investigated, sample sizes and type, and key findings of the studies were extracted from the identified papers. The identified papers were categorised into three groups based on the outcomes of the paper; *physical demands*, *performance* and *injury*. Seventeen studies did not fall under these groups and were reviewed under the category *other*. Within these categories, the studies were further categorised into *what* and *how* studies, based on the research question. Studies that identified the frequencies of specific variables were categorised as *what* studies. These were typically studies which used broad statistical analyses of large databases. Studies that identified the associations between different variables to describe how an event occurred were categorised as *how* studies. Grouping the studies into these two categories allowed for more homogenous comparisons during the review process.

Furthermore, classifying the studies into these two groups also allowed for different requirements for the different types of video analysis studies. Video analysis research involves the analysis of the frequencies or counts of specific variables, termed key performance indicators (KPIs) (132). Typically, *what* studies identify KPIs associated with specific outcome. The primary requirement for *what* studies is that the samples used are sufficiently large so that the findings are generalisable. It is also important that the samples are representative of the general rugby population, including multiple teams, seasons or levels of play, for the findings to be considered useful. The crucial requirement for *how* studies is that contextual variables are included in their analyses. The purpose of these studies is to understand how an outcome occurs. As rugby is a dynamic sport, any finding must provide or account for the context in which the finding occurred for it to be applicable (123). This brings up the final requisite for the studies. With the view that video analysis research should be progressive, the research questions of *how*

studies should be based on the findings of *what* studies, and the practical applications of the research, based on the findings of how studies (Figure 1.2).

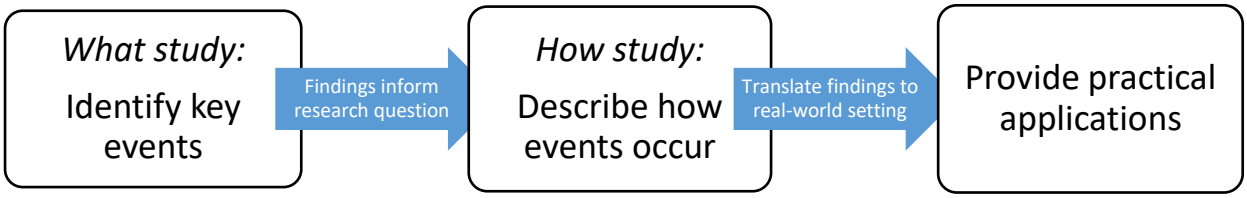

Figure 1.2 The sequence of applied video analysis research of match performance.

With these requirements in mind, a number of polar questions (Table 1.1) were developed to review the studies. The questions were developed through the use of previous literature (121), and questions developed specifically for this review. The questions specifically addressed areas of criticism of performance analysis research (121, 123, 206). The first set of questions evaluated the sample selected for the study, and the second the provision of definitions for the variables used in the analysis. The third group of questions evaluated the inclusion of variables that provide context to the event analysed. A common criticism of video analysis is that it has a tendency towards reductionism (8, 74, 206). If the actions identified and described in these studies are analysed in isolation, the context in which they occur can be lost. A number of approaches have been suggested on how to provide context (8, 70, 74, 206). All these approaches involve identifying patterns between the event identified in the study and specific task and environmental variables (contextual variables) related to the analysed event or match. The questions used in this review evaluated the number of contextual variables included in studies. The final question identified whether or not the studies provided practical applications for their findings.

Statistical analysis

The results of the critical evaluation were analysed using descriptive statistics (count and percentages), to describe and compare the frequency of occurrences.

Results

A total of 92 studies were included in the review. The papers were categorised into three groups (i.e., *performance*, *physical demands*, *injury*) based on the outcomes of the paper (Figure 1.3). Seventeen papers did not fall into these categories; the outcomes of these papers included the development and comparisons of tools (17, 44, 101, 118, 145, 147), touchline safety (56), decision-making behaviours (26), and the effects of law changes (163, 177, 193, 194, 218), professionalism (47, 48, 143), and time (154) on various match characteristics.

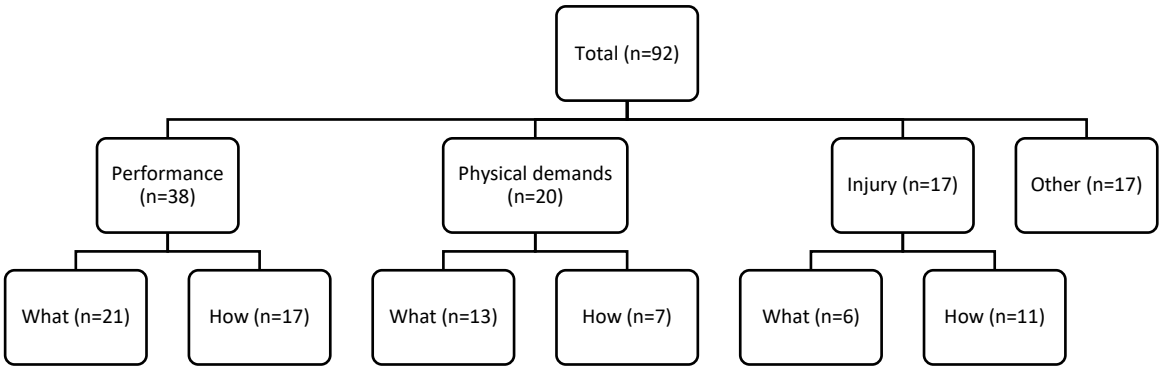

Figure 1.3 Categories of video analysis studies; n = the number of studies.

Sample size and selection

Three out of 21 performance-related studies in the sub-category *what* had sample sizes larger than 100 games. Forty-seven percent of these studies included data from multiple competitions or seasons, and 38% of the samples were from one-off tournaments that do not occur annually. Tables 1.2 and 1.3 provide a summary of the sample sizes and types used in the studies.

Table 1.2 A summary of the sample sizes

Sample size	Physical demands				Performance				Injury related			
	What		*How*		*What*		*How*		*What*		*How*	
	Yes (n)	Studies	Yes (n)	Studies	Yes (n)	Studies	Yes (n)	Studies	Yes (n)	Studies	Yes (n)	Studies
Number of matches												
<10	8	(3, 4, 38, 39, 81, 102, 119, 127)	3	(81, 112, 200)	4	(9, 11, 141, 197)	5	(27, 100, 126, 214, 215)	1	(161)	0	
10-35	3	(46, 156, 210)	3	(45, 77, 157)	8	(23, 103, 113, 115, 142, 198, 199, 205)	8	(40, 50, 85, 88, 111, 114, 159, 201)	1	(149)	1	(54)
36-100	2	(146, 209)	0		6	(13, 134, 195, 196, 202, 208)	2	(99, 216)	1	(55)	1	(125)
101-200	0		0		0		2	(36, 72)	0		0	
201-300	0		0		1	(160)	0		1	(175)	0	
300+	0		0		2	(203, 204)	0		2	(104, 144)	0	
Not published	0		1	(150)	0		0					
Number of players												
<10	0		0		0		0		0		0	
11-20	2	(3, 4)	0		0		0		0		0	
21-30	5	(38, 39, 46, 119, 156)	2	(112, 150)	0		0		1	(161)	0	
31-40	1	(210)	1	(200)	0		0		0		0	
41-50	0		1	(45)	0		0		0		0	
51-100	0		1	(77)	0		0		0		0	
101-200	0		0		0		0		0		0	
201-300	0		1	(157)	0		0		0		0	
300+	2	(146, 209)	0		1	(160)	0		0		0	
not published	1	(127)	0		0		0		0		0	
Number of events												
<20	0				0		0		0		2	(120, 124)
21-30	0				0		2	(27, 100)	0		1	(221)
31-40	0				1	(11)	0		0		0	
41-50	0				0		1	(40)	0		1	(192)
51-100	2	(82, 102)	1	(81)	0		0		0		4	(86, 87, 131, 183)
101-200	0				1	(115)	0		0		0	
201-300	0				0		0		0		0	
301-400	0				0		3	(36, 114, 126)	1	(149)	1	(16)
401-500	0				1	(142)	0		0		0	
501-1000	0				1	(113)	2	(99, 159)	0		0	
1001-2500	0				0		5	(85, 88, 111, 214, 215)	0		0	
2501-5000	0				0		0		0		0	
5000+	0				2	(195, 196)	1	(216)	3	(55, 144, 175)	2	(54, 125)

n: number of studies

Table 1.3 A summary of the types of samples selected

Sample	Yes (n)	Studies	No (n)	Studies	N/A (n)	Studies
Physical demands – What						
Complete season/tournament?	2	(146, 209)	11	(3, 4, 38, 39, 46, 82, 102, 119, 127, 156, 210)		
Is the research from a one off tournament(s)?	2	(82, 209)	11	(3, 4, 38, 39, 46, 102, 119, 127, 146, 156, 210)		
Includes data from more than one season/tournament?	4	(4, 5, 38, 146)	9	(39, 46, 82, 102, 119, 127, 156, 209, 210)		
Did the study differentiate between competition stages?	2	(82, 102)	10	(3, 4, 38, 39, 46, 82, 119, 127, 146, 156, 209)	1	(210)
Physical demands – How						
Complete season/tournament?	0		7	(45, 77, 81, 112, 150, 157, 200)		
Is the research from a one-off tournament(s)?	0		7	(45, 77, 81, 112, 150, 157, 200)		
Includes data from more than one season/tournament?	5	(45, 77, 81, 150, 157)	2	(112, 200)		
Did the study differentiate between competition stages?	0		5	(45, 77, 81, 112, 157)	2	(150, 200)
Performance - What						
Complete season/tournament?	12	(11, 13, 23, 115, 160, 195, 196, 202-204, 208)	9	(9, 103, 113, 141, 142, 197-199, 205)		
Is the research from a one-off tournament(s)?	8	(9, 11, 23, 197-199, 205, 208)	13	(13, 102, 113, 115, 134, 141, 142, 160, 195, 196, 202-204)		
Includes data from more than one season/tournament?	11	(13, 113, 115, 134, 142, 160, 195, 196, 202-204)	10	(9, 11, 23, 102, 141, 197-199, 205, 208)		
Did the study differentiate between competition stages?	4	(9, 196, 199, 205)	15	(11, 23, 102, 113, 115, 134, 141, 142, 160, 195, 197, 198, 203, 204, 208)	2	(13, 202)
Performance - How						
Complete season/tournament?	5	(36, 72, 99, 111, 201)	12	(27, 40, 50, 85, 88, 100, 114, 126, 159, 214-216)		
Is the research from a one-off tournament(s)?	2	(99, 126)	15	(27, 36, 40, 50, 72, 85, 88, 100, 111, 114, 159, 201, 214-216)		
Includes data from more than one season/tournament?	2	(50, 114)	15	(27, 36, 40, 72, 85, 88, 99, 100, 111, 126, 159, 201, 214-216)		
Did the study differentiate between competition stages?	0		15	(27, 36, 50, 72, 85, 88, 99, 111, 114, 126, 159, 201, 214-216)	2	(40, 100)

Table 1.3 (cont.) A summary of the types of samples selected

Sample	Yes (n)	Studies	No (n)	Studies	N/A (n)	Studies
Injury - What						
Complete season/tournament?	3	(104, 144, 175)	3	(55, 149, 161)		
Is the research from a one-off tournament(s)?	0		6	(55, 104, 144, 149, 161, 175)		
Include data from more than one season/tournament?	4	(55, 104, 144, 149)	2	(161, 175)		
Did the study differentiate between competition stages?	0		1	(144)	5	(55, 104, 149, 161, 175)
Injury - How						
Complete season/tournament?	3	(16, 86, 87)	8	(54, 120, 124, 125, 131, 183, 192, 221)		
Is the research from a one-off tournament(s)?	0		11	(16, 54, 86, 87, 120, 124, 125, 131, 183, 192, 221)		
Include data from more than one season/tournament?	10	(16, 54, 86, 87, 120, 124, 125, 131, 183, 192, 221)	1	(124)		
Did the study differentiate between competition stages?	0		4	(120, 124, 183, 192)	7	(16, 54, 86, 87, 125, 131, 221)

n: number of studies

Definitions of variables

Fifty percent of the studies provided full definitions for the variables used in the analyses. In 19% of the studies, the variables were partially defined, 5% referred to definitions published elsewhere and 26% provided in-sufficient definitions. A summary of the operational definitions provided can be found in Table 1.4.

Table 1.4 A summary of the definitions provided for all studies

Definitions provided	Number of studies (n)	Percentage of total (%)
Fully defined	46	50.0
Partially defined	17	18.5
Reference made to definition	5	5.4
Insufficiently defined	24	26.1

Context

Less than half of the sub-category *how* studies included match-related contextual variables in their analyses (16 out of 35). Twenty-six percent of the studies included variables related to the opposition strength, 8% variables related to match location and 6% of studies included variables related to environmental conditions.

Nineteen out of 35 sub-category *how* studies (54%) included more than three event-related contextual variables in their analysis. Eighty-four percent of performance related studies and 64% of injury studies included variables related to the outcome of the event. One hundred percent of studies in the category physical demands included and differentiated between variables related to playing position, compared to 47% of performance studies and 45% of injury studies. Seventy-three percent of injury-related studies and 59% of performance studies included variables which describe the playing situation. A summary of the use of contextual variables can be found in Tables 1.5 and 1.6.

Table 1.5 The number of categories of contextual variables included in the analysis; where a category was not applicable to the study, it was counted as included

Number of match categories included	**Number of studies**	**Studies**
0	19	(27, 40, 45, 50, 54, 77, 81, 85, 88, 99, 100, 113, 120, 157, 192, 201, 214, 216, 221)
1	13	(16, 36, 72, 86, 111, 112, 124-126, 131, 183, 200, 215)
2	3	(87, 150, 159)
3	0	
Number of event categories included	**Number of studies**	**Studies**
0	1	(124)
1	7	(16, 72, 86, 114, 120, 201, 221)
2	8	(27, 100, 125, 126, 192, 200, 215, 216)
3	16	(40, 45, 50, 54, 77, 81, 85, 87, 88, 99, 111, 112, 150, 157, 183, 214)
4	3	(36, 131, 159)

Table 1.6 A summary of the *how* studies that included contextual variables in the analyses

Context	Yes (n)	Studies	No (n)	Studies	N/A (n)	Studies
Physical demands						
Was the strength of the opposition considered?	1	(200)	6	(45, 77, 81, 112, 150, 157)		
Was the match location considered?	0		5	(45, 77, 81, 157, 200)	2	(112, 150)
Were environmental factors considered?	1	(150)	6	(45, 77, 81, 112, 157, 200)		
Was there a comparison between outcomes?	3	(81, 157, 200)	4	(45, 77, 112, 150)		
Were the playing positions considered?	7	(45, 77, 81, 112, 150, 157, 200)	0			
Performance						
Was the strength of the opposition considered?	4	(36, 111, 159, 215)	13	(27, 40, 50, 72, 85, 88, 99, 100, 114, 126, 201, 214, 216)		
Was the match location considered?	2	(72, 159)	14	(27, 36, 40, 50, 85, 88, 99, 100, 111, 114, 201, 214-216)	1	(126)
Were environmental factors considered?	0		17	(27, 36, 40, 50, 72, 85, 88, 99, 100, 111, 114, 126, 159, 201, 214-216)		
Was there a comparison between outcomes?	14	(27, 36, 40, 50, 72, 85, 88, 99, 111, 114, 126, 159, 201, 214-216)	3	(99, 100, 114)		
Were the playing positions considered?	7	(36, 40, 50, 85, 114, 159, 214)	8	(27, 72, 88, 111, 126, 201, 215, 216)	2	(99, 100)
Was the field location of the events considered?	9	(27, 36, 40, 50, 88, 99, 100, 111, 159)	8	(72, 85, 114, 126, 201, 214-216)		
Was there specific information relating to the playing situation of the assessed variables?	10	(36, 85, 88, 99, 111, 126, 159, 214-216)	7	(27, 40, 50, 72, 100, 114, 201)		
Injury						
Was the strength of the opposition considered?	0		11	(16, 54, 86, 87, 120, 124, 125, 131, 183, 192, 221)		
Were environmental factors considered?	1	(131)	10	(16, 54, 86, 87, 120, 124, 125, 183, 192, 221)		
Was there a comparison between outcomes?	7	(16, 54, 86, 87, 125, 131, 183)	4	(120, 124, 192, 221)		
Were the playing positions considered?	5	(54, 87, 131, 183, 192)	6	(16, 86, 120, 124, 125, 221)		
Was there specific information relating to the playing situation of the assessed variables?	7	(54, 87, 120, 125, 131, 183, 221)	4	(16, 86, 124, 192)		
Was technique assessed?	7	(16, 86, 87, 125, 131, 192, 221)	4	(54, 120, 124, 183)		

Practical application of studies

Eighty-one percent of studies identified in this review provided practical applications for their findings. Differentiating between *what* and *how* studies showed that 76% of *what* studies provided practical applications compared to 86% of *how* studies. Table 1.7 provides a summary of these results.

Table 1.7 A summary of the reference to practical application

Reference to practical applications		Yes (n)	Studies	No (n)	Studies
Physical demands	***- What***	13	(3, 4, 38, 39, 46, 82, 102, 119, 127, 146, 156, 209, 210)	0	
	- How	6	(45, 77, 112, 150, 157, 200)	1	(81)
Performance	***- What***	13	(9, 13, 23, 103, 113, 115, 134, 160, 195, 202, 203, 205, 208)	8	(11, 141, 142, 196-199, 204)
	- How	13	(36, 40, 50, 72, 85, 88, 99, 100, 111, 159, 201, 215, 216)	4	(27, 114, 126, 214)
Injury	***- What***	5	(104, 144, 149, 161, 175)	1	(55)
	- How	11	(16, 54, 86, 87, 120, 124, 125, 131, 183, 192, 221)	0	

n: number of studies

Discussion

The video analysis of match footage is a common tool used to provide researchers with objective, quantifiable data about match performance (12). Although video analysis studies are often grouped together, there is a large disparity in the type of data gathered and the level of analysis conducted within these studies. The studies range from broad statistical analyses of commercial databases to more in-depth case studies (18). As a result of this disparity, the findings of these studies have been challenged because of the questionable generalisability of the findings, and the reductionist nature of some of the analyses (70, 74, 121, 123). In response to this finding a critical review of video analysis research in rugby union was performed, appraising the samples used, the provision of definitions to the variables analysed, the inclusion of contextual variables in the analysis and the provision of practical applications for the findings.

Sample size and selection

There was a large range in the sample sizes of the studies identified in this review. Sample sizes range from three studies with samples of less than five matches (39, 100, 102), to four studies analysing over 300 matches (104, 144, 203, 204). Two of the studies with samples of less than 5 matches (39, 102) were not purely video analysis studies and involved taking blood samples of the players. This may account for the small samples. The other study, a case study (100), was categorised as a *how* study and required the analyst to code each match manually. The four studies with large samples were all categorised as *what* studies and had access to large commercial or team databases for their analyses. However, differentiating the studies into *what* and *how* studies did not drastically reduce the range in sample size. Within the sub-category *what*, 13 studies had samples of less than 10 games, in contrast to the four studies with samples of over 300 games. Similarly, within the *how* sub-category, samples ranged from one study with a sample of 35 min of four games (39) to two studies which analysed 125 matches (36, 72). There is, therefore, a need for a consensus on the sample size that would accurately reflect the rugby union population.

Not all studies described the samples used in terms of the number of matches analysed. Some studies described their samples in terms of the number of players investigated, and some by the number of events analysed (Table 1.2). Interestingly, there was an association between the three outcome categories of studies identified in this review and the description of the sample. For example, *physical demands* studies predominantly describe their samples in terms of players analysed, whereas *performance* studies refer to the number of matches analysed, and *how performance* studies focus largely on the number of events. The *injury* studies described matches in the sub-category of *what* studies and events in the *how* sub-category of studies.

This suggests that any consensus statement would need to differentiate between the different categories and/or sub-categories.

A requisite of *what* studies is that the samples are sufficiently large for general claims to be made from their results. In the context of 129 games in an English Premiership season, or 135 in a Super Rugby season, only 3 of the 21 performance studies (14%) and 3 of the 6 injury studies (50%) investigated 100 matches or more. One third of the performance studies specifically analysed matches from the Rugby (Union) World Cup, a competition that only consists of 48 matches. Only one of these studies (208) analysed all 48 matches, in comparison with two studies with samples of five matches (11, 197). Furthermore, the effect of the change of time (47, 48, 143, 154) and competition (142) on match characteristics questions the validity of analysing one-off tournaments and highlights the importance of including multiple seasons or competitions in samples to improve the generalisability of the results. However, 10 out of 21 performance studies included only one season or competition in their sample, and 8 studies were from one-off tournaments. These findings question the generalisability of the samples, and subsequently the results. The results from the injury-related *what* studies are more positive, with 67% of studies including data from multiple seasons or competitions, and none of the studies analysing one-off tournaments.

In *how* studies, it was more applicable to refer to the number of events analysed, than matches. Although all 17 studies in this sub-category reported the number of matches analysed, with the exception of George et al. (2015) (72), the studies did not analyse entire matches; instead they analysed certain events and outcomes identified in matches which were specific to the aims of the particular study. There is a large range in the number of events analysed in these studies, with some studies reporting samples of 20–30 events (27, 100, 221), and others with more than

5000 events (54, 125, 216). However, as the frequency of different events differs within matches, the statistical power of a sample cannot simply be assessed by the number of events analysed. For example, at first glance, a study of 8653 events (216) would seem to have more statistical power than a study of 362 events (36). The first study analysed rucks and the second line breaks. In a match, there are approximately 142 rucks (216), compared to an average of three line breaks per match (36). The line breaks study, thus, coded 125 matches to identify and analyse the 362 line break events (36). The study that analysed rucks, analysed 8563 rucks in 60 matches (216). Therefore, although the one study analysed far fewer events than the other, it analysed more than twice as many matches. This provides a challenge when assessing the individual merits of each study. Reporting sample size calculations may provide a more suitable basis to evaluate sample sizes (121). Unfortunately, only one of the 35 sub-category *how* studies identified in this review reported a sample size calculation (54) (examples of how to perform a sample size calculation can be found in Kirkwood & Sterne ({Kirkwood, 2003 #998}) and Hopkins ((97))).

Studies in the category *physical demands* aim to identify and describe the physical demands of playing a rugby union match. A study of the match-to-match variability of high-speed activities in football (76) showed that a sample size of at least 80 players would have sufficient statistical power to make meaningful inferences about the physical demands of match play. If that number is taken as a sufficiently powered sample only three *physical demands* studies had samples larger than 80 players. This suggests that 76% of the studies were underpowered.

Definitions of variables

There was a lack of clarity and transparency in the definitions of the variables used in the studies. Only 50% of studies fully defined the variables used in their analysis, with 26%

providing no definitions. As a result, it becomes difficult for other researchers to compare the results of these studies or replicate them (121). What further compounds this problem is that definitions of variables differ. For example, one study (201) used the International Rugby Board's definition of a tackle, where a ball-carrier needs to be brought to ground for a tackle to occur (223), whereas other studies have defined a tackle as any attempt to stop or impede a ball-carrier, whether or not the ball-carrier is brought to ground (54, 144). Although both studies are analysing tackles, they may not always be analysing the same event. Therefore, comparisons between the findings of these studies need to be interpreted with caution. This review highlights the need for a consensus among researchers using video analysis in rugby union, on the operational definitions of variables used in rugby research comparable (i.e. like the injury definitions for rugby union (57)).

Context

Particularly in *how* studies, it is important that the frequency of KPIs are not analysed in isolation, but that the context in which the KPI occurs is included in the analysis. A number of approaches have been suggested on how to provide context to the KPIs; through the use of ecological system dynamics (123, 206) through a constraints-based approach (74) or through temporal pattern analyses (12). All of these approaches involve identifying patterns between the identified KPIs and specific task and environmental variables (contextual variables) related to the analysed event or match.

The first group of variables provide context to the match that was analysed. The relative strength of the opposition, the location of the match or the environmental conditions may alter a team's tactics and, therefore, have an effect on the frequency of a KPI (36, 43). In an analysis of line breaks, den Hollander and colleagues found that teams created more line breaks when

playing against weaker opposition, compared to equally ranked or stronger opposition (36). Similarly, George and colleagues (2015) found that teams created more line breaks, missed fewer tackles and scored more points playing at home, compared to playing away (72). Yet, only 9 out of 35 of the studies (26%) accounted for opposition strength, 8% differentiated between match location, and only 2 studies (6%), (1 study on *physical demands* (150) and 1 *injury* study (131)) included environmental conditions in their analysis. Information regarding environmental conditions, like rainfall, can be difficult to gather retrospectively. Weather websites usually provide information about the amount of precipitation there was on the day of the match, but not the specific time or consistency of the rainfall. Overall, the inclusion of variables that give context to the match was poor. Over half the studies reviewed did not include any match-related variables in their analysis, and only three studies included two of the three categories of match variables in their analyses.

The results of studies that included variables that provide context to the event analysed were more positive. The majority of studies included more than three out of a possible four categories and only one study did not include any contextual variables (124). The category of context included seemed to depend on the type of study. The majority of *performance* studies included the match or event outcome in their analysis, most of *injury* studies included variables which described the playing situation in their analysis, and every *physical demands* study included playing position in their analysis.

To be useful, KPIs need to relate to an outcome (70). For example, comparing the frequencies of KPIs with successful and unsuccessful events, injury and non-injury events or different outcomes to a phase of play enables the researcher to determine if a variable is specifically related to the event or if it occurs in general. In this way, one outcome acts as a control for

another outcome which also allows researchers to apply more sophisticated probability statistics (36). The comparison of outcomes was common in both performance (84%) and injury (64%) studies. The inclusion of outcome variables was less common in *physical demands* studies. Only three of the seven studies compared match or event outcomes, and only one of those studies was related to the distances players cover in a match. Interestingly, this study found no differences in the physical movement patterns between winning and losing teams (157).

There are clear physiological differences in the match demands between forwards and backline players in rugby union (43), and therefore it is not surprising that 100% of the *physical demands* studies differentiated between playing positions. Studies have also shown differences in skill demands between playing positions (36, 40, 195). Van Rooyen (2012) reported differences between the number of tackles made by forwards and backs, with back row forwards attempting and completing more tackles than any other positional group (195). Positional differences have also been found in the number of line breaks made, with backline players more likely to complete line breaks, compared to forwards (36, 40), and significant differences in the types of skills used by inside and outside backs in the build-up play leading to line breaks (36). Despite these findings highlighting the difference in skill demands between positions, only 47% of *performance* studies and 45% of *injury* studies differentiated between playing position.

The category playing situation accounts for variables that describe the situation in which the event occurred. These can be variables that describe the interactions between teammates and opposition players. Examples of this are studies that analysed the interactions between attacking and defensive line shapes and movements when identifying key variables (36, 88, 215, 216) . Similarly, some studies analysed the interactions between opposing players in

contact (54, 85, 87, 183, 221). As this category was specific to events, and *physical demands* studies mainly described the demands of entire matches and not events, only studies related to *performance* and *injuries* were reviewed in this category. Most of the studies reviewed attempted to account for the playing situation, with 73% of *injury* studies and 59% of *performance* studies including variables related to the playing situation.

These findings show that most of the *how* studies reviewed attempted to provide context for their results, although perhaps more attention could be given to variables related to the match context. The authors also acknowledge there are restrictions and limitations in including too many variables in an analysis. Many journals have word count restrictions, which impacts on the number of variables a study can report on. A study may, thus, have initially included variables in their analysis, but not included them in the publication as the findings were insignificant. Authors may also divide their study up into multiple papers, and unless read together the context of their findings may be lost. Despite these limitations, all of the *how* studies reviewed included at least one contextual variable in their analyses, and 30 of the 35 papers included at least two types of contextual variables in their analyses.

Practical application of studies

A primary purpose of video analysis is to provide individuals involved in sports with objective and reliable information which can be used to inform practice (132). Therefore, it is not surprising that 93% of studies gave practical applications for their findings. However, it is debatable whether all these findings, specifically those from *what* studies, provide practical information (121). For example, a study by Ortega and colleagues identified the differences between winning and losing teams in 58 Six Nations games (134). They found that winning teams scored more points and lost fewer set-pieces, compared to losing teams (134). The

practical applications for their findings were that 'teams can use the information to set goals for players and teams in both practices and matches' (134). As most teams set themselves out to out-score the opposition, as well as win all of their set-pieces, the practical applications offered by the study offers very little applicable information to coaches. However, from a research perspective, the study has identified three areas for future studies to investigate; how teams score points, win lineouts and win scrums. A series of studies by Wheeler and colleagues (214, 215), analysed the skills that led to tackle breaks, an outcome identified as an effective means of scoring points in rugby union (215). The key skills associated with tackle breaks were fending and evasive manoeuvres. Thus, the researchers suggested coaches develop evasive agility training programmes to improve their players' ability. As these *how* studies were able to investigate further into specific skills and events, the authors were able to provide more specific practical applications for those directly involved in rugby. To facilitate the transfer and adoption of research outcomes from research to practice, it is suggested that the practical application provided by video analysis research come from the findings of *how* studies, and the results of *what* studies inform the research questions of *how* studies.

The final step in the process of applying research to practice is to evaluate the effect of the research findings on practice and performance. For the results of *physical demands* studies, this process is simple. These studies provide insight into the average distance players run, at which speeds they run, and the amount of time they spend at work and at rest. Coaches and strength and conditioning coaches can use this information to set criteria, and, subsequently, measure their players, using standardised physical tests, to assess whether they meet these demands (84). This process provides practitioners with applicable information to develop player-specific training programmes and goals. After a significant period of time, a player's movement patterns in a match could be assessed to see if the changes in training, informed by

research, improved his or her physical performance. However, evaluating the impact of findings from *performance* and *injury* studies is not as simple. The findings are mostly related to skills and technique, predominantly focussing on techniques related to tackling (16, 85, 86, 179) and ball-carrying (36, 214, 215). These studies provide coaches with insightful information to improve performance and reduce injuries. Before a coach can develop training programmes specific to their players' needs, they need to be able to assess player's skill proficiency in an objective and reliable manner. Although attempts to measure skill in rugby have been reported (84), to the author's knowledge, little has been documented on rugby union specific contact skill assessment tools. Therefore, to assess the effect of tackle related research findings, there is a need for valid rugby union specific skill assessment tools.

Conclusions

The aim of this paper was to provide a critical review of video analysis research in rugby union. The review identified a large disparity in the type of data gathered in the studies and the level of statistical analysis conducted within the studies. The studies were categorised based on the outcome of the study (*physical demands*, *performance* or *injury related*) and the type of analysis (*what* or *how*) to facilitate more homogenous comparisons during the review process.

There was a large range in the sample sizes of the studies. The review raised concerns over the generalisability of the findings used in the majority of the studies reviewed and recommends that researchers adopt the practice of sample size calculations to ensure that studies are adequately powered.

Half of the studies appraised did not fully define the variables used in their analyses. There were also differing definitions of a variable between studies. These findings highlight the need

for a consensus on the definitions of variables used in rugby union research so that the findings from different studies are more.

Despite a common criticism that video analysis research has a tendency towards reductionism, all the *how* studies reviewed included contextual variables in their analysis with 86% including more than two categories.

Finally, an aim of video analysis research is to provide information to coaches and practitioners to inform practice. This information should be useful to a coach by not only answering the question of what happens in a match but also how it happens. To assist in this process, it is suggested that researchers in this field start by developing research questions to identify the *what*, to provide novel findings used to develop the research questions to understand the *how*. This process will allow researchers to provide coaches with practical information, based on the results of *how* studies, which are useful and applicable to develop practice.

Chapter 2: Literature review of tackle and ruck technique in rugby

A version of this chapter has been submitted as:

den Hollander S, Ponce C, Lambert M, Jones B, & Hendricks, S. **Tackle and Ruck Technical Proficiency in Rugby Union and Rugby League: A Review'** *to the International Journal of Sports Science & Coaching*

Introduction

In rugby union (RU) and rugby league (RL) players physically engage each other to compete for territory and ball possession (59, 129). The most frequent form of physical engagement is the tackle (55, 107) - defined as an event where a player carrying the ball (the ball-carrier) is physically impeded by another player (the tackler) (55, 107). In an average professional game, 160 tackles are made in RU and 590 in RL (94, 108). In both RU and RL, success is determined, in part, by the ability to win these tackle contests (59, 215). The tackle also has the highest injury frequency in both RU and RL, with tackle related injuries accounting for 54% of all injuries in professional RU (158) and 47% in professional RL (191). While the ball-carrier and tackler(s) actions before and during the tackle are largely similar in RU and RL, the actions of players after the tackle are different. In RL, the contest for ball possession discontinues after a completed tackle, with the attacking team maintaining ball possession for 6 tackles before handing over the ball, if still in possession (e.g., not scored a try or kicked the ball). In RU, the contest for ball possession continues until one or more players from each team are on their feet and physically contesting each other over the ball – this is known as a ruck. Once the ruck is formed, players are no longer allowed to play the ball and must drive over it to make it available for their teammates to play. In professional RU, ruck related injuries accounted for 10% of all injuries (158) and like the tackle, the ability to dominate the ruck contest is associated with overall player performance and team success (110). Other contact events in RU include scrums, line-outs and mauls. These events do not occur as frequently as tackles and rucks (149), and as such have lower injury incidence rates (149) and have less of an effect on match performance (212).

Proficient contact technique, for both the ball-carrier and tackler, is recognised as a leading factor in reducing tackle injury risk (15, 33, 86) while also increasing a player's chances of

tackle success (85, 179, 214). As such, international (World Rugby and the Rugby League International Federation) and national (for example, South African Rugby Union, New Zealand Rugby Union, Rugby Football League (UK)) governing bodies have invested substantial funding and resources into developing programmes that educate players, coaches and referees on the importance of proper technique during contact events (73, 153, 190, 207). To assist these educational programmes, and in general, to optimise contact training, research on technical proficiency in RU (specifically for the tackle and ruck) and RL (tackle only) has also grown in recent years. Studies have identified specific techniques related to injury and performance, and what player qualities and contextual factors influence technical proficiency. For example, players with better physical characteristics (e.g. upper body strength and power) have better tackle contact technique (168).

Other contact events in rugby include scrums (RU and RL) collisions (RU and RL), and mauls (RU only). However, these events do not occur as frequently (55, 128), and therefore, have lower injury incidence rates (.

With that said, to date, research on tackle and ruck contact technique in RU and RL has not been consolidated and synthesised in a manner for stakeholders to assimilate. Therefore, the purpose of this review was to systematically review RU and RL studies on tackle contact technique and RU studies on ruck contact technique.

Methods

A systematic review of the scientific literature was conducted with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Data sources and Search Strategy

Two reviewers independently searched three databases (SCOPUS, PubMed and Web of Knowledge) for eligible studies published up until 31 December 2018. The search strategy used consisted of a combination of the word 'rugby' connected through the Boolean term AND with the either tackl*, ball-carr*, ruck, technique, contact skill, characteristic or mechanism. The papers were screened for eligibility at the title, abstract and full-text level. The reference lists of papers that met the eligibility criteria were searched, and any relevant papers were screened for eligibility at the title, abstract and full-text level. Any disagreements on eligibility were resolved by consensus between the reviewers.

Eligibility criteria

The eligibility criteria for the review were as follows:

- An original research study published in a peer-reviewed journal.
- The study was published in the English language.
- The study was on either RU or RL; including rugby sevens (a variant of RU)
- The study analysed any technical movement pattern of a player in the tackle, ball-carry into contact, or ruck in the phases immediately before (preparation), during (execution) or immediately after (follow-through) contact.
- The study related the analysed technical variables to either a factor (physical measurements, age, experience, fatigue, context) or an outcome measure (performance, injury, level of play).

The following studies were excluded from the review:

- Studies on wheelchair rugby.

- The study assessed tackles or rucks but did not include the involved players' technical movement patterns in the analysis.
- The study analysed players' technical movement patterns but did not relate the results to a factor or outcome measure

Data extraction

The following data were recorded and extracted onto an Excel spreadsheet: publication details (title, author, year of publication), details of the sample (RU or RL, country, playing level, age group, sex, size, environment), the techniques analysed, the factors analysed, the outcome measure, the statistics used, the level of significance and, if reported, the effect size (ES), and lastly the key findings.

Review Typology

A narrative synthesis format was chosen to review and analyse the pool of literature. A narrative synthesis is an 'approach to the systematic review and synthesis of findings from multiple studies that rely primarily on the use of words and texts to summarize and explain the finding of the synthesis' (25, 138). Narrative syntheses can be utilized to review and assess quantitative and qualitative data and, in contrast to 'narrative reviews' and 'evidence syntheses', involve a systematic and pre-defined search strategy with a focus on producing a more textual synthesis versus other types of systematic reviews such as quantitative meta-analyses.

Results

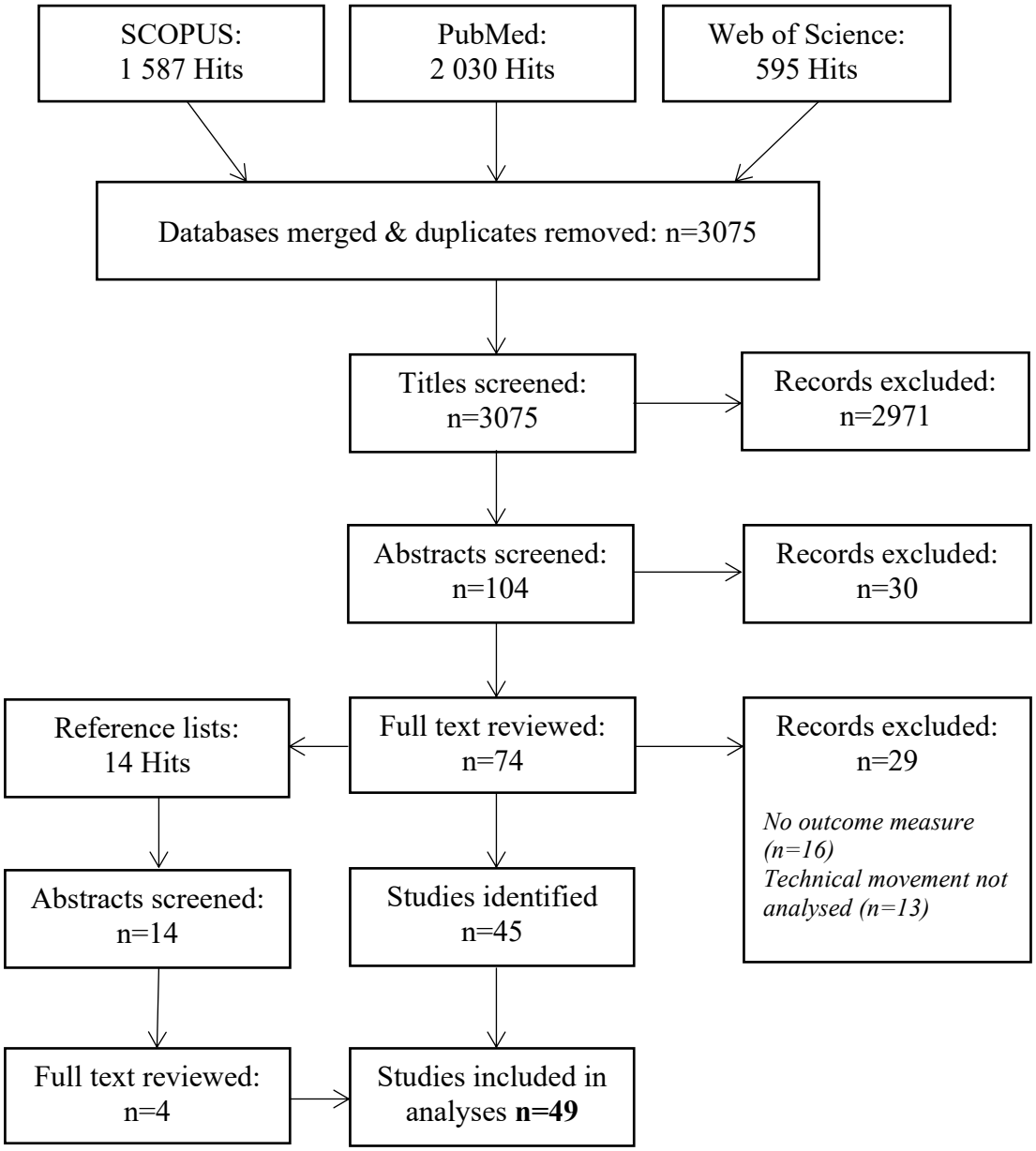

Figure 2.1 PRISMA flow diagram of literature search.

Forty-nine studies were included in the review. An overview of the search process can be seen in Figure 2.1. Twenty studies were in RL and 29 in RU (28 studies were found in RU and one study in rugby sevens). Eighteen (90%) of the studies in RL were authored by affiliates of the Australian Catholic University. Thirty-six percent of studies in RU studies were authored by affiliates of the University of Cape Town, and 23% by a group of authors affiliated with Trinity College. A global view of the authors and affiliations of the studies can be seen in Figure 2.2

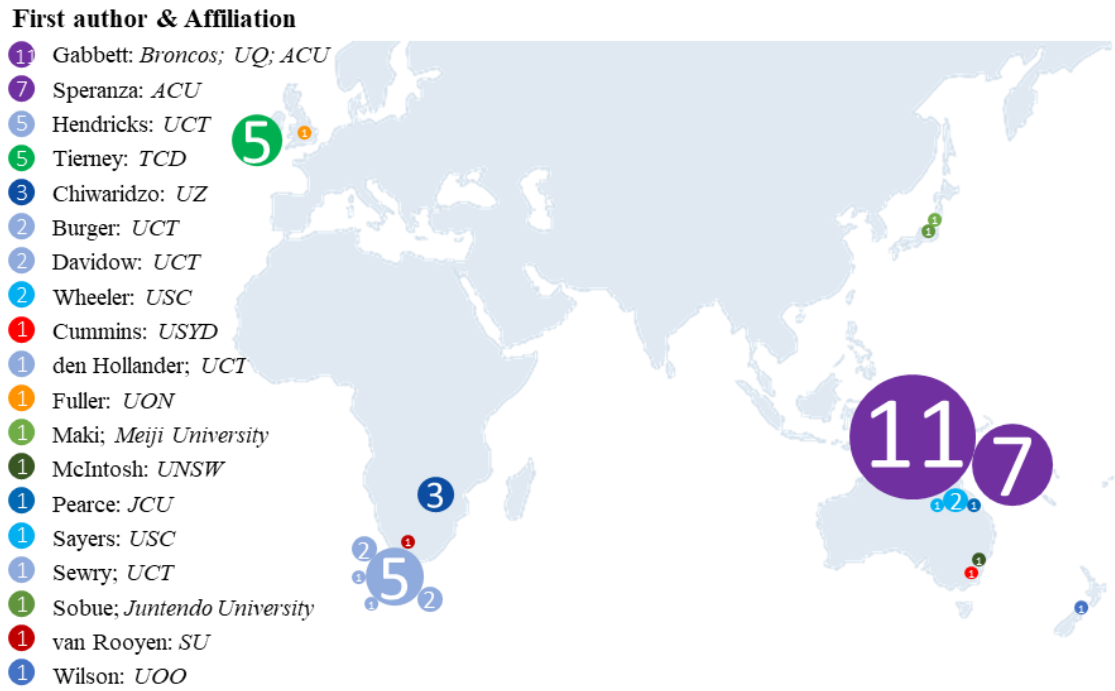

Figure 2.2 A global view of tackle and ruck technique research in rugby (size and number in balls represent the number of publications, colour of balls represents the university affiliation).

Tables 1 and 2 provide an overview of the studies in RU and RL, respectively. Ninety percent of RL studies (n=18) only analysed the tackler's technique, 10% (n=2) analysed both the tackler and ball-carrier's technique. Thirty-two percent of RU studies (n=9) only analysed the tackler's technique, 11% (n=3) only the ball-carrier's technique, 50% (n=14) both the tackler and ball-carrier's technique, and 7% (n=2) the tackler's technique, ball-carrier's technique and the technique of a player in the ruck.

Most RU studies assessed the effect of contact technique on injury outcomes (n=14; 50%) and performance outcomes (n=8; 29%). In RL, 55% studies assessed the effect of physical qualities on contact technique (n=11). Other variables commonly compared to contact technique in RL included match performance (n=6; 30%) and level of play (n=6; 30%).

Table 2.1 Summary of studies in rugby union (including RU Sevens)

Author(s) (year)	Sample Size	Age Group	Level	Analysis Environment	Technique Analysed	Analysis Model	Outcome(s) or Factor(s) variables	Key Findings
Burger et al. (2016) [16]	297 tackles	U18	Elite	Match	Tackle Ball-carry	Technical Criteria	Injury	Higher total technique scores were associated with non-injury tackle events.
Burger et al. (2017) [15]	297 tackles	U18	Elite	Match	Tackle Ball-carry	Technical Descriptors	Injury	Awareness of contact and fending were likely to reduce the risk of injury for the ball-carrier. Shoulder tacklers were likely to reduce the risk of injury for the tackler.
Chiwaridzo, Ferguson & Smits-Engelsman (2019) [20]	87 players	U19	Educational	Training	Tackle	Technical Criteria	Level of play	Tackling proficiency did not discriminate between levels of play.
Chiwaridzo, Ferguson & Smits-Engelsman (2019) [19]	71 players	U16	Educational	Training	Tackle	Technical Criteria	Level of play	Players who competed at a higher level of play had higher tackle technique scores, compared to players who competed at a lower level.
Chiwaridzo, Ferguson & Smits-Engelsman (2020) [21]	158 players	U16 U19	Educational	Training	Tackle	Technical Criteria	Age group & level of play	U19 players scored better in tackle technique assessment than U16 players. Players who competed at a higher level of play had higher tackle technique scores, compared to players who competed at a lower level.
Davidow et al. (2018) [33]	327 tackles	Senior	Amateur Elite	Match	Tackle Ball-carry	Technical Criteria	Injury	Higher total technique scores were associated with non-injury tackle events.
Davidow et al. (2020) [34]	19 players	Senior	Amateur	Training	Tackle	Technical Criteria	Fatigue	For both shoulders (dominant & non-dominant), fatigue had an overall decremental effect on tackling proficiency.
den Hollander et al. (2019) [37]	131 players	U21 Senior	Amateur	Training	Tackle Ball-carry Ruck	Technical Criteria	Level of play	Senior level players scored significantly higher than the academy level players in the tackle, ball-carry and ruck technique assessments.
Fuller et al. (2010) [54]	6219 tackles	Senior	Elite	Match	Tackle Ball-carry	Technical Descriptors	Injury	Head placement in front had a higher risk of injury to tackler than head to the side or above the ball-carrier.

Table 2.1 (cont.) Summary of studies in rugby union (including RU Sevens)

Author (year)	Sample Size	Age Group	Level	Analysis Environment	Technique Analysed	Analysis Model	Outcome(s) or Factor(s) variables	Key Findings
Hendricks et al. (2014) [85]	2092 tackles	Senior	Elite	Match	Tackle Ball-carry	Technical Descriptors	Performance	Head up and forward, counteracting the fend, shoulder tackles targeted at ball-carriers mid-torso, using arms to wrap or pull, and leg drive were associated with successful tackles.
Hendricks et al. (2015) [86]	24 tackles 65 rucks	U18	Elite	Match	Tackle Ball-carry Ruck	Technical Criteria	Injury	Higher total technique scores were associated with non-injury tackle and ruck events.
Hendricks et al. (2016) [87]	24 tackles	U18	Elite	Match	Tackle Ball-carry	Technical Descriptors	Injury	In 72% of tackles that lead to concussions the tacklers head was not 'up and forward.
Hendricks et al. (2018) [94]	4479 tackles	Senior	Elite	Match	Tackle Ball-carry	Technical Descriptors	Performance	Fending increased chances of offloading and breaking tackle. Actively placing ball increased probability of maintaining possession after the ruck.
Hendricks et al. (2019) [91]	135 matches	Senior	International (Sevens)	Match	Tackle Ball-carry	Technical Descriptors	Performance	Strong leg drive was associated with tackle success for both the ball-carrier and tackler. Fending increased the prospect of breaking the tackle. Actively placing the ball increased the likelihood of maintaining possession after the ruck.
Maki et al. (2017) [122]	11 tackles	Senior	Elite	Match	Tackle	Technical Descriptors	Injury	There was no significant correlation between tackler characteristics and injury.
McIntosh et al. (2010) [125]	6618 tackles	U15 U18 U20 Senior	Educational Amateur Elite International	Match	Tackle Ball-carry	Technical Descriptors	Injury	No specific tackle technique was observed to be associated with a significantly increased risk of injury.
Sayers & Washington-King (2005) [155]	48 matches	Senior	Elite	Match	Ball-carry	Technical Descriptors	Performance	Effective running patterns and evasive movements were associated with successful ball-carries.
Sewry et al. (2015) [159]	763 tackles	Senior	Elite	Match	Tackle Ball-carry	Technical Descriptors	Performance	Evasive movements, tacklers' head position, contact with shoulder, leg drive, arm and shoulder usage were associated with success.

Table 2.1 (cont.) Summary of studies in rugby union (including RU Sevens)

Author (year)	Sample Size	Age Group	Level	Analysis Environment	Technique Analysed	Analysis Model	Independent variable(s)	Key Findings
Sobue et al. (2018) [162]	3970 tackles	U21	International	Match	Tackle	Technical Descriptors	Injury	The injury incidence for head incorrectly positioned was 69.4/1000 tacklers, compared to 2.7/1000 tackles for correct head positioning.
Suzuki et al. (2020) [173]	34 matches	Senior	Educational	Match	Tackle Ball-carry	Technical Descriptors	Injury	Head placement in front had a higher risk of injury to tackler than head to the side or above ball-carrier
Tierney et al. (2016) [183]	48 tackles	Senior	International	Match	Tackle	Technical Descriptors	Injury	Tacklers' head placement, and ball-carrier change of direction had significance for causing tackle related head impacts.
Tierney et al. (2017) [180]	233 tackles	Senior	Elite	Match	Tackle Ball-carry	Technical Criteria	Performance	Explosiveness and leg drive were associated with positive tackle outcomes for both ball-carrier and tackler.
Tierney et al. (2018) [181]	307 tackles	Senior	Elite	Match	Ball-carry	Technical Criteria	Injury	Explosiveness and fending by ball-carrier was associated with head impact (HI) assessments for tackler.
Tierney et al. (2018) [183]	307 tackles	Senior	Elite	Match	Tackle	Technical Criteria	Injury	Head up and forward, and head placement reduced risk of a HI assessment for the tackler.
Tierney et al. (2018) [182]	233 tackles 211 carries	Senior	Elite	Match	Tackle Ball-carry	Technical Criteria	Fatigue	Player time in game does not affect tackle technique proficiency.
van Rooyen, Yasin, & Viljoen (2014) [201]	15 matches	Senior	International	Match	Tackle	Technical Descriptors	Performance	Leaning forward, with centre of gravity ahead of base of support, was associated with effective tackles.
Wheeler & Sayers (2009) [214]	1372 carries	Senior	Elite	Match	Ball-carry	Technical Descriptors	Performance	Active fend strategies, leg drive and low body position were associated with successful carries.
Wheeler, Askew, & Sayers (2010) [215]	1372 carries	Senior	Elite	Match	Tackle Ball-carry	Technical Descriptors	Performance	Evasive movements were associated with successful carries.
Wilson et al. (1999) [221]	28 tackles	Senior	Elite International	Match	Tackle Ball-carry	Technical Descriptors	Injury	Most tackle injuries resulted from front on tackles.

Table 2.2 Summary of studies in rugby league

Author(s)	Sample Size	Age Group	Level	Analysis Environment	Technique Analysed	Analysis Model	Outcome(s) or Factor (s)	Key Findings
Cummins & Orr (2015) [30]	201 matches	Senior	Elite	Match	Tackle	Technical Descriptors	Performance	Transferring centre of gravity over front foot and driving right shoulder in contact was associated with effective shoulder charge tackles.
Gabbett & Kelly (2007) [66]	11 players	Senior	Professional	Training	Tackle	Technical Criteria	Line speed	Fast line speed reduced total tackle proficiency scores.
Gabbett, Kelly & Pezet (2007) [67]	86 players	Senior	Professional	Training	Tackle Ball-carry	Technical Criteria	Physical measures	Total ball-carry technique scores were positively associated with body mass and 40m sprint speed.
Gabbett (2008) [59]	8 players	Senior	Professional	Training	Tackle	Technical Criteria	Fatigue & physical measures	Fatigue resulted in progressive reductions in tackle technique. Players with greater VO_2 max and agility had lower reductions in tackle technique under fatigue.
Gabbett & Ryan (2009) [68]	39 players	Senior	Elite	Training	Tackle	Technical Criteria	Experience, level of play, performance & injury	Tackle technique was positively associated with playing level, experience, and successful and positive tackles in matches.
Gabbett (2009) [60]	12 players	Senior	Elite	Training	Tackle	Technical Criteria	Physical measures	Tackling ability was associated with age, skinfolds, mass, and waist and gluteal girths.
Gabbett, Jenkins, & Abernethy (2010) [62]	41 players	U15	Amateur Elite	Training	Tackle	Technical Criteria	Level of play & physical measures	Fast acceleration and lower body power contributed positively to effective tackling ability.
Gabbett, Jenkins, & Abernethy (2011) [63]	37 players	Senior	Amateur Elite	Training	Tackle	Technical Criteria	Experience, level of play & physical measures	Level of play, age, experience, skinfold thickness, acceleration, and lower body power were correlated with tackle technique scores.
Gabbett, Jenkins, & Abernethy (2011) [64]	58 players	Senior	Elite	Match Training	Tackle	Technical Descriptors & Criteria	Performance	Greater tackler proficiency was associated with the number of tackle attempts.
Gabbett, Jenkins, & Abernethy (2011) [65]	86 players	Senior	Elite	Training	Tackle	Technical Criteria	Team selection	Tackle ability did not influence team selection.

Table 2.2 (cont.) Summary of studies in rugby league

Author(s)	Sample Size	Age Group	Level	Analysis Environment	Technique Analysed	Analysis Model	Outcome(s) or Factor (s)	Key Findings
Gabbett et al. (2012) [69]	66 players	Senior	Elite	Training	Tackle	Technical Criteria	Injuries	There were no significant correlations between tackling ability and tackle related injuries.
Gabbett (2016) [61]	11 players	Senior	Amateur	Training	Tackle	Technical Criteria	Fatigue & physical measures	Fatigue resulted in progressive reductions in tackle technique. Players with greater lower body strength had the highest tackle technique scores under fatigue conditions.
Pearce et al. (2019) [136]	88 players	U18 U20 Senior	Amateur	Training	Tackle	Technical Criteria	Level of play	Senior level players demonstrated greater tackle proficiency, compared to u18 & u20 level players
Speranza et al. (2015) [168]	36 players	U20 Senior	Amateur	Training	Tackle	Technical Criteria	Level of play & physical measures	Tackling ability was associated with squats, bench press, relative squats, and plyometric push ups.
Speranza et al. (2015) [169]	16 players	Senior	Amateur	Training	Tackle	Technical Criteria	Performance & physical measures	Higher total tackle technique proficiency scores were associated with positive tackles.
Speranza et al. (2016) [170]	24 players	Senior	Amateur	Training	Tackle	Technical Criteria	Physical training	Tackling ability significantly increased after an 8-week physical training programme.
Speranza et al. (2017) [165]	16 players	Senior	Amateur	Training	Tackle Ball-carry	Technical Descriptors & Criteria	Performance & physical measures	Tackling ability was associated with tacklers making front-on tackles, with a medium body height, in matches, which lowered the odds of a missed tackles in matches.
Speranza et al. (2017) [164]	12 players	Senior	Amateur	Training	Tackle	Technical Criteria	Change over season	There was no significant change in tackling ability over the course of season.
Speranza et al. (2018) [167]	31 players	Senior	Amateur	Training	Tackle	Technical Criteria	Level of play & physical measures	Level of play was associated with tackle technique,
Speranza et al. (2018) [166]	18 players	Senior	Amateur	Training	Tackle	Technical Criteria	Performance & physical measures	Tackle technique was positively associated with dominant tackles and negatively associated with missed tackles.

Techniques

Tables 2.3 and 2.4 provide a summary of the tackle and ball-carry techniques analysed in RU, including the number of studies that analysed the technique, and whether the technique was associated with reduced injury risks or positive performance outcomes. Eleven tackle techniques and five ball-carry techniques were associated with both a reduced risk of injury and a higher likelihood of tackle success.

Twelve of the 29 RU studies used technical criteria in their assessment of the tackle, ball-carry and/or ruck. Nine of the 12 studies used the same standardized technical criteria consisting of 16 tackle techniques, 14 ball-carry techniques and 15 ruck techniques (16, 33, 34, 37, 86, 179-182). The technical criteria were categorised into three phases of movement: pre-contact (preparation phase), contact (execution phase) and post contact (follow-through phase). Five of the nine studies reported a total score for the number of techniques performed ((16, 33, 34, 37, 86)), and three of the studies reported totals for each phase of movement ((16, 33, 37)). Three of the 12 studies developed their own technical criteria for the tackle, consisting of 10 tackle techniques (19-21). Although, their 10 technical criteria were consistent with the 16 tackle techniques found in the other 9 studies. No additional techniques (to the technical criteria) were identified in the other 17 RU studies. Total tackle technique score was associated with contact related injuries in 2 out of 3 studies ($p<0.01$; $ES>0.6$). No performance related studies reported total tackle technique scores or scores for the phases of movement in the results. Similarly, total ball-carry technique score was associated with contact related injuries in 2 out of 3 studies ($p<0.01$; $ES>0.6$) and no performance related studies reported total ball-carry technique scores in the results. Total ruck technique was not associated with ruck injuries ($p>0.05$; $ES<0.6$), however making contact with the opponent's centre of gravity, and wrapping arms around opponent post contact when rucking were negatively associated with

Table 2.3 Tackle techniques associated with injury prevention and performance in rugby union

Tackle Technique	Studies (N)	Injury Prevention	Performance
Pre-contact			
Identify ball-carrier onto shoulder	**4**	✓	–
Body position - upright to low (dipping)	**6**	✓	✓
Back straight, centre of gravity ahead of support base	**4**	✓	✓
Alignment square to ball-carrier	**5**	✓	–
Head up and face forward	**6**	✓	✓
Boxer stance - elbows low and close, hands up	**5**	✓	–
Shortening steps	**5**	✓	✓
Approach from front/oblique	**5**	✓	–
Contact			
Explosiveness on contact	**4**	–	✓
Contact with shoulder	**8**	✓	✓
Contact in centre of gravity	**5**	✓	✓
Head placement on the correct side of ball-carrier	**8**	✓	✓
Post contact			
Shoulder drive upon first contact	**4**	✓	✓
Leg drive upon contact	**7**	✓	✓
Punch arms forward, wrap and pull (hit and stick)	**5**	✓	✓
Release ball-carrier and compete for possession	**4**	✓	✓

n: number of studies
✓ positive association; – no association

Table 2.4 Ball-carry techniques associated with injury prevention and performance in rugby union

Ball-Carry Technique	Studies (N)	Injury Prevention	Performance
Pre-contact			
Focus on tackler	**7**	✓	–
Body position - upright to low (dipping)	**4**	✓	✓
Back straight, centre of gravity ahead of support base	**4**	✓	–
Shift ball away from contact to correct arm	**4**	–	–
Head up, face forward	**4**	✓	–
Shuffle or evasive manoeuvre	**5**	–	✓
Contact			
Fend into contact	**6**	✓	✓
Side-on into contact	**4**	✓	–
Explosiveness on contact	**4**	✓	✓
Body position – from low up into contact	**4**	✓	–
Ball in correct arm and protected	**4**	–	✓
Post contact			
Use of arm and/or shoulder to push tackler	**4**	✓	–
Leg drive upon contact	**4**	✓	✓
Go to ground and present ball	**5**	✓	✓

n: number of studies
✓ positive association; – no association

injury outcomes in the ruck ($p<0.05$; ES>1.2). An overview of the tackle and ball-carry techniques analysed in RU, the reported significance of a technique on the study outcome and the effect size of the technique on the outcome are shown in Appendices 2.1 and 2.2.

Table 2.5 provides a summary of the relationships between total tackle technique scores and various player qualities and contextual factors. Body composition, lower body strength, experience and match performance were positively associated with tackling ability in at least 50% of the RL studies that included these variables in their analyses.

Nineteen of the 20 RL studies (95%) used standardised technical criteria to assess tackle technique (criteria shown in Appendix 2.3). The technical criteria were not grouped or categorised into phases, but all the studies reported a total score for the techniques performed. Five of the 19 studies included additional tackle techniques to the list of criteria (explosiveness on contact, lower body position, approach from front, head placement) and two included ball-carrier techniques (evasive movement, fend, side-on in contact, explosive, leg drive). No additional techniques were identified in the RL study that did not use the standardised technical criteria. Only 6 studies reported on the relationships between the individual tackle techniques and the study outcome, in which four of the studies showed the relationship between tackle technique and level of play (Appendix 2.3). Contact with shoulder was the only technique not associated with level of play. An overview of the factors associated with tackling ability in RL, the significance of the factor on tackling ability, and the effect size of the factor on tackling ability is shown in Appendix 2.4.

Table 2.5 Factors associated with tackling ability in rugby league

Factors	Studies (n)	Tackling Ability
Physical measurements		
Body composition	**8**	✓
Lower body strength	**4**	✓
Upper body strength	5	✓
Lower body power	9	✓
Upper body power	5	✓
Agility	7	✓
Speed and Acceleration	7	✓
Endurance	**2**	✓
Experience	**5**	✓
Match performance	**5**	✓
Injury risk	**2**	–
Level of play	**6**	✓
Fatigue	**2**	✓

n: number of studies
✓ positive association; – no association

Discussion

The purpose of this review was to consolidate and synthesise RU and RL studies on tackle technique and RU studies on ruck contact technique for rugby stakeholders. Forty-nine studies were identified, which were similarly distributed between RU (59%) and RL (41%). Eighty-three percent of tackle contact technique studies in RU were based on video analysis studies during matches, and for most of them, the ball-carrier and tackler were studied. Only two studies analysed ruck contact technique, one in matches (37) and one in training (85). The studies in RU aimed to understand the relationship between contact technique and injury or contact technique and performance. In contrast, studies in RL analysed contact technique during controlled field sessions and had a particular focus on the tackler. Also, the aim of most of the studies in RL was to identify factors that may affect tackle technique. The contrast in research studies between RU and RL highlights questions for future research on contact technique within the respective rugby code and potential collaboration opportunities.

Tackle and ruck contact technique has been studied by associating technical determinants with an outcome (deterministic model) or using a set of criteria that represents the 'ideal' form of the movement (diagnostic prescriptive model) (109, 117). In addition, tackle contact technique is typically divided into three phases, pre-contact (preparation phase), contact (action phase) and post-contact (follow-through phase), to focus the observation and interpretation (7, 117). Technical proficiency scores - i.e. scoring ball-carrier, tackler and ruck technique using a diagnostic prescriptive model - have been particularly useful for both RU and RL. The scoring is straightforward, a player is awarded either one point or zero depending on whether a particular technical criterion is met or not. The sum of these points is subsequently used to represent the technical proficiency of the player, which is easy to interpret. The criteria have been shown to have good validity in training and matches (16, 37, 168), and therefore can be considered as a diagnostic and monitoring tool.

Tables 2.3 and 2.4 summarise the techniques that are significantly associated with a reduction in tackle injury risk and an increased likelihood of tackle success in RU. This provides clear support for National and International Injury Prevention programmes that advocate that safe tackle technique is also effective technique (83). It is worth noting that if a technique was not significantly associated with an outcome, it should not be interpreted as inconsequential. An over-reliance on identifying significant relationships can lead to false-negative findings. For example, when identifying techniques that differ between successful and unsuccessful tackles, if players perform the same technique in both successful and unsuccessful tackles, it will not reflect to have a positive association with performance. Yet if the player did not perform the technique, it may have had a detrimental effect on their performance. Therefore, the techniques not significantly associated with an outcome should still be executed, while the significant techniques can be stressed or emphasised in training.

Experience and level of play were positively associated with tackling ability in RL. These findings highlight the importance of tackling technique for player development. The findings also suggest that players may need significant exposure to, and repetition of the skill to maximise technique and, therefore, prevent injuries. Furthermore, aerobically fitter players with greater lower body strength tended to have more proficient tackle technique. Similarly, players with greater aerobic fitness and greater lower body strength had the best tackling ability under fatigued conditions. This points out the importance of physical conditioning for enhancing tackle technique.

We identified 11 tackle techniques and five ball-carry techniques associated with both reduced injury risks and effective performance outcomes. These findings show that safe techniques are effective. However, due to the physical nature of the tackle contest, factors other than technique (speed, size, power) may affect the outcome of a tackle. It would then be possible to perform an effective tackle with techniques associated with increased injury risks. Therefore, we recommend that future research identifying and prescribing proficient contact technique should first determine the safety of a technique before determining the technique's effectiveness. Furthermore, a meta-analysis of contact technique and injury risks, and performance outcomes, is recommended, to assess the quality of the individual studies, and the weighting of the relationship of the techniques and respective outcomes. Currently, the diagnostic prescriptive model has been applied to three contact skills in RU (the shoulder tackle, carrying the ball into contact and ruck clearing) and two contact skills in RL (under-the-ball and over-the-ball shoulder tackles). For future work in the area, we recommend that criteria for other types of tackles (smother, chop, double tackles) and ball-carrier actions (offload), ruck skills (sealing, poaching), and other contact events (scrum, maul) be developed. Additionally, further research on the effect of ruck technique on injury risks and performance outcomes in RU is warranted.

Conclusion

The aim of this paper was to consolidate and synthesis RU and RL research on tackle and ruck technique. We identified 20 studies in RL and 29 studies in RU. Studies in RU analysed tackles and rucks in matches, to understand the relationship between contact technique and injury risks or performance outcomes. Studies in RL analysed tackles in controlled field sessions, to identify factors that may affect tackle technique. The contrast in research aims highlight opportunities for future research within the respective codes of rugby.

In RL, aerobically fitter players with greater lower body strength had more proficient tackle technique. These findings highlight the importance of physical conditioning for tackle technique. In RU, 11 tackle techniques and 5 ball-carry techniques were associated with reduced injury risks and positive performance outcomes. These findings support national injury prevention programmes that advocate that safe contact technique is also effective technique. Deterministic models and diagnostic prescriptive models were used to analyse contact technique in RU and RL. Diagnostic prescriptive models were particularly useful to describe and compare contact technique within and between studies. We recommend additional diagnostic prescriptive models are developed for other contact skills in RU and RL.

Aims and Objectives of the Thesis

Given the importance of proficient technique to improve performance and reduce injury risks in the tackle, the over-arching aim of this thesis is to identify strategies to develop player's contact technique proficiency. The first step in developing technique in training is to assess technique (93). Drawing from research in rugby league (67), a contact technique assessment tool was developed for rugby union. In the tool, tackle, ball-carry and ruck technique were assessed in a two-on-two contact drill, using diagnostic prescriptive models. Given the importance of rucks for performance, the high injury risk, and the close relationship between the tackle and ruck, ruck technique was included the assessment tool.

The aims of this thesis were to assess the validity and representativeness of a contact skill assessment tool, and to identify factors which affect the degree to which contact technique in training transfer to match technique. To fulfil these aims the specific objectives of this thesis were twofold; 1) To assess the validity and representativeness of the contact assessment tool, and 2) To gain a comprehensive insight into the factors which may affect the degree to which contact technique developed in training transfers to matches.

The following chapters in the thesis consists of five studies. The first two studies contribute to fulfilling the first objective of the study (Chapters 3-4). Chapters 5-7 contribute to fulfilling the second objective. The specific questions answered in each chapter are outlined below. The final chapter of this thesis (Chapter 8) summarises the answers to each question and synthesis the findings of all the studies. Finally, practical implications and recommendations for future research are provided.

Specific Research Questions

Chapter 3:

- Does the contact assessment tool have good construct validity? i.e. do the results discriminate between different levels of play?
- What are the tackle, ball-carry and ruck technique scores of players in training at different levels of play?

Chapter 4:

- What is the representative learning design of the contact technique drill? i.e. do the contact events in the drill represent contact events in the match?
- Are tackle, ball-carry and ruck technique scores associated with the same performance outcomes in training and in matches?
- Were there differences in the tackle ball-carry or ruck technique proficiency scores between contact events in training and contact events in matches?

Chapter 5:

- What is the relationship between players' physical qualities and their tackle and ruck technique?

Chapter 6:

- Does knowledge of the importance of tackle technique to improve performance or reduce the risk of injury translate to proper tackle technique execution?

Chapter 7:

- What is the relationship between players' contact technique in matches and their match performance and injury risk?
- Does good contact technique in training transfer to improved match performance and reduced injury risks?

Chapter 3: Tackle and ruck technique proficiency within academy and senior club rugby union.

A version of this chapter has been published as:

den Hollander S, Lambert M, Jones B, & Hendricks, S. **Tackle and ruck technique proficiency within academy and senior club rugby union.** *Journal of Sports Science* 2019; 1-10.

Introduction

With approximately 9.6 million players registered in 123 countries, rugby union is one of the most popular collision sports in the world (222). The game is characterised by intermittent bouts of high intensity running and collisions between players as they compete for territory and ball possession. Tackles and rucks are the phases of the games with the highest frequency of collisions. On average, 165 tackles and 110 rucks occur per game at the professional level (94) and 155 tackles and 115 rucks at the community level (149). In addition, the tackle has the highest injury risk and incidence, and the ruck the second highest injury incidence, across all levels of play (149, 219). Given the risk of injury and the importance of these collision events from a performance perspective, identifying safe and effective tackle and ruck technique has become a high priority for the governing body of the sport, World Rugby (28, 188, 189).

To determine which techniques are associated with performance and reduces injury risk, studies have used video analysis to study contact events in matches (15, 16, 33, 85, 86, 179). Most of these studies used standardised technical criteria to assess tackle and ball-carry technique in contact (16, 33, 86, 179). The criteria outline specific observable movements or actions in a tackle, for both the tackler and the ball-carrier. One point is awarded for each criterion the player performs, and the points are totalled to determine the technical proficiency of the tackle or ball-carry. The results of these studies suggest that better technique can improve performance and reduce injury risk, for both the tackler and ball-carrier (16, 33, 86, 179). This approach has also been used for the ruck, with specific techniques being associated with reducing the risk of concussion (86). Developing strategies to improve tackle and ruck technique is, therefore, key to enhancing performance and improving safety in rugby union.

Safe and effective tackle and ruck technique can be developed through training (92). Yet, studies suggest that current coaching resources may not be sufficient to design technical training sessions to prepare players adequately for matches. (89, 90). The first step in designing a technical training session is to assess the technical skill level of their player (93). However, although contact technique has been assessed in matches, there is currently no published tool to assess tackle and ruck technique in rugby union in training (84, 133). Tools to assess technical skills in training have been developed in other sports (1, 67, 151). For example, in rugby league, a one-on-one tackle drill, with standardized technical criteria has been used to assess tackling technique. This assessment has been associated with physical measurements (60, 62, 64, 67, 168), fatigue (59, 61), match performance (68, 165), and injuries (69). The assessment has also be used to measure the effect of an eight-week strength and power training programme on tackle technique (170), and differences in tackle technique between different levels of play (62, 65). These studies also provide validity for the assessment tool; for example, the tackle assessment drill had good construct validity as it could discriminate between the levels of play (1).

Along with providing objective information to develop technical training programmes, technique assessments also provide information for talent identification and development programmes (84). Typically, in talent identification and development programmes, reference data of physical qualities are used to monitor the progress of players from academy to elite level (116, 184, 187). This reference data, however, does not exist for tackle and ruck technique proficiencies in rugby union. Therefore, to establish reference data for the tackle and ruck technique, and provide construct validity for a technique assessment tool for rugby union, the tackle and ruck technique proficiency of rugby union players was assessed during training at three different levels of play.

Methods

Participants

One hundred and thirty-one male amateur rugby union players (n=131; 61 forwards & 70 backline players) participated in the study. The first level of players (seniors) were from one senior men's rugby union club, competing at the highest level of local amateur rugby in the region (Western Cape, South Africa) (n=37; 16 forwards & 21 backline players). The second (n=51; 21 forwards & 30 backline players) and third level (n=43; 19 forwards & 24 backline players) players were from a local rugby academy that competes in the u20 version of the senior men's competition. The academy players were graded by the coaches into two squads, academy 1st and 2nd. All the players were free from injury, and had played rugby union for at least one calendar year. All procedures were approved by the designated university's human research ethics committee (HREC 811/2015; Appendix 3.1).

Experimental Design

A cross-sectional study design was used to compare the tackle and ruck proficiency of senior, academy 1st and academy 2nd level players. Testing was conducted during regular training sessions in preseason. Before testing players were warmed up, and were familiarized with the contact drill.

Contact drill

Contact skill proficiency was examined in a standardised two-on-two contact drill. A similar drill has been used to assess contact technique in rugby league (67, 68, 169). The drill was performed in the corner of a rugby field, to simulate a real match scenario. The dimensions of the grid are illustrated in Figure 1. The drill started with a simulated ruck, where the ball was passed by the scrumhalf, via the first attacker, to the ball-carrier. The ball-carrier then advanced

the ball forward in the direction of the tackler. The ball-carrier was told to 'score the try' over the try-line. The ball-carrier was allowed to evade the tackle, but instructed to remain in the channel created by the touch-line and the parallel 5m line, and not to pass the ball. The tackler was told to prevent the ball-carrier from scoring the try through the use of safe and effective technique. The first defender was instructed to not assist in the tackle. Once the ball-carrier was brought to ground, the first defender and first attacker formed a ruck. The first attacker was instructed to allow the first defender to arrive at the breakdown first. Then the first attacker cleared out the first defender, using the drive technique (instead of the roll technique). The first defender was instructed to be competitive at the breakdown, but to keep their head and shoulders above their hips (as the roll technique would be a more effective clearing technique in this body position). The tackler was instructed to join the defensive line after the tackle, not the ruck. If the ball-carrier was tackled out of play, or scored a try, he was instructed to go to ground so that a ruck could be formed.

The drill was filmed from a side angle, 5m from the touchline, and the footage was assessed using standardized technical criteria for tackling, ball-carrying, and rucking proficiency. Participants performed four trials in each role of the drill; as either the scrumhalf, first defender, tackler, ball-carrier, or first attacker, providing four clips of footage of each participant attempting a tackle, carrying the ball into contact and clearing out their opponent in a ruck (the technique of the first defender and scrumhalf were not assessed).

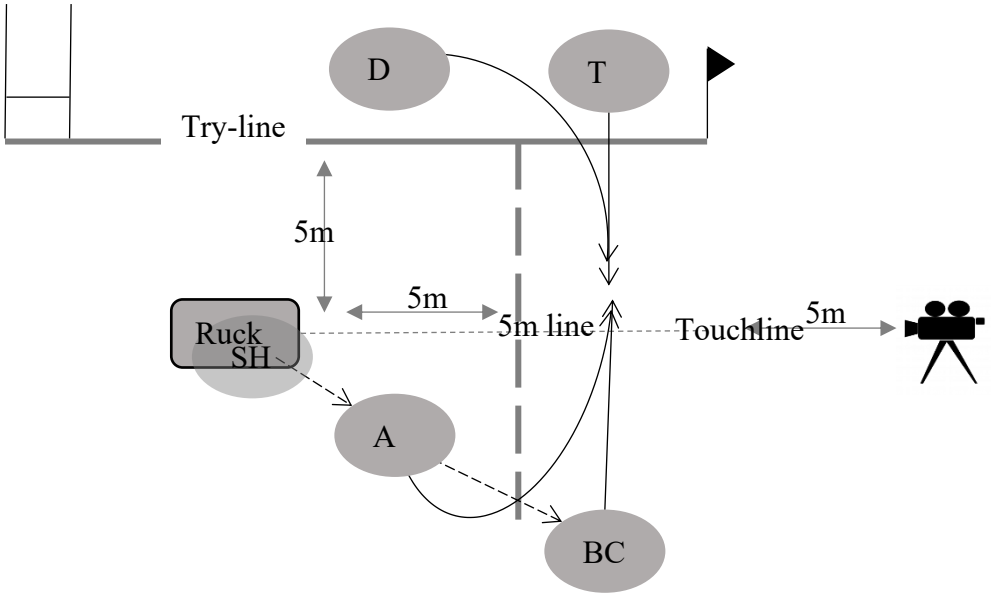

Figure 3.1 Schematic layout of contact drill. Dotted lines represent the path of the ball; solid lines represent the movement paths of the participants. T: Tackler; BC: Ball-carrier; D: First defender; A: First Attacker; SH: Scrumhalf.

The criteria used to assess the tackle and ball-carrying technique were the same used to assess tackle and ball-carrying technique in previous research (16, 33, 86) (a description of the criteria is shown in tables 3.1-3.2). The criteria used to assess ruck-clearing technique were developed based on previous research (86) and coaching literature (139) (A description of the ruck criteria is shown in table 3.3). The author recorded and analysed all the events. Players were awarded 1 point for each criterion they performed and 0 points if they failed to perform the criterion. The criteria were categorised into three phases; pre-contact, contact and post contact, and a subtotal was recorded for each category, as well a total score (arbitrary units) for each tackle, ball-carry and ruck a participant performed.

Statistical Analyses

Data were tested for normality using a Shapiro-Wilk test. As the data were normally distributed, a one-way analysis of variance was used to compare differences in tackle, ball-carry and ruck technique between the senior, academy 1st and academy 2nd levels. Differences

in scores between the levels were compared for each technique on the list, for the totals of each phase of the tackle, ball-carry and ruck (pre-contact, contact and post contact) and for the respective totals. A pairwise comparison of means with Bonferroni's adjustment was applied for the *post-hoc* testing. The level of significance was set at $p \leq 0.05$. Cohen's effect size statistic was used to determine the magnitude of the differences between the three levels (24). Effect sizes of <0.20, 020-0.59, 0.60-1.19, 1.20-1.99 and >2.00 were considered trivial, small, moderate, large and very large, respectively (98). STATA 11.1 (StataCorp LP, USA) was used for all statistical analyses.

Reliability

To assess the reliability of the analyst, five player's tackles, carries and rucks were coded on two separate occasions (intra-rater). For the purpose of assessing the inter-rater reliability of the analyst, a second analyst, with experience with the criteria, assessed the same five player's tackles, carries and rucks. Intra-rater and inter-rater reliability were calculated using the interclass correlation coefficient (ICC) and the typical error of measurement (TEM) (16, 98). The ICC's for both the intra- and inter-rater tackle, ball-carry, and ruck assessments were 1.0. The TEM's for the intra-rater tackle, ball-carry, and ruck assessments were 0.7, 0.5 and 0.5, respectively, and for the inter-rater; 0.6, 0,6 and 0.5 respectively.

Results

Senior players scored significantly higher than academy 1st and 2nd team players in tackling, ball-carrying and ruck-clearing (Figure 3.2).

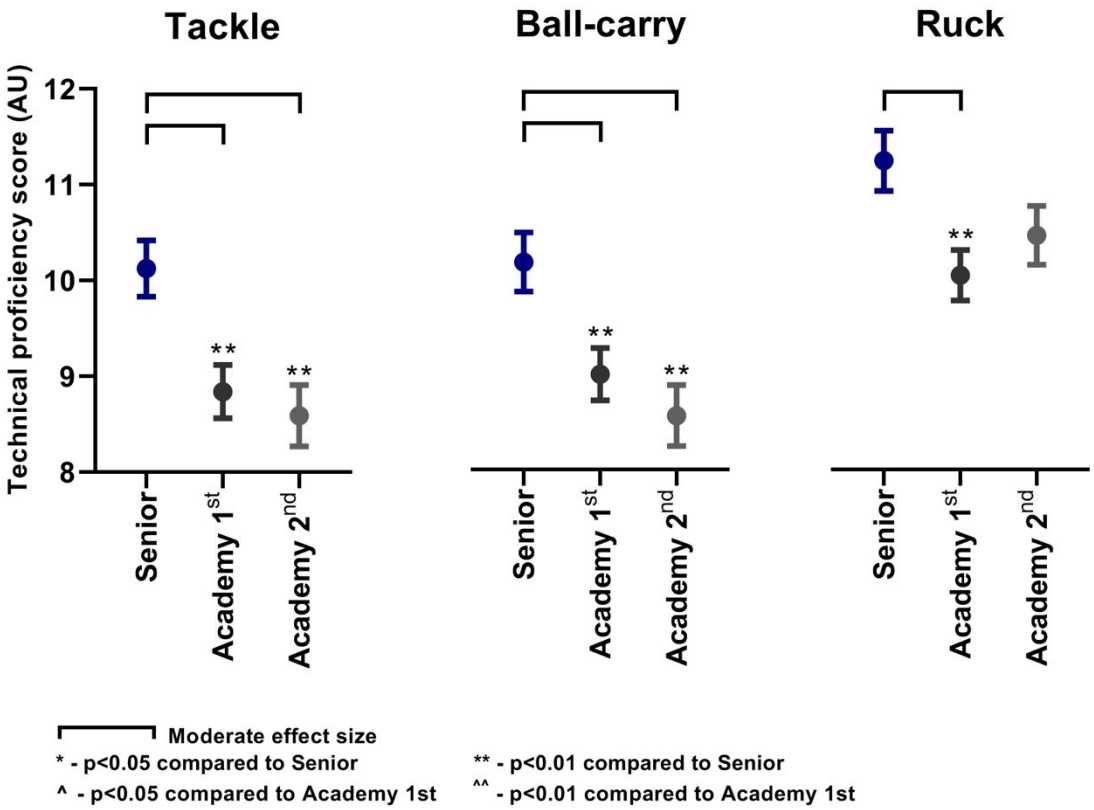

Figure 3.2 Total proficiency scores for tackling, ball-carrying and ruck-clearing for senior, academy 1st and 2nd team players. Data are reported as means and 95% confidence intervals. Moderate effect sizes and significance levels are shown.

Significant differences with small effect sizes were found between the pre-contact tackle techniques of the senior players and the academy 1st ($p < 0.01$; ES = 0.5) and 2nd team players ($p < 0.01$; ES = 0.5). Similarly, significant differences with moderate effect sizes were found between the post contact tackle techniques of the senior players and the academy 1st ($p < 0.01$; ES = 0.6) and 2nd team players ($p < 0.01$; ES = 0.7) (Figure 3.3). Differences between groups for each tackling technical criterion are shown in Table 3.1.

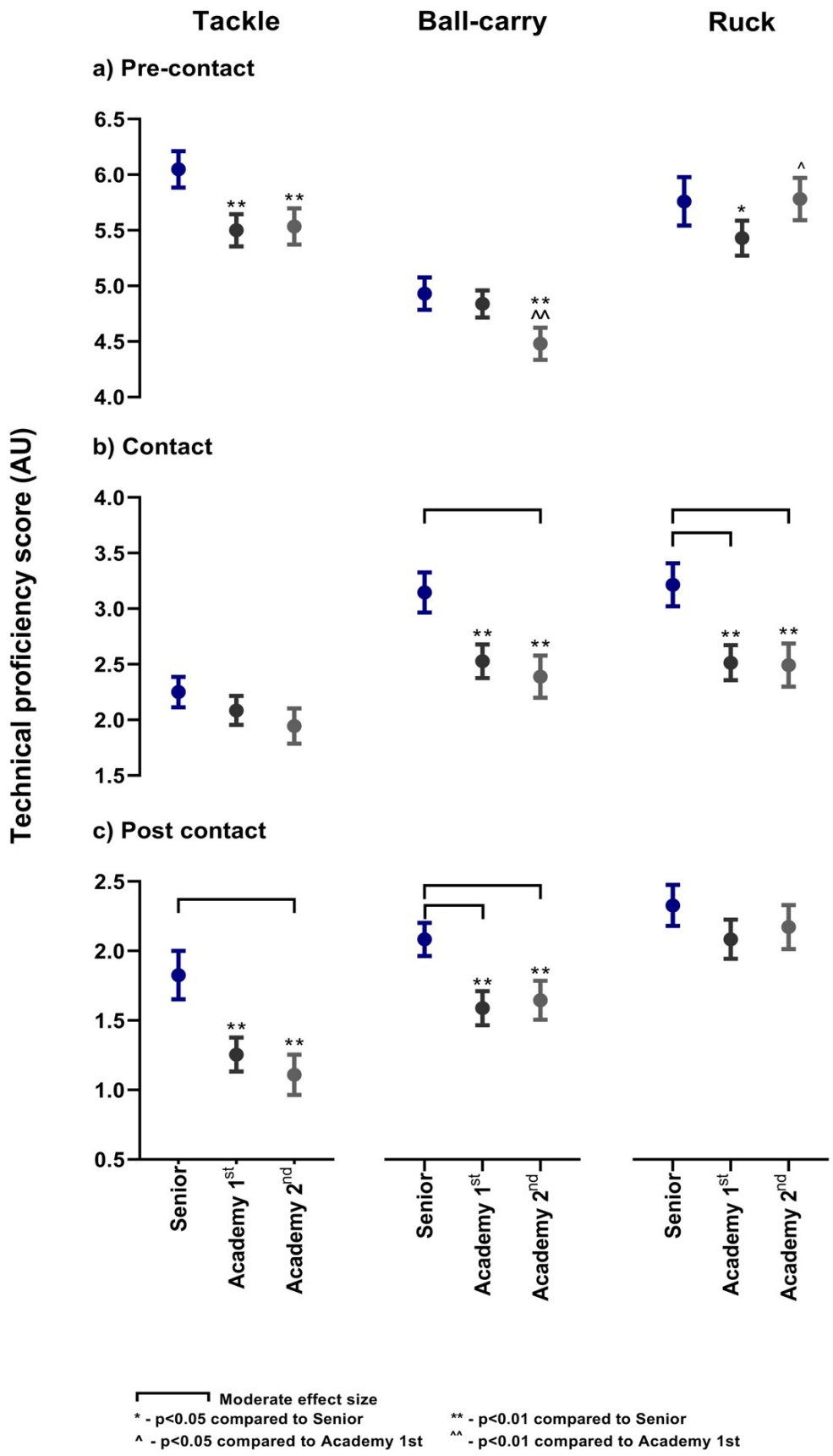

Figure 3.3 Tackling, ball-carrying and ruck-clearing proficiency scores during a) pre-contact, b) contact, and c) post contact technique for senior, academy 1st and 2nd team players. Data are reported as means and 95% confidence intervals. Moderate effect sizes and significance levels are shown.

Table 3.1 Tackle technique proficiency results for the senior, academy 1st and academy 2nd team players (includes means with 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations)

Tackle	Senior (n=144)		Academy 1st (n=200)		Academy 2nd (n=146)		Senior vs Academy 1st		Senior vs Academy 2nd		Academy 1st vs academy 2nd	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	ES	Interpretation	ES	Interpretation	ES	Interpretation
Pre-contact	6.1	5.9-6.2	5.5	5.4-5.7	5.5	5.4-5.7	0.5	Small**	0.5	Small**	0.0	Trivial
Identify ball-carrier and position to ensure shoulder contact is made	1.0	0.9-1.0	0.9	0.9-1.0	0.9	0.8-1.0	0.2	Trivial	0.3	Small*	0.2	Trivial
Reposition from an upright to crouched/bent at the waist body position i.e. lower centre of gravity	0.9	0.9-1.0	1.0	0.9-1.0	0.9	0.9-1.0	-0.2	Trivial	-.01	Trivial	0.1	Trivial
Keep backs straight with centre of gravity forward of the support base	0.5	0.4-0.6	0.2	0.1-0.2	0.2	0.1-0.3	**0.7**	**Moderate****	**0.7**	**Moderate****	0.0	Trivial
Alignment square to ball-carrier (hips aligned)	1.0	1.0-1.0	0.9	0.9-1.0	0.9	0.9-1.0	0.3	Small	0.4	Small**	0.1	Trivial
Head up and face forward	0.9	0..9-1.0	0.9	0.9-1.0	1.0	0.9-1.0	0.0	Trivial	-0.1	Trivial	-0.1	Trivial
Bend elbows with hands raised above the level of the elbow and elbows close to torso	0.4	0.3-0.4	0.1	0.1-0.2	0.1	0.1-0.1	**0.6**	**Moderate****	**0.7**	**Moderate****	0.1	Trivial
Exhibit shorter and faster steps when approaching ball-carrier (feet remain active)	0.4	0.3-0.5	0.6	0.5-0.6	0.7	0.6-0.7	-0.3	Small*	-0.5	Small**	-0.2	Small
Approach from front/oblique	1.0	1.0-1.0	0.9	0.9-1.0	1.0	0.9-1.0	0.4	Small**	0.3	Small	-0.1	Trivial
Contact	2.3	2.1-2.3	2.1	2.0-2.2	1.9	1.8-2.1	0.2	Trivial	0.3	Small*	0.2	Trivial
Explosiveness (rapid leg movement) on contact	0.2	0.1-0.3	0.1	0.1-0.2	0.1	0.1-0.1	0.2	Trivial	0.3	Small*	0.1	Trivial
Contact the ball-carrier with the shoulder as the first point of contact	0.7	0.7-0.8	0.6	0.5-0.7	0.5	0.5-0.6	0.2	Small	0.4	Small*	0.2	Trivial
Contact ball-carrier in centre of gravity (upper pelvis/lower torso)	0.4	0.3-0.5	0.6	0.5-0.6	0.5	0.4-0.6	-0.3	Small*	-0.2	Small	0.1	Trivial
Place head beside or behind ball-carrier's body correctly (tackler right shoulder, ball-carrier left side; tackler left shoulder, ball-carrier right side)	0.9	0.9-1.0	0.8	0.7-0.9	0.8	0.7-0.9	0.4	Small**	0.4	Small*	-0.0	Trivial
Post contact	1.8	1.7-2.0	1.3	1.1-1.4	1.1	1.0-1.3	**0.6**	**Moderate****	**0.7**	**Moderate****	0.2	Trivial
Use shoulder to impede and disrupt the ball-carrier	0.4	0.3-0.5	0.3	0.2-0.3	0.2	0.1-0.2	0.3	Small*	**0.6**	**Moderate****	0.3	Small
Leg drive upon contact	0.2	0.1-0.2	0.1	0.1-0.1	0.1	0.0-0.1	0.2	Small	0.3	Small	0.1	Trivial
Wraps arms around ball-carrier and maintains hold	0.7	0.7-0.8	0.6	0.5-0.7	0.6	0.5-0.6	0.3	Small*	0.4	Small*	0.0	Trivial
Release ball-carrier and join the defensive line	0.5	0.4-0.6	0.3	0.3-0.4	0.3	0.2-0.4	0.4	Small**	0.4	Small**	0.0	Trivial
Total	10.1	9.8-10.4	8.9	8.6-9.1	8.6	8.3-8.9	**0.7**	**Moderate****	**0.8**	**Moderate****	0.1	Trivial

n: number of tackles
* p <0.05

** p<0.01

Table 3.2 Ball-carrying technique proficiency results for the senior, academy 1st and academy 2nd team players (includes means with 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations

Ball-Carry	Senior (n=144)		Academy 1st (n=197)		Academy 2nd (n=144)		Senior vs Academy 1st		Senior vs Academy 2nd		Academy 1st vs Academy 2nd	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	ES	Interpretation	ES	Interpretation	ES	Interpretation
Pre-contact	4.9	4.8-5.1	4.8	4.7-5.0	4.5	4.3-4.6	0.1	Trivial	0.5	Small**	0.4	Small**
Focus on tackler	1.0	1.0-1.0	1.0	1.0-1.0	1.0	1.0-1.0	0.0	Trivial	-0.1	Trivial	-0.1	Trivial
Reposition from an upright to crouched/bent at the waist body position i.e. lower centre of gravity	0.9	0.8-0.9	0.8	0.8-0.9	0.7	0.6-0.8	0.1	Trivial	0.4	Small*	0.3	Small*
Keep backs straight with centre of gravity forward of the support base	0.9	0.8-0.9	0.7	0.7-0.8	0.8	0.7-0.8	0.4	Small**	0.3	Small	-0.1	Trivial
Shift ball away from contact to correct arm	0.8	0.7-0.8	0.8	0.7-0.8	0.6	0.5-0.7	0.0	Trivial	0.4	Small**	0.4	Small**
Head up, face forward	1.0	1.0-1.0	1.0	1.0-1.00	1.0	1.0-1.0	-0.1	Trivial	-0.2	Small	-0.2	Trivial
Shuffle, side-step or change direction to evade contact	0.5	0.4-0.6	0.5	0.5-0.6	0.4	0.4-0.5	-0.1	Trivial	0.1	Trivial	0.2	Small
Contact	3.2	3.0-3.3	2.5	2.4-2.7	2.4	2.2-2.6	**0.6**	**Moderate****	**0.7**	**Moderate****	0.1	Trivial
Fend into contact	0.3	0.2-0.4	0.3	0.2-0.3	0.4	0.3-0.4	0.1	Trivial	-0.1	Trivial	-0.2	Trivial
Side-on into contact	0.7	0.6-0.8	0.6	0.5-0.7	0.5	0.4-0.6	0.2	Small	0.4	Small*	0.2	Small
Explosiveness (rapid leg movement) on contact	0.8	0.7-0.9	0.5	0.4-0.6	0.6	0.5-0.7	**0.7**	**Moderate****	0.5	Small**	-0.2	Trivial
Drive the body upwards into contact from a crouched/bent at the waist body position	0.5	0.4-0.6	0.4	0.3-0.5	0.3	0.3-0.4	0.3	Small	0.4	Small*	0.1	Trivial
Ball in correct arm and protected	0.8	0,8-0.9	0.8	0.7-0.8	0.6	0.5-0.7	0.2	Trivial	0.5	Small**	0.3	Small*
Post contact	2.1	2.0-2.2	1.6	1.5-1.7	1.7	1.5-1.8	**0.6**	**Moderate****	0.6	Small**	-0.1	Trivial
Use arm and shoulder to disrupt tackler	0.5	0.4-0.5	0.3	0.2-0.3	0.3	0.2-0.4	0.4	Small**	0.3	Small*	-0.1	Trivial
Leg drive upon contact	0.7	0.7-0.8	0.6	0.5-0.7	0.7	0.6-0.7	0.3	Small	0.1	Trivial	-0.1	Trivial
Go to ground and present ball	0.9	0.9-1.0	0.7	0.7-0.8	0.7	0.6-0.8	0.5	Small**	**0.6**	**Moderate****	0.1	Trivial
Total	10.2	9.9-10.5	9.0	8.7-9.3	8.6	8.2-8.9	**0.6**	**Moderate****	**0.8**	**Moderate****	0.1	Trivial

n: number of ball-carries
* p <0.05
** p<0.01

Table 3.3 Ruck clearing technique proficiency results for the senior, academy 1st and academy 2nd team players (includes means with 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations

Ruck	Senior (n=144)		Academy 1st (n=197)		Academy 2nd (n=144)		Senior vs Academy 1st		Senior vs Academy 2nd		Academy 1st vs Academy 2nd	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	ES	Interpretation	ES	Interpretation	ES	Interpretation
Pre-contact	5.8	5.5-6.0	5.4	5.3-5.6	5.8	5.6-6.0	0.3	Small*	-0.0	Trivial	-0.3	Small*
Identify opponent threatening ball possession	0.9	0.9-1.0	1.0	1.0-1.0	1.0	0.9-1.0	-0.2	Small	-0.1	Trivial	0.1	Trivial
Reposition from an upright to crouched/bent at the waist body position i.e. lower centre of gravity	1.0	0.9-1.0	1.0	0.9-1.0	1.0	1.0-1.0	0.0	Trivial	-0.1	Trivial	-0.1	Trivial
Keep backs straight with centre of gravity forward of the support base	0.7	0.6-0.8	0.5	0.5-0.6	0.6	0.5-0.7	0.3	Small*	0.2	Trivial	-0.1	Trivial
Entering the ruck from an on-side position	1.0	1.0-1.0	1.0	1.0-1.0	1.0	1.0-1.0	0.1	Trivial	0.2	Trivial	0.1	Trivial
Head up, face forward	0.8	0.7-0.8	0.8	0.7-0.8	0.8	0.8-0.9	0.0	Trivial	-0.2	Trivial	-0.2	Small
Bend elbows with hands raised above the level of the elbow and elbows close to torso	0.2	0.1-0.3	0.1	0.1-0.2	0.2	0.1-0.3	0.2	Small	-0.3	Small	-0.2	Small
Exhibit shorter and faster steps when approaching ball-carrier (feet remain active)	0.5	0.4-0.6	0.4	0.4-0.5	0.5	0.4-0.6	0.1	Trivial	-0.1	Trivial	-0.2	Trivial
Head and shoulders above hips	0.8	0.7-0.8	0.7	0.6-0.7	0.7	0.6-0.8	0.2	Trivial	0.1	Trivial	-0.1	Trivial
Contact	3.2	3.0-3.4	2.5	2.4-2.7	2.5	2.3-2.7	**0.7**	**Moderate****	**0.7**	**Moderate****	0.0	Trivial
Dip and step into contact	0.5	0.4-0.5	0.3	0.3-0.4	0.4	0.3-0.5	0.3	Small	0.1	Trivial	-0.1	Trivial
Enter from low to high body position	0.9	0.8-0.9	0.7	0.6-0.8	0.7	0.6-0.8	0.4	Small*	0.4	Small*	0.0	Trivial
Contact opponent with shoulder as the first point of contact	0.8	0.8-0.9	0.7	0.6-0.7	0.6	0.5-0.8	0.4	Small*	0.5	Small**	0.1	Trivial
Head placement on correct side of opponent	1.0	1.0-1.0	0.8	0.8-0.9	0.8	0.7-0.9	**0.6**	**Moderate****	**0.6**	**Moderate****	0.1	Trivial
Post contact	2.33	2.2-2.5	2.1	1.9-2.2	2.2	2.0-2.3	0.3	Small	0.2	Trivial	-0.1	Trivial
Wraps arms around ball-carrier and maintains hold	0.7	0.6-0.8	0.6	0.5-0.6	0.7	0.6-0.8	0.3	Small	0.0	Trivial	-0.3	Small
Leg drive upon contact and clean out opponent	0.8	0.7-0.8	0.7	0.6-0.8	0.6	0.6-0.7	0.1	Trivial	0.3	Small	0.2	Trivial
Stay on feet	0.9	0.8-0.9	0.8	0.7-0.9	0.8	0.8-0.9	0.2	Trivial	0.1	Trivial	-0.1	Trivial
Total	11.2	10.9-11.5	10.3	9.8-10.3	10.5	10.1-10.8	**0.7**	**Moderate****	0.4	Small**	-0.2	Small

n: number of rucks
* p <0.05
** p<0.01

The level of play had a significant difference, with a moderate effect, on ball-carrying technique during the contact phase between the senior players and the academy 1st ($p < 0.01$; ES = 0.6) and 2nd team players ($p < 0.01$; ES = 0.7) and the post contact phase between the senior players and the academy 1st ($p < 0.01$; ES = 0.6) and 2nd team players ($p < 0.01$; ES = 0.6) (Figure 3). Differences between groups for each ball-carrying technical criterion are shown in Table 3.2.

Academy 1st team players had significantly lower pre-contact ruck technique scores than senior ($p = 0.04$; ES = 0.3) and academy 2nd team players ($p = 0.02$; ES = 0.3) (Figure 3.3). Both 1st and 2nd team academy players had significantly lower contact ruck technique scores than senior players (Figure 3.3). Differences between groups for each ball-carrying technical criterion are shown in Table 3.3.

Discussion

This study describes the differences in tackle and ruck technique of amateur rugby union players across different levels of play. We found that the senior level players scored significantly higher than the academy level players in the tackle, ball-carry and ruck technique assessments. These findings highlight the importance of developing tackle and ruck technique to allow players to progress through the levels of competition safely. Players seem to be aware of the technical aspects of tackling and ball-carrying (80), and, furthermore, instructional videos on how to improve tackle technique have had mixed effects on the actual improvements in tackle technique (105). Thus, the best conceivable method to develop safe tackle and ruck technique is during training, where players can practice these techniques until they become instinctive. This underlines the need for contact skill training programmes in rugby union talent development (92). To effectively monitor the progress of the players in response to a skill

training programme, it is important to measure their basic technical skills at the onset (93). In this study we demonstrated a tool which can be used for this purpose.

The differences between the levels of play shows that the tool used to assess tackle and ruck technique in training has good construct validity (1). Although this is the first study to assess tackle and ruck technique in training in rugby union, similar studies have been done in rugby league, where a tackle technique assessment tool identified significant differences between elite and sub-elite u16 players (62) and professional and semi-professional senior players (63). However, these studies only assessed the tackler's technique, and not the ball-carry or ruck technique. Our study is the first study to validate the assessment of tackle, ball-carry and ruck technique in a training drill.

Compared to the academy levels, we found that senior players scored significantly higher in certain techniques which are associated with outcomes of performance and injuries. For the tackle, senior players scored higher in backs straight, centre of gravity ahead of their base of support, boxer stance and shoulder drive upon first contact than the academy first and second levels. These techniques have been positively associated with improved performance outcomes (85, 159, 179, 201) and a reduced risk of injury (16, 33, 86, 182). For the ball-carry, senior players scored higher on the explosive on contact criterion than both academy levels, which has similarly been positively associated with outcomes of improved performance (179) and negatively associated with tackle related injuries (16, 33, 180). For the ruck, senior level players had a perfect score for head placement on correct side - significantly higher than the academy levels. To our knowledge, only one study has assessed ruck technique in rugby union (86). Although, no study has shown this technique to have a significant effect on ruck outcomes, multiple studies have found head placement on correct side to have a significantly

negative effect on tackle injuries (33, 54, 86, 162, 182, 183). Injury incidence rates are reportedly lower at senior level than academy level (211), and senior players' higher scores in techniques associated with reduced injury risks may attribute to these lower rates. However, future research is needed to identify whether tackle and ruck technique assessed in training can predict performance and contact injuries outcomes in rugby union.

Although attempts were made to improve the ecological validity and representativeness of the assessment tool (instructions to players, locating drill on rugby field), we acknowledge that the drill only partially simulates a tackle and ruck match scenario. With that said, the technical proficiency scores in the current drill are comparable to the scores from matches. Burger et al. (2016), using the same scale, reported technical proficiency scores in elite U18 matches of 9.4 and 8.9 for the tackler and ball-carrier, respectively. In comparison, the academy 1st team, which is a similar cohort to the elite U18 players, scored 9.0 and 8.9 for tackling and ball-carrying technique, respectively. A study to determine the direct relationship between the technical proficiency in the contact drill and technical proficiency in matches is however required to substantiate this reasoning. One person assessed all the tackles, ball-carries and rucks. This helped improve the reliability, while the criteria reduced the subjectivity of the assessment. The assessor was blinded to the two levels within the academy. The distinct physical features between the senior and academy level players made it difficult to be completely blinded to the two groups, and we acknowledge this as a limitation. The tackles, ball-carries and rucks were assessed in isolation, thus any interactions between the technical scores were not analysed. This may be a consideration for future analyses. Finally, although we have argued that a lack of coaching is the largest inhibiting factor for technical skill acquisition and execution, we acknowledge that there may be other inhibiting factors. A player's personal beliefs about the importance of executing specific techniques, or their physical ability to actually perform the techniques may be other contributing factors. The

association between physical characteristics and effectiveness in contact in rugby is well established (160, 168). Furthermore, in rugby league, tackle technique was shown to improve after an eight-week strength and power training programme (170). Therefore, we suggest future studies identify possible relationships between physical and psychological factors and contact technique.

Conclusion

This is the first study to assess tackle and ruck technique in training and provides reference data at different levels of play in amateur rugby. The findings of this study also show that the two-on-two contact drill is a valid method of evaluating tackle and ruck technical proficiency in rugby union and provide coaches with a practical tool to facilitate this process.

Chapter 4: The representative learning design of a contact assessment drill

Introduction

Rugby union is a popular collision sport played in over 120 countries around the world (222). The tackle and ruck are key components of the sport, with an average 160 tackles and 110 rucks occurring per game, at the professional level (88). Successful teams complete more tackles and are more effective at the ruck than unsuccessful teams, with fewer rucks lost and faster recycle times at the ruck (212). The greatest proportion of injuries also occur during these two contact events, with tackle and ruck related injuries accounting for 64% of all injuries in professional rugby union (158). Given the high injury incidence and importance of these contact events, identifying factors that can reduce the risk of injury, without compromising performance, is a high priority for all stakeholders in rugby union (190).

Implementing proper technique in the tackle and the ruck has been associated with reduced injury risks and improved performance in matches (16, 86, 94). For example, a tackler placing their head on the correct side of the ball-carrier when contacting the ball-carrier is less likely to get injured in the tackle (33, 86, 182). Similarly, ball-carriers are more likely to win the tackle contest if they actively fend off the tackler (85, 94, 214). Furthermore, higher total tackler, ball-carrier and ruck technique proficiency scores (determined by scoring a players technique to a list of standardised technical criteria (86)) have been associated with positive measures of performance and non-injury outcomes (16, 33, 86, 179). These findings provide coaches with objective guidelines to develop contact technique proficiency in training.

Training plays a pivotal role in developing players' skills and physical qualities (217). A key component to whether skills developed in training transfer to the match environment is the degree to which training activities represent match activities (35, 148). The arrangement of conditions and constraints of training activities to represent match activities refers to the

representative learning design (RLD) of the training environment (137). For example, a study in youth soccer found that players who took part in 14 training sessions involving small-sided games (high RLD) performed better in passing and decision making during matches, compared to players who participated in conventional training sessions (low RLD) (140). Assessing and monitoring the RLD of training is, therefore, important to ensure optimal environments are formed to facilitate the transfer of skills from training to matches (51, 135). The RLD of a training drill can be assessed by comparing how the outcomes of a skilled performance in training represent the outcomes of a skilled performance in matches (i.e. whether better tackle technique proficiency resulted in a successful tackle in training and in matches) (51). This method assesses the representativeness of the components of the drill. Another method to assess the RLD of a training drill is by comparing the underpinning measures of a skilled performance in training and matches (i.e. the differences in technique proficiency in training and matches) (51). This method directly assesses the transference of skills from training to matches. In Chapter 3, we demonstrated the validity of assessing tackle and ruck technique proficiency during a two-on-two contact drill. The purpose of this study was to evaluate the RLD of the contact technique assessment drill. Accordingly, tackle and ruck technique proficiency scores were compared to tackle and ruck outcomes within training and matches, and differences in tackle and ruck technique proficiency were compared between training and matches.

Method

Participants

Twenty-four male amateur rugby union players participated in the study. The players were from the same rugby union club, competing at the highest level of local amateur rugby in the region (Western Cape, South Africa) (n = 24; 14 forwards & 10 backline players). All the

players were free from injury and had played rugby union for at least one calendar year. Informed consent was obtained from the participants to use the data from the study. All procedures were approved by the designated university's human research ethics committee (HREC 604/2018; Appendix 4.1).

Experimental design

A cross sectional study design was used to describe the relationship between contact technique proficiency in training and matches. Tackle, ball-carry and ruck technique proficiency in training was assessed, retrospectively, during a contact drill that took place before the competitive rugby season began (i.e. pre-season). Tackle, ball-carry and ruck technique proficiency in matches was assessed, retrospectively, during 14 competitive league matches.

Contact Drill

A two-on-two contact training drill was used to assess the contact technique proficiency of the players. Before testing players were warmed up and familiarized with the drill. A description of the drill is provided in Chapter 3 (Figure 3.1). In brief, the drill started with a simulated ruck, where the ball was passed, via the first attacker, to the ball-carrier. The ball-carrier then advanced the ball forward in direction of the tackler. The ball-carrier was instructed to 'score the try' and the tackler to prevent the ball-carrier from scoring the try through the use of safe and effective tackle technique. Once the ball-carrier was brought to ground, the first defender and first attacker formed a ruck. The first attacker was instructed to allow the first defender to arrive at the breakdown first, and then clear out the first defender, using the drive technique. Each player performed four tackles, four ball-carries and four rucks.

Match Analysis

Fourteen amateur rugby union matches played in the 2018 Western Province Super League A were analysed from video recordings. Front-on tackles, front-on ball-carries, and rucks were coded using performance analysis software (Sports Code Elite Version 11.2.18) on an Apple iMac (Apple, USA) displayed at eye level. The analysis software allows for the control of time-lapse during the recorded game and the recording and saving of each event into a database. The analyst was able to pause, rewind and watch the footage in slow motion. The highest frequency at which the analyst can slow down the footage was 25 frames per second (25 Hz). An initial 408 tackles, 840 carries and 637 rucks were coded. From these events, 267 tackle, 320 ball-carries and 289 rucks were identified as suitable for analysis, as the match events needed to be similar (e.g. starting point, type, direction, number of players involved) to the contact events simulated in the training drill. A diagram of this process, with reasons for exclusions is shown in Figure 4.1.

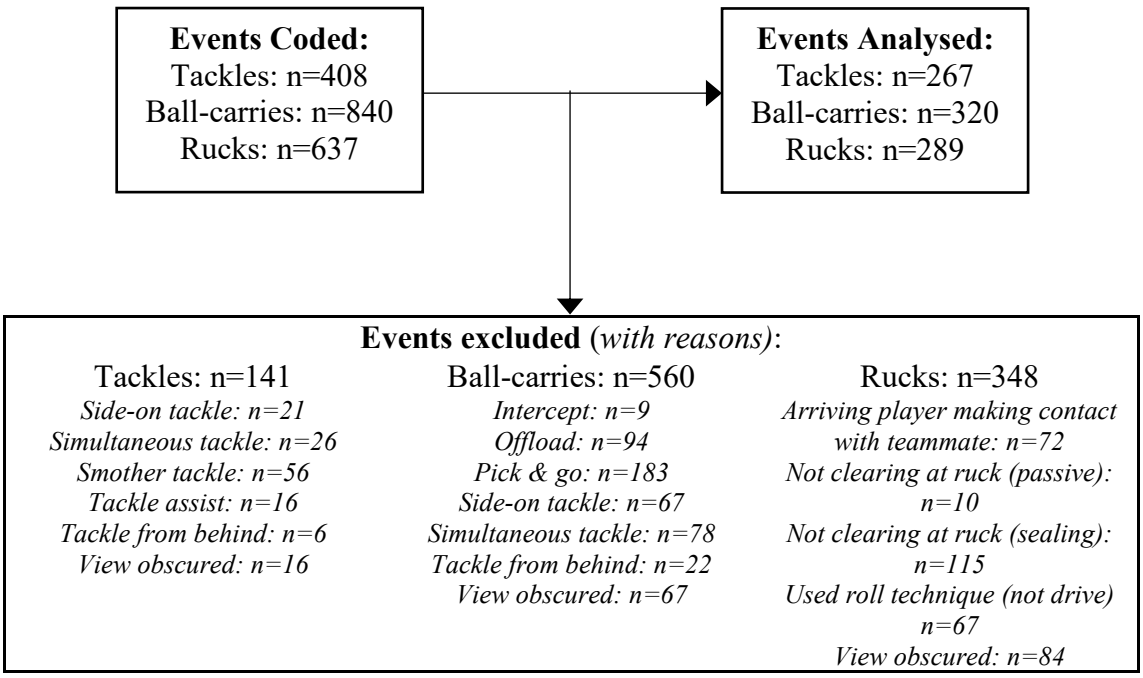

Figure 4.1 Flow diagram of identification process of match events.

Contact Technique Proficiency

Each tackle, ball-carry and ruck from the training drill and match footage was assessed, retrospectively, using standardised tackle, ball-carry and ruck technical criteria (Chapter 3, Tables 3.1-3.3). Players were awarded 1 point for each criterion they performed and 0 points if they failed to perform the criterion. The number of criteria performed were totalled to provide a score (arbitrary units) for each tackle, ball-carry and ruck.

Outcome definitions

The outcome of each tackle, ball-carry and ruck from training and matches was recorded. The outcomes, with descriptions, are listed below:

Tackle Outcomes:

- Less effective - the ball-carrier is tackled but progresses beyond the tackle gain line (179, 201)
- Effective - the ball-carrier is tackled and prevented from progressing beyond the tackle gain line (179, 201)
- Missed tackle - the tackler was unable to bring the ball-carrier to ground, allowing the ball-carrier to advance during open play (94)

Ball-carry outcomes:

- Less effective - the tackler prevents the ball-carrier from progressing beyond the tackle gain line before bringing the ball-carrier to ground (the horizontal line across the field at the point of contact in the tackle) (179, 201)
- Effective - the ball-carrier is tackled but progresses beyond the tackle gain line (179, 201)
- Tackle-break - the ball-carrier successfully penetrates the attempted tackle and continues to advance with the ball (94)

Ruck Outcomes:

- Ineffective - the player is unsuccessful in clearing out the opposition player from the ruck (152)
- Effective - the player successfully clears the opposition from the ruck, making the ball available to play (152)

Reliability

To assess the reliability of the analyst, 20 training tackles, ball-carries and rucks and 20 match tackles, ball-carries and rucks were coded on two separate occasions (intra-rater). For the purpose of assessing the inter-rater reliability of the analyst, a second analyst, with experience with the criteria, assessed the same 40 (20 training & 20 match) tackles, carries and rucks. Intra-rater and inter- rater reliability were calculated using the interclass correlation coefficient (ICC) and the typical error of measurement (TEM) (Burger et al., 2016; Hopkins et al., 2009). For the technique assessed in training, the ICCs for both the intra- and inter-rater tackle, ball-carry, and ruck assessments were 1.0. The TEMs for the intra-rater tackle, ball-carry, and ruck assessments were 0.7, 0.5 and 0.5, respectively, and for the inter-rater; 0.6, 0,6 and 0.5, respectively. For the technique assessed in matches, the ICCs for both the intra- and inter-rater tackle, ball-carry, and ruck assessments were 0.9, 0.9 and 0.8, respectively. The TEMs for the intra-rater tackle, ball-carry, and ruck assessments were 0.4, 0.5 and 0.5, respectively, and for the inter-rater; 0.6, 0.7 and 0.7, respectively.

Statistical Analyses

The data were tested for normality, using a Shapiro-Wilk test. As the data were normally distributed, a one way analyse of variance (ANOVA) was used to compare differences in the total tackle, ball-carry and ruck technique proficiency scores between the relevant tackle, ball-

carry and ruck outcomes, within and between training and matches. A one-way ANOVA was also performed to compare differences for each individual tackle, ball-carry and ruck technical criterion between training and matches. Post-hoc analyses were conducted using Bonferroni adjustments. The level of significance was set at $p \leq 0.05$. Cohen's effect size statistic was used to determine the magnitude of the differences between the outcomes, and assessment environments (training or match) (24). Effect sizes of <0.20, 020–0.59, 0.60–1.19, 1.20–1.99 and >2.00 were considered trivial, small, moderate, large and very large, respectively (98). STATA 11.1 (StataCorp LP, USA) was used for all statistical analyses.

Results

The relationships between training and match tackle, ball-carry and ruck technique proficiency scores are shown in Table 4.1. Players scored significantly higher in training compared to matches in all contact events (Table 4.1).

Table 4.1 Contact technique proficiency scores for tackles, ball-carries and rucks in training and matches (includes means with 95% confidence intervals (95% CI), and percentage difference in means between match and training, effect sizes (ES) and interpretations)

Outcomes	**Training**			**Match**			**Training vs Matches**		
	n	mean	95%CI	n	mean	95%CI	Difference in means (%)	ES	Interpretation
Tackle	92	10.6	10.2-10.9	267	9.0	8.8-9.3	15.1	0.8	Moderate**
Missed	10	8.5	7.0-10.0	65	7.3	6.9-7.7	14.9	0.7	Moderate
Less effective	72	10.7	10.3-11.0	169	9.3	9.0-9.6	13.1	0.9	Moderate**
Effective	10	11.9	10.8-13.0	33	11.2	10.7-11.8	5.9	0.4	Small
Ball-carry	89	10.3	9.9-10.7	320	9.3	9.1-9.5	9.7	0.5	Small**
Less effective	5	9.2	6.7-11.7	35	8.1	7.5-8.6	12.0	0.6	Moderate
Effective	69	10.0	9.6-10.4	226	9.0	8.8-9.2	10.0	0.6	Small**
Tackle break	15	11.9	10.9-12.8	59	11.3	10.9-11.7	5.0	0.5	Small
Ruck	87	11.3	10.9-11.6	289	9.8	9.6-10.0	13.3	0.8	Moderate**
Ineffective	21	10.1	9.4-10.9	86	8.6	8.2-9.0	4.9	0.9	Moderate**
Effective	66	11.7	11.3-12.0	203	10.3	10.1-10.6	12.0	0.8	Moderate**

n: number of tackles;
*p < 0.05;
**p < 0.001.

Tackler Technique Proficiency

Tackler technique proficiency scores for missed tackles were significantly lower than less effective tackles and effective tackles in training and in matches (Figure 4.2). Technique scores were also significantly lower for less effective tackles in matches compared to training ($p < 0.01$, ES = 0.9, moderate).

There were significant differences with moderate effect sizes in training and match scores, between the individual tackler technical criteria *alignment square to ball-carrier* ($p < 0.01$, ES = 1.0, moderate), and *use of shoulder to impede or disrupt the ball-carrier* ($p < 0.01$, ES = 0.6, moderate). Differences between training and match technique for each tackler technical criterion are shown in Table 4.2.

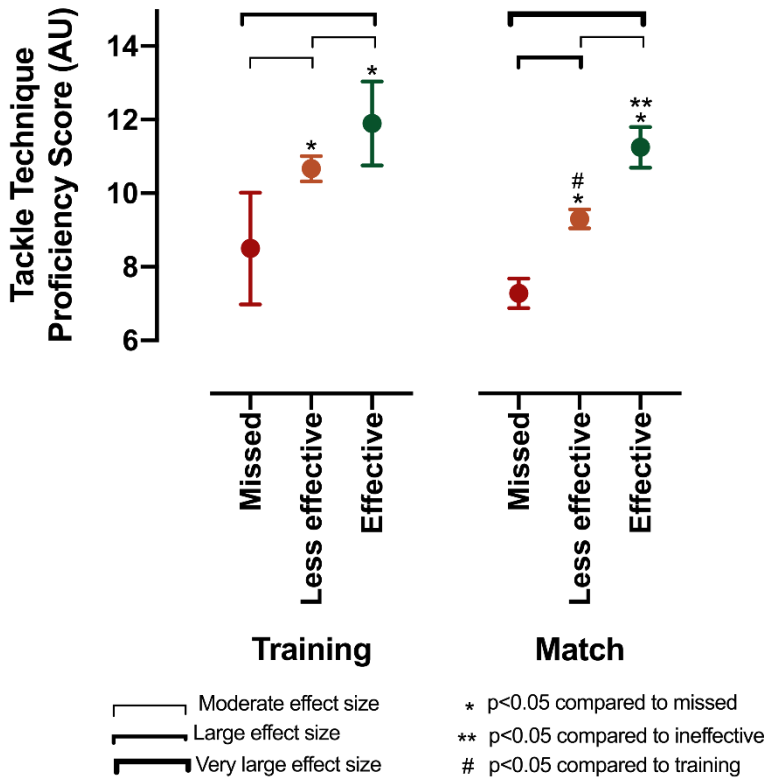

Figure 4.2 Total tackler technique proficiency scores during training and matches. Data are reported as means and 95% confidence intervals. Moderate to very large effect sizes and significance are shown.

Ball-Carrier Technique Proficiency

Ball-carrier technique scores were significantly higher for tackle breaks compared to effective and less effective ball-carries in training and matches (Figure 4.31). Effective ball-carries technique scores in matches were also significantly lower than tackle breaks in matches ($p < 0.01$, ES = 1.4, large) and effective ball-carries in training ($p < 0.01$, ES = 0.6, small). Differences between training and match technique for each ball-carrier technical criterion are shown in Table 4.3.

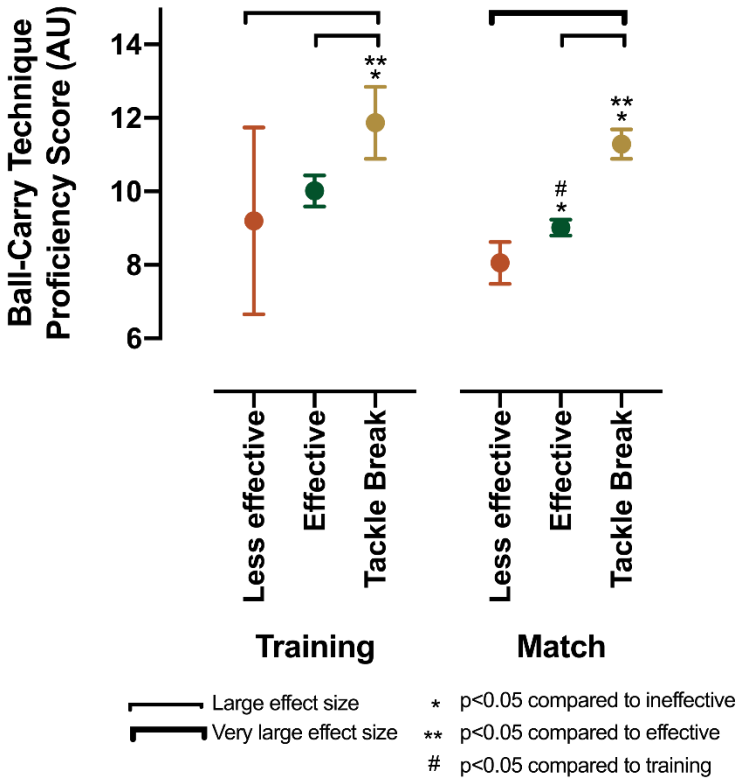

Figure 4.3 Total ball-carry technique proficiency scores during training and matches. Data are reported as means and 95% confidence intervals. Moderate to very large effect sizes and significance are shown.

Ruck Technique Proficiency

Ruck technique proficiency scores were significantly higher for effective rucks compared to ineffective rucks in training and in matches (Figure 4.4). There were also significant differences with moderate effect sizes between effective rucks in training and effective rucks in matches ($p < 0.01$, ES = 0.8, moderate), and ineffective rucks in training and ineffective rucks in matches ($p < 0.01$, ES = 0.9, moderate). Scores for the individual ruck contact technique *enter from low to high position* ($p < 0.01$, ES = 1.0, moderate) and post contact technique *stay on feet* ($p < 0.01$, ES = 1.4, large) were significantly higher in training compared to matches. Differences between training and match technique for each ruck technical criterion are shown in Table 4.4.

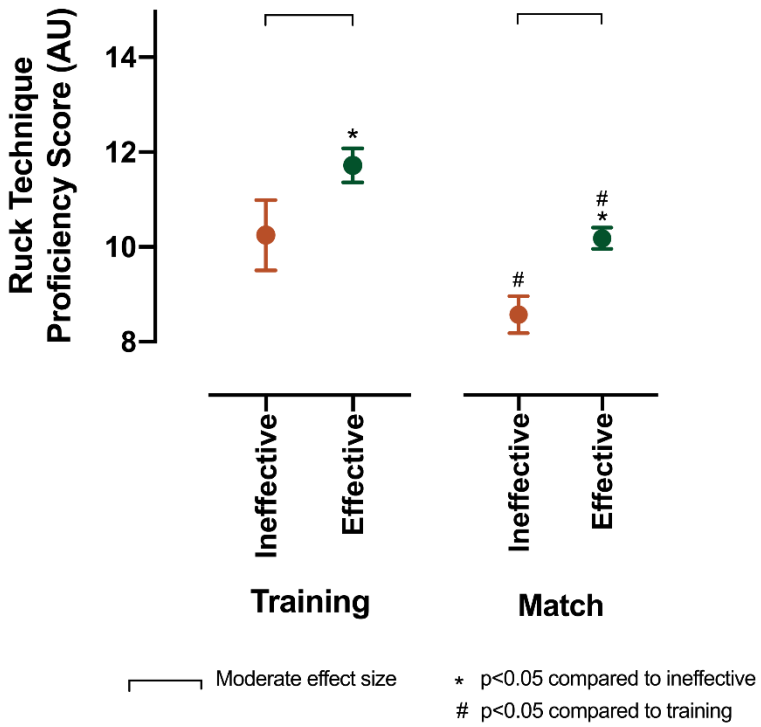

Figure 4.4 Total ruck technique proficiency scores during training and matches. Data are reported as means and 95% confidence intervals. Moderate effect sizes and significance are shown.

Table 4.2 Tackle technique proficiency results: training vs match for all tackles and by outcome (includes means with 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations)

	Training (Total)		**Match** (Total)		**Total** Training (n=92) vs Match (n=267)		**Missed** Training (n=10) vs Match (n=65)		**Less Effective** Training (n=72) vs Match (n=169)		**Effective** Training (n=10) vs Match (n=33)	
	Mean	95% CI	Mean	95% CI	ES	Interpretation	ES	Interpretation	ES	Interpretation	ES	Interpretation
Pre-contact												
Identify ball-carrier and position to ensure shoulder contact is made	1.0	0.9-1.0	1.0	1.0-1.0	0.1	Trivial	-0.4	Small	0.0	Trivial	0.0	Trivial
Reposition from an upright to crouched/bent at the waist body position	0.9	0.9-1.0	0.8	0.8-0.9	0.3	Small*	0.4	Small	0.2	Small	0.6	Moderate
Keep backs straight with centre of gravity forward of the support base	0.6	0.5-0.7	0.4	0.4-0.5	0.4	Small**	0.4	Small	0.5	Small**	-0.8	Moderate*
Alignment square to ball-carrier (hips aligned)	**1.0**	**1.0-1.0**	**0.7**	**0.6-0.7**	**1.0**	**Moderate****	**1.2**	**Moderate***	**0.9**	**Moderate****	**0.7**	**Moderate****
Head up and face forward	0.9	0.9-1.0	0.9	0.8-0.9	0.2	Small	-0.6	Small	0.2	Small	-0.1	Trivial
Bend elbows with hands raised above the level of the elbow and elbows close to torso	0.3	0.2-0.4	0.2	0.1-0.2	0.4	Small**	0.6	Moderate*	0.6	Small**	-0.5	Small
Exhibit shorter and faster steps when approaching ball-carrier (feet remain active)	0.3	0.2-0.4	0.4	0.4-0.5	-0.2	Trivial	-0.1	Trivial	-0.3	Small	-0.2	Small
Approach from front/oblique	1.0	1.0-1.0	1.0	1.0-1.0	0.1	Trivial	0.2	Trivial	0.1	Trivial	0.0	Trivial
Contact												
Explosiveness (rapid leg movement) on contact	0.3	0.2-0.3	0.2	0.2-0.3	0.1	Trivial	-0.8	Moderate	0.4	Small	-0.5	Small
Contact the ball-carrier with the shoulder as the first point of contact	0.8	0.7-0.8	0.7	0.6-0.7	0.2	Small	0.4	Small	0.0	Trivial	0.6	Small
Contact ball-carrier in centre of gravity (upper pelvis/lower torso)	0.4	0.3-0.5	0.3	0.4-0.5	-0.2	Trivial	-0.2	Trivial	-0.3	Small	0.4	Small
Place head beside or behind ball-carrier's body correctly	1.0	0.9-1.0	0.9	0.8-0.9	0.3	Small*	-0.4	Small	0.5	Small**	0.1	Trivial
Post contact												
Use shoulder to impede and disrupt the ball-carrier	**0.6**	**0.5-0.7**	**0.2**	**0.2-0.3**	**0.7**	**Moderate****	**0.8**	**Moderate****	**0.6**	**Small****	**0.6**	**Moderate**
Leg drive upon contact	0.2	0.1-0.3	0.1	0.1-0.2	0.3	Small*	-0.1	Trivial	0.3	Small*	0.8	Moderate
Wraps arms around ball-carrier and maintains hold	0.8	0.7-0.9	0.6	0.6-0.7	0.3	Small*	0.5	Small	0.0	Trivial	0.7	Moderate
Release ball-carrier and join the defensive line	0.5	0.4-0.6	0.5	0.4-0.5	0.2	Trivial	-0.2	Trivial	0.1	Trivial	0.2	Trivial

n: number of tackles;
*$p < 0.05$;
**$p < 0.001$.

Table 4.3 Ball-carry technique proficiency results: training vs match for all ball-carries and by outcome (includes means with 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations)

	Training (Total)		**Match** (Total)		**Total** Training (n=89) vs Match (n=320)		**Less Effective** Training (n=5) vs Match (n=35)		**Effective** Training (n=69) vs Match(n=226)		**Tackle Breaks** Training (n=15) vs Match(n=59)	
	Mean	95% CI	Mean	95% CI	ES	Interpretation	ES	Interpretation	ES	Interpretation	ES	Interpretation
Pre-contact												
Focus on tackler	1.0	0.9-1.0	1.0	1.0-1.0	0.1	Trivial	0.0	Trivial	0.2	Trivial	0.0	Trivial
Body position - upright to low (dipping)	0.8	0.7-0.9	0.7	0.6-0.7	0.3	Small*	0.1	Trivial	0.4	Small**	0.0	Trivial
Back straight, centre of gravity ahead of support base	0.9	0.8-0.9	0.8	0.7-0.8	0.2	Small	0.3	Small	0.2	Small	0.2	Trivial
Shift ball away from contact to correct arm	0.8	0.8-0.9	0.7	0.6-0.7	0.3	Small*	0.9	Moderate	0.3	Small	0.6	Moderate
Head up, face forward	1.0	0.9-1.0	0.9	0.9-0.9	0.2	Trivial	0.4	Small	0.3	Small	-0.4	Small**
Shuffle or evasive manoeuvre	0.4	0.3-0.5	0.3	0.2-0.3	0.4	Small**	-0.8	Moderate	0.6	Small**	0.1	Trivial
Contact												
Fend into contact	0.3	0.2-0.4	0.3	0.2-0.3	0.0	Trivial	0.4	Small	0.1	Trivial	-0.3	Small
Side-on into contact	0.8	0.7-0.8	0.5	0.4-0.5	0.6	Small**	-0.5	Small	0.6	Small**	0.9	Moderate**
Explosiveness on contact	0.8	0.8-0.9	0.9	0.9-0.9	-0.1	Trivial	0.4	Small	-0.3	Small*	0.2	Small
Body position – from low up into contact	0.5	0.4-0.6	0.4	0.3-0.4	0.3	Small*	0.3	Small	0.4	Small**	0.1	Trivial
Ball in correct arm and protected	0.8	0.8-0.9	0.8	0.8-0.9	0.0	Trivial	0.6	Small	0.1	Trivial	0.2	Trivial
Post contact												
Use of arm and/or shoulder to push tackler	0.5	0.4-0.6	0.5	0.5-0.6	-0.1	Trivial	0.6	Moderate	-0.2	Trivial	-0.1	Trivial
Leg drive upon contact	0.7	0.6-0.8	0.8	0.7-0.8	-0.1	Trivial	-0.4	Small	-0.2	Small	0.0	Trivial
Go to ground and present ball	1.0	0.9-1.0	0.9	0.8-0.9	0.4	Small*	0.6	Moderate	0.4	Small*	0.0	Trivial

n: number of ball-carries;
*$p < 0.05$;
**$p < 0.001$.

Table 4.4 Ruck technique proficiency results: training vs match for all rucks and by outcome (includes means with 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations)

	Training (Total)		**Match** (Total)		**Total** Training (n=87) vs Match (n=289)		**Ineffective** Training (n=21) vs Match (n=86)		**Effective** Training (n=66) vs Match(n=203)	
	Mean	95% CI	Mean	95% CI	ES	Interpretation	ES	Interpretation	ES	Interpretation
Pre-contact										
Identify target	0.9	0.8-1.0	1.0	0.9-1.0	-0.2	Trivial	0.1	Trivial	-0.3	Small*
Body position - upright to low (dipping)	1.0	1.0-1.0	0.9	0.9-1.0	0.3	Small*	0.1	Trivial	0.4	Small*
Back straight, centre of gravity ahead of support base	0.6	0.4-0.7	0.6	0.6-0.7	-0.1	Trivial	-0.1	Trivial	-0.2	Trivial
Enter from behind/alongside last man's feet	1.0	1.0-1.0	1.0	1.0-1.0	0.1	Trivial	-0.1	Trivial	0.2	Small
Head up, face forward	0.9	0.8-0.9	0.7	0.7-0.8	0.3	Small*	0.2	Small	0.3	Small
Boxer stance – elbows low and close, hands up	0.1	0.0-0.2	0.2	0.1-0.2	-0.2	Trivial	-0.3	Small	-0.2	Trivial
Shortening steps	0.5	0.4-0.6	0.6	0.5-0.6	-0.1	Trivial	-0.1	Trivial	-0.2	Trivial
Head and shoulders above hips	0.8	0.7-0.9	0.8	0.8-0.9	-0.1	Trivial	-0.1	Trivial	-0.2	Trivial
Contact										
Dip and step into contact	0.4	0.3-0.5	0.6	0.6-0.7	-0.4	Small**	-0.5	Small*	-0.4	Small*
Enter from low to high position	**0.9**	**0.8-1.0**	**0.5**	**0.5-0.6**	**1.0**	**Moderate****	**0.9**	**Moderate****	**1.0**	**Moderate****
Contact with shoulder	0.8	0.8-0.9	0.6	0.6-0.7	0.5	Small**	0.5	Small	0.5	Small**
Head placement on correct side of opponent	1.0	1.0-1.0	0.9	0.8-0.9	0.5	Small**	0.7	Moderate*	0.4	Small*
Post contact										
Punch arms forward, wrap and pull (hit and stick)	0.8	0.7-0.9	0.5	0.5-0.6	0.6	Small**	0.6	Moderate**	0.5	Small**
Leg drive upon contact and clean out opponent	0.8	0.7-0.9	0.6	0.5-0.6	0.4	Small**	0.5	Small*	0.4	Small**
Stay on feet	**0.9**	**0.8-0.9**	**0.3**	**0.3-0.4**	**1.4**	**Large****	**1.1**	**Moderate****	**1.4**	**Large****

n: number of ball-carries;
*$p < 0.05$;
**$p < 0.001$.

Discussion

This study assessed the representative learning design of a contact technique assessment drill, by describing the relationship between tackle and ruck technique in training and matches. Tackler, ball-carrier and ruck technique proficiency was assessed in two environments - training and matches - and the relationships between technique proficiency and performance outcomes within and between these environments were compared. Within training and match environments, tackler, ball-carrier and ruck technique scores were significantly associated with performance outcomes. Therefore, the outcomes of skilled performance in training represented the outcomes of skilled performance in matches. There were differences in the total technique scores between training and matches, with small to moderately higher scores in training compared to matches. However, much of the variation was attributed to a few individual technical criteria.

Contact technique scores were significantly higher in successful tackles, tackle breaks and effective rucks, compared to missed tackles, ball-carries and ineffective rucks, respectively, in training and in matches. These findings show that the conditions created in the training drill adequately represented match conditions, as the same technical movements required to perform well in matches were required to perform well in the training assessment drill. These findings also contribute to the body of research on contact technique and performance outcomes in rugby. The associations between contact technique and outcomes in matches are in support of previous studies that found similar differences in tackler and ball-carrier technique proficiency between successful and unsuccessful tackles, and effective and less effective tackles in elite level matches (94, 179, 201). In rugby league, good tackling ability on a standardised proficiency test has been associated with a greater proportion of dominant tackles and successful tackles in matches (68, 165, 169). This study described the relationship between

tackle and ruck technique and performance outcomes within training. Therefore, future research is needed to identify whether the same relationships exist between tackle and ruck technique assessed in training and match performance outcomes in rugby union.

There were small to moderate differences between training and match technique scores. The tackle is a dynamic and open phase of match play, with no structured starting point (16, 71). Although attempts were made to enhance the ecological validity of the drill used in this study, the nature of a training drill added a structured starting point to the tackles. This added structure may explain the differences in technique scores. Indeed, in skill development and training, the amount of structure in a training session can be used to alter the difficulty of a task, as it is more difficult to perform a skill proficiently in unstructured conditions (93). There were moderate to large differences between training and matches for a few individual contact techniques. Some of these differences may also be related to the structured nature of the drill. For example, there was a moderate difference between training and matches in the tackle technique scores for *alignment square to ball-carrier.* In training, the technique had a perfect score of 1.0, however, the ball-carrier was instructed to remain in a 5-metre channel, making it much easier for the tackler to align their bodies to the ball-carrier, compared to matches where the ball-carrier is unrestricted. Therefore, technique proficiency may need to be assessed in various training environments (structured/semi-structured/unstructured), to improve the RDL of the assessment environment and more effectively identify weaknesses in technique proficiency. However, as the exposure to contact in a dynamic environment can be considered a risk factor for injuries, with the highest incidence of training injuries occurring in contact training (213), it is advisable to start contact technique training in a structured environment and gradually remove or add constraints from the environment as players technique develops (51, 93). There were also moderate to large differences between matches and training in the ruck

techniques *enter from low to high* and *stay on feet*. The two techniques are related - a player moving upwards in contact is more likely to stay on their feet than a player moving downwards in contact. According to laws of the game, 'players must endeavour to remain on their feet throughout the ruck' (Law 15.12) (223). Our findings suggest that this law may not have been enforced, as none of the players were penalised for going off their feet. The importance of ruck techniques in terms of effectiveness at the breakdown and injury prevention is under researched. Therefore, future studies are required to describe these relationships, to determine whether the laws of the ruck should be adapted or better enforced to protect players from possible injury risks. Finally, where moderate to large differences were found, technique proficiency was consistently higher in training compared to matches. It is, therefore, surmisable that if a technique is not implemented in training it is not likely to be implemented in matches. This highlights the importance of addressing weaknesses in technique identified in training, as the weaknesses are likely to be amplified in matches.

Conclusion

This study compared tackle and ruck technique proficiency between performance outcomes, within and between training and match. Contact technique scores were lower in matches compared to training. These findings demonstrate the importance of addressing technical weaknesses identified in training to improve players performance in matches. The findings also highlighted the importance of assessing contact technique in less structured drills, to improve the RDL of the assessment environment and more effectively identify weaknesses in technique proficiency. Contact technique scores were associated with performance outcomes in training and in matches.

Chapter 5: Relationships between physical qualities and contact technique in academy rugby union players

Introduction

Rugby union is a collision sport played in over 120 countries worldwide (222). The sport is intermittent in nature, characterised by high intensity activities, including sprints, tackles and rucks, interspersed with lower intensity activities (224). To effectively engage in these activities, players require highly developed physical qualities along with the ability to proficiently execute complex sport-specific skills. (46, 150). To determine whether players can meet these requirements, physical qualities and skills are often assessed at the start of a season (41, 84).

The physical qualities of players are often assessed with standardised testing batteries (41). These batteries are used as a screening tool to determine the strengths and weaknesses of players, to identify areas where they may need to improve to perform at a certain level or to identify any potential injury risk factors. Indeed, greater results in speed, power and endurance assessments have been associated with positive measures of match performance (31, 160, 174), and poor scores in functional mobility have been identified as a risk factor for contact related injuries in rugby union (2, 176). The objective data provided from these assessments enable strength and conditioning coaches to develop optimal programmes to develop the physical qualities of players, and ultimately improve their match performance.

The assessment of skills as part of a preseason testing battery in rugby union is less common (84). In rugby league, a number of studies demonstrated the use of a tackle drill to assess tackle technique proficiency (63, 64, 168). The drill was filmed, and the tackler's technique was assessed retrospectively, using standardised technical criteria. The criteria represented the 'ideal' tackle and players were awarded one point for each of criterion they performed in the tackle (63, 64, 168). In rugby union, a similar method was used to assess tackle and ruck

technique proficiency. The tackle and ruck are the two most frequent contact events in rugby union (92). As such, a player's performance in the tackle and ruck are a key indicator of a teams' overall match performance (212). In addition, these two contact events also place players at a high risk of injury, with approximately 55% of all injuries occurring during the tackle and 10% during the ruck (58, 158). Yet, similar to physical qualities, executing proper technique in the tackle and ruck has been associated with positive measures of match performance and lower contact related injury risks (16, 86, 179). Therefore, a screening tool to assess players' contact technique will allow coaches to identify areas needed to improve match performance, identify any potential injury risk factors, and obtain objective data to develop contact skill training programmes (84).

Physical qualities and tackle and ruck technique are similarly associated with measures of performance and injury outcomes. As such, understanding the interactions between physical qualities and proper technique is essential to optimise player development. Strengths and weaknesses in players contact technique proficiency may be a result of limitation in physical qualities. However, little is known about the effect of various physical qualities on contact technique in rugby union. Therefore, the aim of this study was to describe the relationship between physical qualities and tackle and ruck technique in rugby union.

Methods

Experimental Design

A cross-sectional study design was used to compare the physical qualities and tackle and ruck technique proficiencies of academy level rugby players.

Participants

Thirty-eight u20 male amateur rugby players (n=38; 18 forwards and 20 backline players) participated in the study. All players were free from injury and had played rugby for at least one calendar year. All procedures were approved by the designated university's human research ethics committee (HREC 778/2017; Appendix 5.1).

Procedures

Testing was conducted at the start of the preseason over two days (Figure 5.1). Before testing players were warmed up and were familiarised with the testing procedures. Players were given adequate time to recover between testing components.

DAY 1

Anthropometry
- Height
- Body Mass
- Skinfolds

Muscular Power
- Vertical Jump
- Broad Jump
- 5kg Medicine Ball Throw

Functional Mobility
- Proprioception Test
- Mobility Tests
- Stability Tests
- Movement Pattern Tests

Speed & Momentum
- 40m with & without ball

Agility
- Illinois with & without ball

Anaerobic Endurance
- Repeat Sprint

DAY 2

Muscular Strength Endurance
- 1 Min Push-Up
- 2 Min Sit-Up

Muscular Strength
- Pull-Up
- 1 RM Bench-Press

Aerobic Endurance
- BRONCO

Contact Technique Proficiency
- Tackle Technique
- Ball-Carry Technique
- Ruck Technique

Figure 5.1 An outline of the two-day testing schedule.

The following measurements were assessed during the testing battery:

Anthropometry. Height was measured, to the nearest 1 cm, using a stadiometer (185). Body mass was measured to the nearest 1 kg on a calibrated scale. Sum of 7 skinfolds was determined by measuring 7 skinfold sites (triceps, biceps, subscapular, suprailiac, abdominal, calf) using calibrated skinfold callipers according to the guidelines set out by the International Society for the Advancement of Kinanthropometry (172).

Functional Mobility. The players performed 10 different functional mobility tests that assessed their proprioception, stability, mobility and movement patterns. Each test was scored on an ordinal scale from 0 to 2 (0; 1; 2) based on the quality of the movement pattern performed, giving a total score out of 20. A full description of the tests is provided in Appendix 5.2.

Muscular Strength. For the relative one repetition max (1RM) bench press (186), players lay supine on a bench with their feet on the floor. An Olympic bar was gripped 5 cm wider than shoulder width apart. The test was started by lowering the bar, in a controlled manner, to the chest and then extending the arms upwards until the player's elbows were in a locked position. The maximal weight (kg) a player was able to lift in one repetition was recorded as their 1RM score. This score was divided by their body mass to determine the players relative 1RM bench press.

Muscular Strength Endurance. For the pull-up test, players assumed a hanging position under a horizontal bar 2.5 m from the ground, using a pronated grip with their arms shoulder width apart (22). The players were required to pull their body up to a position where their chin was above the bar before returning to the start position, with their elbows fully extended. The

maximal number of times a player was able to lift their chin above the bar was recorded. For the 1 min push-up test, players assumed a prone position, with their knees, hips and shoulders off the ground and their elbows fully extended. To perform a push-up, the players lowered their chest to the ground, by bending their elbows, until their chest was a fist away from the ground and then raised their chest away from the ground, until their elbows were fully extended (22). The number of push-ups a player was able to do in 1 min was recorded. For the 2 min sit-up test, players assumed a supine position with their knees bent, shoulder blades, hips and feet on the ground and their hands placed on the contralateral shoulder. To perform a sit-up, the players were to lift their upper back off the ground, until their elbows touched their knees, before returning to the start position (22). The number of sit-ups a player was able to do in 2 min was recorded.

Muscular Power. For the vertical jump test (62), the initial standing reach height was measured using a board, with the player standing with their feet flat on the ground and their arms and hand fully extended above their head. After assuming a crouched position, the player jumped vertically and touched the board at the highest possible point. The players performed three jumps and the highest jump height was recorded as their vertical jump height. The adjusted vertical jump score was determined by subtracting their standing reach height from their vertical jump height. For the broad jump test, players stood behind a line marked on the ground. The players were required to jump forward, as far as possible, taking off and landing with two feet on the ground. The players performed three jumps, with the furthest distance recorded as their broad jump score. For the medicine ball throw test (185), the players sat against a wall, with their lower back and shoulders in contact with the wall and their legs extended in front of them, holding a 5 kg medicine ball against their chest. From this position, the players threw the ball forward as far as possible, while keeping their back against the wall. The point the ball

landed was recorded as the distance thrown. The players performed three trials and the furthest distance thrown was recorded as their medicine ball throw score.

Agility. The Illinois agility test, modified from Cureton (32), was used to assess the player's agility. Cones were set up as prescribed by Cureton (32), with timing gates positioned at the start and finish. The players were instructed to start at their own time, and start 0.5 m behind the initial timing gates. The players started the test by accelerating through the starting timing gate towards and around each cone in a prescribed sequence, and through the finish timing gate. The time taken to complete the test was recorded. Players performed two trials from the left and two trials from the right, and then repeated the test holding a rugby ball. The fastest times without and with the ball were recorded as their Agility and Agility with ball scores, respectively.

Speed. Running speed was assessed from 0-10 m and 0-40 m using timing gates (41). The players were instructed to start at their own time and start 0.5 m behind the initial timing gates. Players performed four trials, two without a ball and two holding a rugby ball. The fastest times over 10 m and 40 m without and with the ball were recorded. 10m-speed with and without the ball was determined by converting the 10 m times to metres per second ($m.s^{-1}$). 40m-speed with and without the ball was determined by converting the 40 m times to $m.s^{-1}$.

Momentum. Momentum ($kg.m.s^{-1}$) at 10 m and 40 m (with and without the ball) was calculated by multiplying the players mass (kg) with their speed at 10m and 40 m ($m.s^{-1}$) values, respectively (41).

Anaerobic Endurance. For the repeat sprint test (42), six cones were placed 5 m apart in a straight line, covering a total distance of 25 m. The players were instructed to run maximally throughout the test. The players started in line with the 1st cone and upon an auditory signal sprinted to the 2nd cone, turned and returned to the 1st cone, turned and sprinted to the 3rd cone and returned to the 1st cone. This pattern was continued at the 4th, 5th, and 6th cone. After 30 sec an auditory signal was given, and the distance covered during that time. This protocol was repeated 6 times, with a 35 sec rest period between trials. The total distance covered in the 6 trials was recorded.

Aerobic Endurance. The Bronco test was used to assess the players aerobic endurance (174). Four cones were placed 20 m apart in a straight line. The players started in line with the 1st cone and upon an auditory signal ran from the 1st cone to the 2nd, turned and returned to the 1st cone, turned and ran to the 3rd cone, turned and returned to the 1st cone, turned and ran to the 4th cone, and turned and returned back to the 1st cone. This sequence was repeated five times, with no rest periods in between. The time taken to complete the test was recorded (min:s).

Contact Technique. A two-on-two contact training drill was used to assess the tackle, ball-carry and ruck technique proficiency of the players. A description of the drill has been described in chapter 3. In brief, the drill started with a simulated ruck where the ball was passed, via the first attacker, to the ball-carrier. The ball-carrier then advanced the ball forward in direction of the tackler. The ball-carrier was instructed to 'score the try' and the tackler to prevent the ball-carrier from scoring the try through the use of safe and effective tackle technique. Once the ball-carrier was brought to ground, the first defender and first attacker formed a ruck. The first attacker was instructed to allow the first defender to arrive at the breakdown first, and then clear out the first defender, using the drive technique. If the ball-carrier was tackled out of play,

or scored a try, he was instructed to go to ground so that a ruck could be formed. The drill was performed in the corner of a rugby field and filmed. The players' tackle, ball-carry and ruck technique proficiency were assessed retrospectively using standardised tackle, ball-carry and ruck technical criteria (37). Players were awarded 1 point for each criterion they performed and 0 points if they failed to perform the criterion. The number of criteria performed were totalled to provide a score (arbitrary units) for each tackle, ball-carry and ruck. Each player performed four tackles, four ball-carries and four rucks, and the total scores were averaged to calculate the tackle, ball-carry and ruck technique proficiency scores for each player.

Statistical Analyses

A Shapiro-Wilk test was used to test the normality of the data. As the data were normally distributed, a linear regression analysis was done to assess the effect of physical qualities on tackle, ball-carry and ruck technique proficiency. The analysis was performed between each physical quality and the total tackle, ball-carry and ruck technique proficiency scores. The level of significance was set at $p \leq 0.05$. Where a significant relationship was found between a physical quality and a proficiency score, a linear regression analysis was performed between the physical quality and each individual contact technique. Cohen's effect size f^2 (ES) was used to determine the magnitude of the relationship between the variables (24). Effect sizes of <0.02, 0.02-0.14, 0.15-0.39 and >0.4 were considered trivial, small, moderate and large, respectively.

Reliability

To assess the intra-rater reliability of the contact technique assessor, five player's tackles, carries and rucks were analysed on two separate occasions. To assess the inter-rater reliability of the assessor, a second assessor, experienced with the criteria, assessed the same five player's tackles, carries and rucks. Intra-rater and inter-rater reliability were calculated using the

interclass correlation coefficient (ICC) and the typical error of measurement (TEM) (16, 98) The ICCs for both the intra- and inter-rater tackle, ball-carry, and ruck assessments were 1.0. For the intra-rater, the TEMs for tackle, ball-carry, and ruck assessments were 0.7, 0.5 and 0.5, respectively. For the inter-rater, the TEMs were 0.6, 0,6 and 0.5, respectively.

Results

Seven physical qualities had a moderate effect on *tackle technique*; *Push-ups* (r^2=0.2; β=0.04; p=0.005), *Sit-ups* (r^2=0.2; β=0.08; p=0.004), *Relative 1RM Bench Press* (r^2=0.2; β=2.32; p=0.003), *Broad Jump* (r^2=0.2; β=-0.47: p=0.001), *Agility* (r^2=0.2; β=-0.03; p=0.019), *40m-Speed with Ball* (r^2=0.1; β=0.93; p=0.027) and *Functional Mobility* (r^2=0.2; β=0.16; p=0.007). *Medicine Ball Throw* had a large effect on *ball-carry technique* (r^2=0.3; β=1.13; p=0.001). Three physical qualities had a moderate effect on *ruck technique*; *height* (r^2=0.3; β=-0.07; p=0.002)*, Agility* (r^2=0.2; β=-0.75; p=0.005) and *Agility with Ball* (r^2=0.2; β=-0.55; p=0.015). Table 5.1 shows an overview of the relationships between physical qualities and tackle, ball-carry and ruck technique.

Tackle Techniques and Physical Qualities

Agility had a moderate effect on three tackle techniques; *Contact the ball-carrier with the shoulder as the first point of contact* (r^2=0.1; β=0.16; p=0.018), *Contact the ball-carrier in the centre of gravity* (r^2=0.1; β=0.16; p=0.018), and *Use shoulder to impede or disrupt the ball-carrier* (r^2=0.1; β=0.16; p=0.018;). Similarly, *40m-Speed* had moderate effect on *Contact the ball-carrier in the centre of gravity* (r^2=0.1; β=0.16; p=0.018) and a large effect on *Use shoulder to impede or disrupt the ball-carrier* (r^2=0.1; β=0.16 p=0.018). An overview of the effect of agility, 40m-speed and functional mobility on tackle technique is shown in table 5.2.

All of the muscular strength assessments and the lower body power assessment *broad jump* had a moderate effect on tackle technique. *Push-ups* had a moderate effect on the tackle techniques *Bend elbows with hands raised above the level of the elbow and elbows close to torso* (r2=0.1; β=0.01; p=0.022) and *Contact the ball-carrier with the shoulder as the first point of contact* (r2=0.2; β=0.01; p=0.002). Similarly, *Pull-ups* had a moderate effect on *Contact the ball-carrier with the shoulder as the first point of contac*t (r2=0.1; β=0.02; p=0.025), and *Relative 1RM Bench Press* had a moderate effect on *Contact the ball-carrier with the shoulder as the first point of contact* (r2=0.2; β=0.44; p=0.004) and *Release ball-carrier and join the defensive line* (r2=0.1; β=0.5; p=0.022;). *Broad jump* had a moderate effect on the post contact technique *Use shoulder to impede and disrupt the ball-carrier* (r2=0.2; β<0.01; p=0.004;). An overview of the effect of strength and lower-body power measures on tackle techniques is shown in table 5.3.

Ball-Carry Techniques and Physical Qualities

Medicine Ball Throw had a moderate effect on the post contact techniques *Use of arm and/or shoulder to push tackler* (r^2=0.1; β=0.16; p=0.018), and *Go to ground and present ball* (r^2=0.3; β=0.13; p=0.001). An overview of the effect of upper body-power on ball-carry techniques is shown in table 5.4.

Ruck Techniques and Physical Qualities

Height had a moderate effect on the pre-contact ruck technique *Identify target* (r2=0.2; β=-0.02; p=0.002). *Illinois* had a moderate effect on the contact technique *Head placement on correct side of opponent* (r2=0.2; β=-0.11; p=0.015). *Illinois with Ball* had a similarly moderate effect *Head placement on correct side of opponent* (r2=0.2; β=-0.11; p=0.004) as well as a moderate effect on *Head up and forward* (r2=0.1; β=-0.12; p=0.032). Table 5.5 shows an overview of the effect of height, agility and agility with the ball on ruck techniques.

Table 5.1 The effect of physiological measures on tackle, ball-carry and ruck technique proficiency scores (includes means, 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations)

			on Tackle Technique		**on Ball-carry Technique**		**on Ruck Technique**	
Physiological Measures	Mean	95% CI	ES	Interpretation	ES	Interpretation	ES	Interpretation
Height (cm)	176.2	172.9-179.6	0.06	Small	0.00	Trivial	0.34	**Moderate****
Weight (kg)	88.3	82.2-94.4	0.03	Small	0.05	Small	0.14	Small*
Sum of 7 Skinfolds (cm)	100.1	83.9-116.4	0.05	Small	0.00	Trivial	0.03	Small
Push-ups (n)	43	38-48	0.26	**Moderate****	0.03	Small	0.03	Small
Sit-ups (n)	38	35-40	0.27	**Moderate****	0.04	Small	0.00	Trivial
Pull-ups (n)	8	6-10	0.12	Small	0.00	Trivial	0.03	Small
Relative 1RM Bench Press ($kg.kg^{-1}$)	1.1	1.0-1.2	0.29	**Moderate****	0.04	Small	0.03	Small
Relative Vertical Jump (cm)	48.7	46.0-51.4	0.15	Small*	0.01	Trivial	0.00	Trivial
Broad Jump (cm)	55.0	52.3-57.3	0.22	**Moderate****	0.05	Small	0.00	Trivial
Medicine Ball Throw (cm)	549.6	525.9-573.3	0.07	Small	0.37	**Large****	0.04	Small
Agility (s)	16.6	16.3-17.0	0.19	**Moderate***	0.00	Trivial	0.29	**Moderate****
Agility with ball (s)	16.9	16.5-17.3	0.06	Small	0.00	Trivial	0.21	**Moderate***
10m-Speed ($m.s^{-1}$)	5.7	5.6-5.7	0.03	Small	0.05	Small	0.02	Trivial
40m-Speed ($m.s^{-1}$)	7.2	7.0-7.3	0.11	Small	0.02	Small	0.07	Small
10m-Speed with ball ($m.s^{-1}$)	5.6	5.5-5.7	0.12	Small	0.06	Small	0.00	Trivial
40m-Speed with ball ($m.s^{-1}$)	7.2	7.0-7.3	0.16	**Moderate***	0.03	Small	0.04	Small
Momentum - 10m (kg. $m.s^{-1}$)	496.0	463.7-528.3	0.02	Small	0.11	Small	0.13	Small*
Momentum - 40m (kg. $m.s^{-1}$)	629.5	591.2-667.8	0.01	Trivial	0.11	Small	0.11	Small
Repeat Sprint (m)	600	570-630	0.03	Small	0.00	Trivial	0.08	Small
BRONCO (min:s)	5:44	5:34-5:55	0.02	Small	0.00	Trivial	0.05	Small
Functional Mobility (AU)	8.5	8.0-9.0	0.25	**Moderate****	0.02	Small	0.00	Trivial

* $p < 0.05$
** $p < 0.01$

Table 5.2 The effect of agility, 40m-speed and functional mobility on tackle technique proficiency (includes means, 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations)

			Agility		**40m-Speed**		**Functional Mobility**	
Tackle Technique Proficiency	Mean	95% CI	ES	Interpretation	ES	Interpretation	ES	Interpretation
Pre-contact								
Identify ball-carrier and position to ensure shoulder contact is made	0.9	0.9-1.0	0.01	Trivial	0.03	Small	0.00	Trivial
Reposition from an upright to crouched/bent at the waist body position	0.9	0.9-1.0	0.13	Small	0.19	**Moderate***	0.01	Trivial
Keep backs straight with centre of gravity forward of the support base	0.2	0.1-0.3	0.00	Trivial	0.00	Trivial	0.11	Small
Alignment square to ball-carrier (hips aligned)	0.9	0.8-0.9	0.00	Trivial	0.00	Trivial	0.00	Trivial
Head up and face forward	0.7	0.6-0.7	0.08	Small	0.03	Small	0.04	Small
Bend elbows with hands raised above the level of the elbow and elbows close to torso	0.2	0.1-0.3	0.01	Trivial	0.00	Trivial	0.06	Small
Exhibit shorter and faster steps when approaching ball-carrier (feet remain active)	0.3	0.2-0.4	0.02	Small	0.05	Small	0.02	Small
Approach from front/oblique	1.0	1.0-1.0	0.05	Small	0.00	Trivial	0.00	Trivial
Contact								
Explosiveness (rapid leg movement) on contact	0.1	0.1-0.2	0.01	Trivial	0.01	Trivial	0.00	Trivial
Contact the ball-carrier with the shoulder as the first point of contact	0.7	0.7-0.8	0.27	**Moderate****	0.41	**Large****	0.03	Small
Contact ball-carrier in centre of gravity (upper pelvis/lower torso)	0.6	0.5-0.7	0.32	**Moderate****	0.13	Small*	0.02	Small
Place head beside or behind ball-carrier's body correctly	0.8	0.7-0.9	0.00	Trivial	0.01	Trivial	0.13	Small*
Post contact								
Use shoulder to impede and disrupt the ball-carrier	0.2	0.1-0.3	0.16	**Moderate***	0.21	**Moderate***	0.13	Small*
Leg drive upon contact	0.1	0.1-0.2	0.14	Small*	0.05	Small	0.07	Small
Wraps arms around ball-carrier and maintains hold	0.6	0.6-0.7	0.00	Trivial	0.02	Small	0.01	Trivial
Release ball-carrier and join the defensive line	0.7	0.6-0.8	0.09	Small	0.05	Small	0.11	Small
Total	8.86	8.5-9.3	0.19	**Moderate***	0.16	**Moderate***	0.25	**Moderate****

* $p < 0.05$
** $p < 0.01$

Table 5.3 The effect of muscular strength and lower-body power on tackle technique proficiency (includes effect sizes (ES) with interpretations)

	Push-ups		Sit-ups		Relative 1RM Bench-press		Broad Jump	
Tackle Technique Proficiency	ES	Interpretation	ES	Interpretation	ES	Interpretation	ES	Interpretation
Pre-contact								
Identify ball-carrier and position to ensure shoulder contact is made	0.01	Trivial	0.00	Trivial	0.01	Trivial	0.00	Trivial
Reposition from an upright to crouched/bent at the waist body position	0.03	Small	0.15	Small*	0.05	Small	0.12	Small*
Keep backs straight with centre of gravity forward of the support base	0.02	Small	0.08	Small	0.07	Small	0.12	Small
Alignment square to ball-carrier (hips aligned)	0.00	Trivial	0.03		0.01	Trivial	0.02	Small
Head up and face forward	0.01	Trivial	0.00	Trivial	0.00	Trivial	0.00	Trivial
Bend elbows with hands raised above the level of the elbow and elbows close to torso	0.16	**Moderate***	0.12	Small*	0.06	Small	0.03	Small
Exhibit shorter and faster steps when approaching ball-carrier (feet remain active)	0.00	Trivial	0.01	Trivial	0.00	Trivial	0.01	Trivial
Approach from front/oblique	0.07	Small	0.18	**Moderate***	0.05	Small	0.03	Small
Contact								
Explosiveness (rapid leg movement) on contact	0.00	Trivial	0.02	Small	0.01	Trivial	0.00	Trivial
Contact the ball-carrier with the shoulder as the first point of contact	0.32	**Moderate****	0.05	Small	0.27	**Moderate****	0.09	Small
Contact ball-carrier in centre of gravity (upper pelvis/lower torso)	0.09	Small	0.03	Small	0.11	Small	0.13	Small*
Place head beside or behind ball-carrier's body correctly	0.11	Small	0.01	Trivial	0.10	Small	0.05	Small
Post contact								
Use shoulder to impede and disrupt the ball-carrier	0.08	Small	0.09	Small	0.06	Small	0.27	**Moderate****
Leg drive upon contact	0.01	Trivial	0.01	Trivial	0.00	Trivial	0.04	Small
Wraps arms around ball-carrier and maintains hold	0.01	Trivial	0.00	Trivial	0.00	Trivial	0.00	Trivial
Release ball-carrier and join the defensive line	0.12	Small*	0.07	Small	0.16	**Moderate***	0.06	Small

* $p < 0.05$
** $p < 0.01$

Table 5.4 The effect of medicine ball throw on ball-carry technique proficiency (includes means, 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations)

			Medicine Ball Throw	
Ball-carry Technique Proficiency	Mean	95% CI	ES	Interpretation
Pre-contact				
Focus on tackler	1.0	1.0-1.0	0.00	Trivial
Body position - upright to low (dipping)	0.8	-.8-0.9	0.01	Trivial
Back straight, centre of gravity ahead of support base	0.6	0.5-0.6	0.02	Small
Shift ball away from contact to correct arm	0.7	0.5-0.8	0.03	Small
Head up, face forward	0.9	0.8-1.0	0.02	Small
Shuffle or evasive manoeuvre	0.4	0.2-0.5	0.01	Trivial
Contact				
Fend into contact	0.2	0.1-0.3	0.06	Small
Side-on into contact	0.5	0.4-0.6	0.10	Small
Explosiveness on contact	0.7	0.5-0.8	0.09	Small
Body position – from low up into contact	0.5	0.4-0.6	0.02	Small
Ball in correct arm and protected	0.7	0.6-0.8	0.02	Small
Post contact				
Use of arm and/or shoulder to push tackler	0.3	0.2-0.4	0.17	**Moderate***
Leg drive upon contact	0.7	0.6-0.8	0.11	Small
Go to ground and present ball	0.9	0.8-1.0	0.34	**Moderate****
Total	8.8	8.3-9.3	0.37	**Large****

* $p < 0.05$
** $p < 0.01$

Table 5.5 The effect of height, agility and agility with ball on ruck technique proficiency (includes means, 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations)

			Height		**Agility**		**Agility with Ball**	
Ruck Technique Proficiency	Mean	95% CI	ES	Interpretation	ES	Interpretation	ES	Interpretation
Pre-contact								
Identify target	0.8	0.7-0.9	0.31	**Moderate****	0.13	Small*	0.06	Small
Body position - upright to low (dipping)	1.0	0.9-1.0	0.00	Trivial	0.00	Trivial	000	Trivial
Back straight, centre of gravity ahead of support base	0.5	0.3-0.6	0.15	Small*	0.10	Small	0.11	Small
Enter from behind/alongside last man's feet	1.0	1.0-1.0	0.03	Small	0.01	Trivial	0.01	Trivial
Head up, face forward	0.5	0.3-0.6	0.08	Small	0.08	Small	0.16	**Moderate***
Boxer stance – elbows low and close, hands up	0.2	0.1-0.3	0.06	Small	0.01	Trivial	0.00	Trivial
Shortening steps	0.4	0.3-0.5	0.14	Small*	0.11	Small	0.02	Trivial
Head and shoulders above hips	0.5	0.4-0.6	0.07	Small	0.03	Small	0.03	Small
Contact								
Dip and step into contact	0.2	0.1-0.3	0.00	Trivial	0.06	Small	0.00	Trivial
Enter from low to high position	0.6	0.5-0.7	0.00	Trivial	0.04	Small	0.10	Small
Contact with shoulder	0.8	0.6-0.9	0.04	Small	0.01	Trivial	0.07	Small
Head placement on correct side of opponent	0.8	0.7-0.9	0.02	Small	0.21	**Moderate***	**0.30**	**Moderate****
Post contact								
Punch arms forward, wrap and pull (hit and stick)	0.4	0.3-0.5	0.10	Small	0.00	Trivial	0.01	Trivial
Leg drive upon contact and clean out opponent	0.4	0.3-0.5	0.02	Small	0.07	Small	0.09	Small
Stay on feet	0.6	0.5-0.7	0.02	Small	0.07	Small	0.11	Small
Total	8.5	8.0-9.0	0.34	**Moderate****	0.29	**Moderate****	0.21	**Moderate***

* $p < 0.05$
** $p < 0.01$

Discussion

This is the first study to investigate the relationship between physical qualities and tackle, ball-carry and ruck technique in rugby union. Seven physical qualities, including measures of strength, power and functional mobility, were associated with tackle technique. Upper body power was associated ball-carry technique, and height and agility were associated with ruck technique. These findings demonstrate the contribution of physical conditioning to develop proficient contact technique in academy level rugby union players.

Tackle Techniques and Physical Qualities

Push-ups, sit-ups, relative 1RM bench press and broad jump were associated with tackle technique. These results substantiate the importance of strength and power during contact events in rugby union (43). In contrast, studies that compared the relationship between physical qualities and tackle performance outcomes in elite rugby union (160) and rugby sevens (152), found similar associations between lower body power and positive tackle outcomes, but not between measures of strength and positive tackle outcomes. The differences in findings suggest strength training may be more impactful at improving proper tackle technique at developmental levels compared to elite, whereas power training is as impactful at both academy and elite levels of competition. However, further research comparing the effects of strength and power training on tackle technique at developmental and elite levels of competition are required.

Functional mobility scores had a moderate effect on tackle technique proficiency. Previous studies have identified poor functional mobility scores as a risk factor for contact injuries (2, 176). As greater functional mobility is related to both better tackle technique proficiency and lower contact injury risks, improving functional mobility may be a key component to

improving proper tackle technique execution, and ultimately reduce the risk of tackle related injuries in rugby union.

Ball-Carry Techniques and Physical Qualities

This is the first study to describe the relationship between physical qualities and ball-carries (in the tackle contest) in rugby union. Upper body power was closely associated with ball-carry technique proficiency, with a strong correlation between medicine ball throw and ball-carry technique scores. Furthermore, medicine ball throw scores were specifically correlated with the post-contact technique *use of arms and shoulder to push tackler.* These findings emphasize the important role upper body power plays in enabling ball-carriers to dominate the tackle contest.

Ruck Techniques and Physical Qualities

Agility was associated with ruck technique proficiency. The importance of agility in the ruck may be related to the unstructured starting points of rucks. Generally, a ruck is formed after a ball-carrier is brought to ground and has to release the ball (the breakdown). At this point, players from either side race to the breakdown to either retain or gain possession of the ball. Agility is important to be effective in this race, as players need to be able to change direction quickly, to adjust to the movements of their teammates and the opposition.

There was also a relationship between height and ruck technique, where shorter players had better ruck technique proficiency. As such, it may be of value to emphasize proper ruck technique to taller players. However, as this is the first study to describe the relationship between height and ruck technique, further research is required at different age groups to gain a better understanding of the effect of height on ruck technique proficiency.

Strengths and Limitations

This study was conducted in an applied setting, demonstrating the inclusion of a skill assessment drill as part of a pre-season testing battery. A limitation of conducting research in applied settings is that the selection of physical assessments used for a study cannot solely be selected be according to measures that can be compared to previous studies, but must suit the needs of the strength and conditioning coaches too. For this reason, a more extensive functional mobility assessment was used (Appendix 5.1), rather than the conventional functional movement screen used in previous studies (2, 176).

This study consists of a relatively large sample of amateur u20 academy rugby union players. The relationships between physical qualities and tackle and ruck technique at other age groups and levels of play may differ. However, this study provides a foundation for future research describing the relationships between physical qualities and contact technique at different age groups and levels of competition.

Conclusion

This is the first study to examine the relationship between physical qualities and contact technique in academy rugby union players. Strength, power and functional mobility were associated with tackle technique. Upper body power was associated with ball-carry technique, and agility and height were associated with ruck technique. These findings demonstrate the contribution of physical conditioning to develop proficient contact technique in academy level rugby union players.

Chapter 6: Knowledge of the importance of proper tackle technique does not translate to proper tackle technique execution

Introduction

In rugby, the tackle is the most frequently occurring contact event and carries the greatest risk of causing injury (29, 95, 149). For example, in youth rugby union a tackle related injury occurs every 90 playing hours (16). One of the major risk factors for sports injuries is technique (6). For the tackle specifically, technique has been shown to reduce the risk of injury during the tackle, for both the tackler and the ball-carrier (16, 86). Proper technique has similarly been shown to increase the likelihood of success in the tackle (85, 179). As such, national injury prevention programmes aim to provide coaches, trainers and players with knowledge of proper tackle technique (190). This knowledge is intended to modify players attitudes towards safety in the tackle, and ultimately improve their tackle technique in training and matches (83, 139).

Knowledge of technical skill can be described as either declarative or procedural (106). Declarative knowledge refers to knowledge that is factual (106). It emphasizes what to do to perform a skill (178). Procedural knowledge refers to the knowledge of how to perform a skill (106, 178). Acquiring declarative knowledge is often described as the first stage of learning (106). This knowledge can then be developed into procedural knowledge (106). For example, when learning to drive a car the first step is to learn the actions for operating a car (declarative knowledge). Through practicing these actions over multiple occasions, the processes (using the clutch, checking mirrors etc.) are internalised until they become habitual and can be performed without thinking about the instructions (procedural knowledge) (171).

The knowledge provided through injury prevention programmes to rugby stakeholders (coaches, trainers and players) can be described as declarative. Rugby stakeholders are provided with technical instructions on how to tackle in a safe and effective manner (83). These techniques can be emphasized in training, to develop the procedural knowledge of proper tackle

technique. For example, in South Africa the dissemination of declarative knowledge to rugby stakeholders seems to be effective, as both players and coaches have reported a high level of awareness of the importance of proper technique to improve performance and reduce injury risks (80, 89, 90). However, whether this declarative knowledge has been effective in modifying players' actions in the tackle contest is yet to be investigated. Therefore, the purpose of this study was to describe the relationship between knowledge and behaviours in the tackle contest, by comparing players' knowledge of the importance of tackle technique with their tackle technique proficiency.

Methods

Participants

Fifty-three South African academy-level male rugby players participated in this study (25 forwards and 28 backline players). All the players were free from injury and had played rugby union for at least one calendar year. All procedures were approved by the designated university's human research ethics committee (HREC 778/2017; Appendix 5.1).

Experimental Design

A cross-sectional design was used to compare rugby players' attitudes towards the importance of technique for injury prevention and performance in the tackle and their tackle technique proficiency. The players' tackle and ball-carry technique proficiency were recorded in a two-on-two contact drill, and assessed retrospectively using standardized tackle and ball-carry technical criteria (37). Players' attitudes and knowledge around the tackle situation were collected through a tackle questionnaire. The questionnaire required the players to rank the importance of each tackle and ball-carry technical criterion (on the standardised technical criteria lists) for performance and injury prevention, using a five-point Likert scale.

Procedures

A two-on-two contact training drill was used to assess the tackle proficiency of the players. Before testing players were warmed up and familiarized with the drill. A description of the drill has been described in previous research (37). In brief, the drill started with a simulated ruck, where the ball was passed, via the first attacker, to the ball-carrier. The ball-carrier then advanced the ball forward in direction of the tackler. The ball-carrier was instructed to 'score the try' and the tackler to prevent the ball-carrier from scoring the try through the use of safe and effective tackle technique. The drill was performed in the corner of a rugby field. The drill was filmed and the players' tackle and ball-carry technique proficiency were assessed retrospectively using standardised tackle and ball-carry technical criteria (37). The author recorded and analysed all the events. Players were awarded 1 point for each criterion they performed and 0 points if they failed to perform the criterion. The number of criteria performed were totalled to provide a score (arbitrary units) for each tackle and ball-carry. Each player performed four tackles and four ball-carries, and the total scores were averaged to calculate the tackle proficiency and ball-carry proficiency score for each player.

After completing the contact drill, the players were sent a questionnaire, electronically, related to their attitudes and knowledge around the tackle situation. The questionnaire, modelled on previous research (78-80, 89, 90), consisted of 10 questions related to training and 5 related to matches. Questions related to importance and behaviours consisted of a question and a 5-point ordinal Likert scale. Importance of an item was rated on the following scale: (1) *not important at all*, (2) *not too important*, (3) *Undecided*, (4) *Somewhat important*, (5) *Very important* (10). The quantity of behaviours was rated on a scale of: (1) *Not at all*, (2) *a little*, (3) *A fair amount*, (4) *Much*, (5) *Very much* (10). If a player was not familiar with any of the techniques listed in questions 6 and 7 they had the option of answering *not familiar* (NF). The questionnaire was

developed on Google Forms (Appendix 6.1). The numerical responses to questions 6a, 6b, 7a and 7b – where players ranked the importance of tackle or ball-carry technique for winning the contest and preventing injuries – were averaged to provide an overall score for how important the player found tackle technique or ball-carry technique for performance and injury prevention.

Statistical Analyses

The normality of the data was tested using a Shapiro-Wilk test. As the data were normally distributed, a linear regression analysis was done to assess the effect of the overall scores for the importance of technique for performance and injury prevention on the technique proficiency scores. The analysis was performed between the questionnaire responses and technique proficiency assessment scores for each individual technique and the overall scores, for tackling and ball-carrying. The level of significance was set at $p \leq 0.05$. STATA 13.0 (StataCorp LP, USA) was used for all statistical analyses.

Reliability

To assess the intra-rater reliability of the analyst, five players' tackles and ball-carries and were analysed on two separate occasions. To assess the inter-rater reliability of the analyses, a second analyst, with experience with the criteria, assessed the same five players' tackles and ball-carries. Intra-rater and inter-rater reliability were calculated using the interclass correlation coefficient (ICC) and the typical error of measurement (TEM) (16, 98). The ICCs for both the intra- and inter-rater tackle and ball-carry assessments were 1.0. The TEMs for the intra-rater tackle, ball-carry, and ruck assessments were 0.7 and 0.5 respectively, and for the inter-rater; 0.6 and 0,6 respectively.

Results

The mean technical proficiency scores were 8.9 out of 16 (95% CI: 8.5-9.3) and 9.3 out of 14 (95% CI: 8.9-9.7) for tackling and ball-carrying respectively. Ninety-six percent of players (n = 51/53) rated the importance of tackle technique to prevent injuries as *somewhat important – very important.* Similarly, 94% (n = 50/53) rated the importance of tackle technique to win the tackle contest as *somewhat important to very important.* For the ball-carrier, 91% (n = 48/53) of players rated the importance of technique to prevent injuries as *somewhat important – very important,* and 92% (n = 49/53) rated the importance of technique to win the tackle contest as *somewhat important – very important.* There was no significant relationship between a player's attitudes towards tackle or ball-carry technique for injury prevention and performance and his tackle or ball-carry technical proficiency score (Figure 6.1).

The mean scores for each of the tackle and ball-carry techniques for injury prevention and performance were above 4 (somewhat important), except for the importance of the ball-carry technique side-on into contact for injury prevention, which had a mean score of 3.9 (undecided – somewhat important). For each individual tackle and ball-carry technique, the rated importance of each technique for injury prevention or performance had no meaningful effect on a player executing the technique in the assessment.

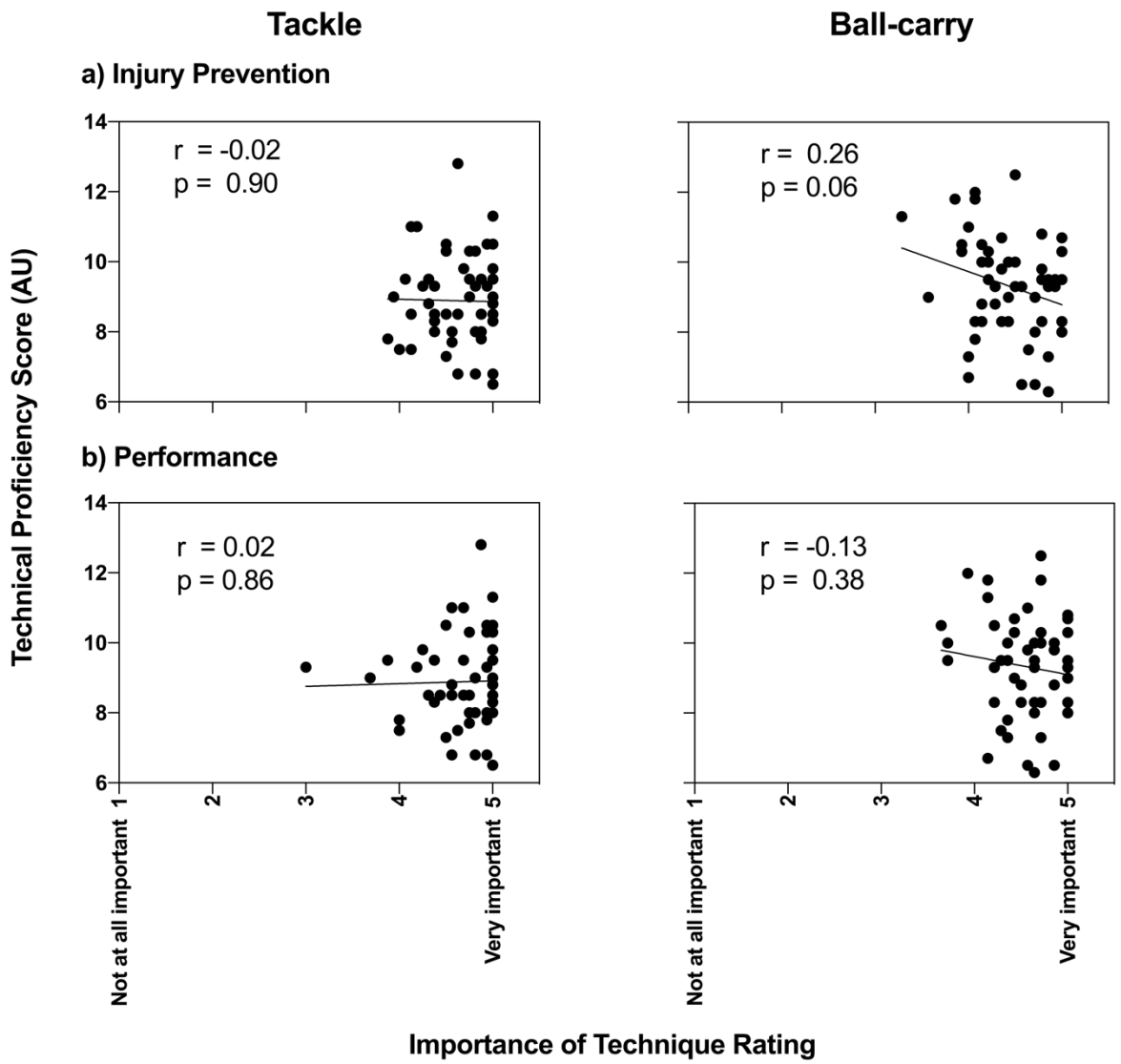

Figure 6.1 The relationship between tackler and ball-carrier technical proficiency scores, and the importance technique to prevent injury and to win the tackle contest. Lines represent line of best fit.

Discussion

The purpose of this study was to determine the effect of players' knowledge and attitudes towards safe and effective technique on their tackle and ball-carry technique execution. We found a high level of awareness of the importance of technique to improve performance and reduce injury risks amongst the players. This work supports previous research (80, 89, 90) and highlights the effectiveness of a national injury prevention programme on increasing coaches' and players' knowledge of the importance of proper tackle technique. However, the knowledge

of the importance of tackle and ball-carry technique did not translate to their tackle and ball-carry technique proficiency scores, respectively. This brings into question the effectiveness of this strategy on actually improving players' tackle technique. Similarly, a systematic review of educational programmes to prevent concussions in rugby union, found little evidence to support the effectiveness of these programmes (52). Although the review found some evidence that these programmes were effective in disseminating information to rugby stakeholders, they found scant evidence that education changed players' behaviours resulting in a reduction in concussions programmes (52). Therefore, although disseminating educational material on safe and effective technique is succeeding in improving declarative knowledge, it may not be sufficient to change behaviour and reduce the tackle injury burden.

The gap between players' declarative knowledge of proper tackle technique and their procedural knowledge of how to execute proper tackle techniques (reflected in their technical proficiency scores) is similar to a gap found in coaches' tackle knowledge and behaviours (90). A study described the tackle knowledge, attitudes and training behaviours of coaches (90) and found that although coaches rated the coaching of safe and effective technique as highly important, this knowledge did not reflect on the amount time they spent coaching tackle technique in training (90). Similarly, a study that examined trends in training volume over 11 seasons of English professional rugby, found that only 24 minutes per player per week (out of an average of 6 hours 48 minutes per player per week of training) was spent in full contact sessions (213). This raises the question of whether the amount of time spent on contact training is sufficient to allow players' declarative knowledge on safe and effective tackle technique to become procedural knowledge. One of the reasons given for the discrepancy between coaches' knowledge of the importance of technique and their training of tackle technique was that they did not feel confident in their ability to coach tackle technique (90). As a result, any full contact

training sessions are likely to be less structured, rather than technique focussed. The dynamic environment of unstructured contact sessions exposes players to greater injury risks (213). Consequently, to protect their players, coaches may reduce the amount of time spent in full contact session, resulting in players not fully developing the technical components of their contact skills. Therefore, strategies that provide frameworks to equip players and coaches on how to train tackle technique safely may be more effective to improve tackle technique (92, 93).

Strategies to develop tackle technique safely have been proposed. Hendricks and colleagues developed a 5-week tackle technique training framework (93). The framework draws from skill acquisition and development literature, and outlines how to progressively develop tackle technique proficiency through altering the conditions and coaching style of the sessions (93). Although more research is required to assess the efficacy of the tackle technique training programme, it serves as a potential tool to translate procedural knowledge to declarative knowledge, and ultimately improve tackle technique in training and matches.

Conclusion

This is the first study to compare players' knowledge of the importance of proper tackle technique for injury prevention and performance with their tackle and ball-carry technique proficiency. Although there was a high level of awareness of the importance of technique to improve performance and promote safety, their knowledge and attitude had no effect on their technique proficiency. The findings reveal a gap between players' knowledge of the importance of proper tackle technique and their execution of proper tackle technique, and support the need for contact skill training programmes in rugby union.

Chapter 7: Contact technique, injury risk, and match performance in club rugby union

Introduction

Rugby is amongst the most played sports in the world, with an estimate of 9.6 million over 120 countries (222). The sport is characterised by contact events, where players physically interact with each other as they compete for territory and possession of the ball (94). The most frequently occurring contact events are the tackle and the ruck (85). In the professional game, players can engage in 9-10 tackles (whether as the ball-carrier or tackler) and 6-15 rucks, depending on their playing position (102). The ability to engage effectively in these events has been associated with overall team success (134, 212, 215). For example, a study of professional rugby union matches found that winning teams completed more tackles, had more effective ball-carries and were more effective at the ruck than losing teams (212). The nature of contact in the tackle and ruck also exposes players to a high risk of injury. Tackle and ruck related injuries account for 64% of all injuries in professional rugby union (158). Given the importance and the associated risk, tackles and rucks have been analysed in training and matches to identify factors that can guide contact training, with the aim of ultimately improving performance and reducing the risk of injury (15, 86, 94).

Video analysis research in rugby union has identified proficient tackle and ruck technique among the most important factors to reduce risk of injury (15, 33, 86) and increase the likelihood of success (85, 179, 214). In matches, proficient contact technique has been shown to differentiate between injury and non-injury contact events, and between effective and less effective tackles and ball-carries (16, 86, 179). The studies assessed contact technique by scoring player's technique according to a standardised list of observable actions (16, 86, 179). One point was awarded for every action observed and the sum of these points represents the technical proficiency score of the tackle, ball-carry or ruck. In training, contact technique assessed in a two-on-two drill were similarly associated with performance outcomes (Chapter

4). Tackle technique scores were higher in successful tackles compared to missed tackles, ball-carry technique scores were higher in tackle breaks compared to ball-carries, and ruck scores were higher in effective rucks compared to ineffective rucks (Chapter 4). These studies highlight the importance of assessing and developing tackle and ruck technique in training, to improve performance and reduce injury risks in matches.

To date, studies that measured tackle and ruck technique in matches have grouped the results according to the event, i.e. injury-related tackles or non-injury-related tackles (sampled from either the injured player's previous tackles or teammates' tackles). From this we cannot necessarily say if the injured player's technique was generally poor, or similarly, if players with good technique performed better in match activities. Furthermore, research on the relationship between a player's tackle and ruck technique in training and their match performance and injury risk in rugby union is limited. Therefore, the purpose of this study was twofold. Firstly, to determine the relationship between contact technique in matches and match performance and injuries. Secondly, to determine whether better contact technique in training transfers to improved match performance and reduced injury risks.

Methods

Participants

Twenty-four amateur male rugby union players participated in the study (n = 24; 14 forwards and 10 backs). The players were from the same rugby union club, competing at the highest level of local amateur club rugby in the region (Western Cape, South Africa). All the players were free from injury and had played rugby union for at least one calendar year. Informed consent was obtained from the participants to use the data from the study. All procedures were

approved by the designated university's human research ethics committee (HREC 604/2018; Appendix 7.1).

Experimental design

A prospective, observational, longitudinal study design was used to describe the relationship between contact technique proficiency in training and in matches and measures of performance and contact injuries in matches. During a pre-season training session, 24 players took part in a contact drill. The drill was filmed and the players' tackle, ball-carry and ruck technique proficiency were assessed, retrospectively, using standardised technical criteria. Match performance was analysed over the course of the season, and match injuries were recorded.

Contact Drill

A two-on-two contact training drill was used to assess the tackle proficiency of the players. Before testing players were warmed up and familiarized with the drill. A description of the drill has been described in Chapter 3. In brief, the drill started with a simulated ruck, where the ball was passed, via the first attacker, to the ball-carrier. The ball-carrier then advanced the ball forward in direction of the tackler. Once the ball-carrier was brought to ground, the first defender and first attacker formed a ruck. The first attacker was instructed to allow the first defender to arrive at the breakdown first, and then clear out the first defender, using the drive technique. Each player performed four tackles, four ball-carries and four rucks. The drill was filmed and each tackle, ball-carry and ruck was assessed using standardised technical proficiency

Match Analysis

Fourteen amateur club rugby union matches from the 2018 Western Province Super League A were recorded and analysed (n=14). Match activities were analysed using performance analysis software (Sports Code Elite Version 11.2.18) on an Apple iMac (Apple, USA) displayed at eye level. The analysis software allows for the control of time-lapse during the recorded game and the recording and saving of each event into a database. The analyst was able to pause, rewind and watch the footage in slow motion. The highest frequency at which the analyst can slow down the footage was 25 frames per second (25 Hz). The operational definitions of the match activities are detailed in Table 7.1. To limit the effect of abnormally high values, data were only included for players who contested a minimum of 160 cumulative minutes of match play (n = 19; 11 forwards and 8 backs) (152). In addition to the match activities, players' match tackles, ball-carries and rucks were coded and the technique proficiency scored. An overview of the identification and selection process of these contact events is shown in Chapter 4 (Figure 4.1).

Contact Technique Proficiency

Tackle, ball-carry and ruck technique proficiency from the training and match footage was assessed using standardised technical criteria (Chapter 3). Players were awarded 1 point for each criterion they performed and 0 points if they failed to perform the criterion. The number of criteria performed were totalled to provide a score (arbitrary units) for each tackle, ball-carry and ruck, and the total scores for each player's tackles, ball-carries and rucks in training and in matches were averaged to determine their training tackle, ball-carry and ruck technique proficiency scores and their match tackle, ball-carry and ruck technique proficiency scores.

Injury Data

The details of each injury were recorded according to the consensus statement on injury definitions data collection procedures for studies of injury in rugby union (57). Injury data were collected for the match injuries for the entire 1st team squad over the course of the season (n=33; 18 forwards, 15 backs).

Table 7.1 Match activity descriptors & definitions

Descriptors	Definitions
Ball-carry related match activities	
Ball-carry (55, 125, 144)	An event where a player carrying the ball (ball-carrier) is impeded by one or more tacklers, whether or not the ball-carrier is brought to the ground.
Effective ball-carry (201)	The ball-carrier is brought to ground by the tackler but progresses beyond the tackle gain line (the horizontal line across the field at the point of contact in the tackle) .
Effective ball-carries (%)	The percentage of ball-carries where the ball-carry is brought to ground but progresses beyond the tackle gain line.
Tackle break (214)	The ball-carrier successfully penetrates the attempted tackle and continues to advance with the ball.
Tackle related match activities	
Tackle (55, 125, 144)	An event where one or more tacklers attempt to impede the ball-carrier, whether or not the ball-carrier is brought to ground.
Tackle made	A tackle where the ball-carrier is successfully brought to ground.
Tackles made (%)	The percentage of tackles attempted where the ball-carrier is brought to ground.
Effective tackle (201)	The ball-carrier is brought to ground and prevented from progressing beyond the tackle gain line.
Effective tackles (%)	The percentage of tackles made where the ball-carrier is prevented from progressing beyond the tackle gain line.
Ruck related match activities	
Ruck arrival (223)	An event where a player make contact with an opposition player (or teammate in contact with an opposition player), while on their feet and over the ball on the ground.
Ruck clearing (94)	The player is actively pushing or driving their opponents off the ball.
Effective ruck (152)	The player successfully clears the opposition from the ruck, making the ball available to play
Effective ruck (%)	The percentage of times a player was successful in their attempt to clear an opponent from the ruck.

Reliability

To assess the reliability of the analyst, 20 tackles, ball-carries and rucks were coded on two separate occasions (intra-rater). For the purpose of assessing the inter-rater reliability of the analyst, a second analyst, with experience with the criteria, assessed the same 20 tackles, carries

and rucks. Intra-rater and inter- rater reliability were calculated using the interclass correlation coefficient (ICC) and the typical error of measurement (TEM) (Burger et al., 2016; Hopkins et al., 2009). The ICCs for both the intra- and inter-rater tackle, ball-carry, and ruck assessments were 1.0. The TEMs for the intra-rater tackle, ball-carry, and ruck assessments were 0.7, 0.5 and 0.5, respectively, and for the inter-rater; 0.6, 0,6 and 0.5, respectively.

Statistical Analyses

Injury incidence rates were calculated according to the guidelines defined in the consensus statement on injury definitions and data collection procedures for studies of injury in rugby union (57). Due to concerns regarding the low sample size of injury events, the Mann–Whitney U test was used to determine differences between the contact technique of players who received an injury and players who did not. Cohen's effect size statistic was used to determine the magnitude of the difference in either tackle, ball-carry or ruck technique between players who sustained an injury and players who did not, for each contact event.

To account for differences in playing times between players, match activities were summed and normalised to a per 80-minute (match) average, using the following equation: reported value = 80 x observed value/minutes played. Between player means and 95% CI were determined for all contact technique assessments and match activities. A linear regression was performed to assess the effect of the tackle, ball-carry and ruck technique proficiency on tackle, ball-carry and ruck related match activities, respectively. Each analysis was done on the entire data sample and by position group (i.e. forward or back). All analyses were first conducted using the training technique data and then repeated using the match technique data. A linear regression was also performed to assess the relationship between tackle, ball-carry and ruck

technique in training and matches. The level of significance was set at $p \leq 0.05$. STATA 13.0 (StataCorp LP, USA) was used for all statistical analyses.

Results

Injuries & Contact Technique

There were a total of 28 match injuries over the 14 game season. Sixty-one percent of the injuries were time loss injuries (n = 17; 5 minimal, 7 mild, 4 moderate & 1 severe), and 9% required medical attention only. An overview of the number, incidence, and severity of time loss injuries per event is shown in Table 7.2.

Table 7.2 The number of time loss injuries, incidence and severity of injury

Events	**Injuries** n (%)	**Incidence** per 1000 playing hours	**Severity** mean days missed
Total	17	60.7	9.1
Tackle	8 (47)	28.6	13.0
Ball-carrier	4 (23.5)	14.3	5.3
Tackler	4 (23.5)	14.3	20.8
Ruck	2 (12)	7.1	9.0
Maul	1 (6)	3.6	8.0
Open Play	4 (23)	14.3	4.8
Unsure	2 (12)	7.1	2.5

From the sub-group of 24 players who participated in the skill assessment protocol, 8 sustained a medical attention injury (33%) and 13 sustained a time-loss injury (54%). Twenty-nine percent of injuries occurred when the player was tackling (n=7, 4 medical attention, 3 time loss), 21% when carrying the ball into contact (n=5, 2 medical attention, 3 time loss), and 8% players were injured in the ruck (n=2, 2 time loss). There were no significant differences in the pre-season technique proficiency scores, or the match technique proficiency scores, between

players who sustained an injury and those who did not sustain a contact injury (Table 7.3 & Table 7.4).

Table 7.3. Training tackle, ball-carry and ruck technique proficiency scores for players who sustained an injury and players who did not (includes means, 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations)

Training Technique Proficiency Scores	**Sustained Injury**		**No Injury**		**Sustained Injury vs No Injury**	
	Mean	95% CI	Mean	95% CI	ES	Interpretation
Tackle	10.5	10.0-10.9	10.6	9.9-11.3	-0.2	Trivial
Ball-carry	10.8	9.6-11.9	10.1	9.4-10.7	0.6	Small
Ruck	10.8	1.2-20.3	11.5	10.9-12.1	0.5	Small

Table 7.4 Match tackle, ball-carry and ruck technique proficiency scores, for players who sustained an injury and players who did not (includes means, 95% confidence intervals (95% CI), and effect sizes (ES) with interpretations)

Match Technique Proficiency Scores	**Sustained Injury**		**No Injury**		**Sustained Injury vs No Injury**	
	Mean	95% CI	Mean	95% CI	ES	Interpretation
Tackle	9.2	7.9-10.3	9.2	7.9-10.4	0.1	Trivial
Ball-carry	9.8	9.2-10.3	9.1	8.6-9.5	1.1	Moderate
Ruck	9.2	6.7-11.7	9.9	9.3-10.5	0.8	Moderate

Match Activities & Contact Technique

The contact technique assessment scores and match activities for backs, forwards and all players combined are shown in Table 7.5. There were no significant relationships between tackle, ball-carry and ruck technique proficiency scores in training and respective measures of match performance, for all the players combined, and when differentiated by playing position (Figures 1-3). For all players, there was an association between ball-carry technique scores in matches and the number of tackle breaks made per game ($p<0.05$, $r^2 = 0.31$). Similarly, for all players, there was an association between tackle technique in matches and the number of number of tackles made per match ($p<0.05$, $r^2 = 0.21$), and the number of effective tackles

made per game ($p<0.05$, $r^2 = 0.20$). Ruck technique in matches was associated with number of effective rucks made per game, for all players ($p<0.05$, $r^2 = 0.21$), and the percentage of ruck involvements where a player was effective, for backs only ($p<0.05$, $r^2 = 0.61$) (Figures 7.1-7.3). The individual scores for each player's training and match technique are shown in Table 7.6. The percentage of training technique represented in match technique ranged from 63% to 100% for tackling, 75% to 106% for ball-carrying, and 65% to 143% for the ruck. There were no meaningful associations between tackle or ruck technique in training and in matches (Figure 7.4). Ball-carry technique in training was associated with ball-carry technique in matches ($p<0.01$, $r^2 = 0.43$) (Figure 7.4).

Table 7.5 Results of the contact technique assessments and match analysis (includes means and 95% confidence intervals (95%CI))

Activity	Backs (n=8)		Forwards (n=11)		All Players (n=19)	
	Mean	95%CI	Mean	95%CI	Mean	95%CI
Training Technique Scores						
Ball-Carry Technique	11.0	10.1-11.9	9.8	9.0-10.6	10.3	9.6-10.9
Tackle Technique	11.1	10.0-12.2	10.7	10.1-11.2	10.8	10.3-11.3
Ruck Technique	12.0	11.4-12.5	11.1	10.0-12.3	11.3	10.7-11.9
Match Technique Scores						
Ball-Carry Technique	9.8	9.3-10.4	8.9	8.4-9.3	9.3	8.9-9.7
Tackle Technique	9.1	8.3-10.0	8.9	8.4-9.4	9.0	8.6-9.4
Ruck Technique	10.2	9.3-11.2	10.1	9.5-10.7	10.2	9.7-10.6
Match Activities						
Tackle Breaks / Game	0.9	0.2-1.5	0.5	0.2-0.8	0.7	0.4-1.0
Ball-Carries / Game	4.6	3.2-6.1	6.0	3.5-8.5	5.4	4.0-6.9
Effective Carries / Game	3.8	2.5-5.1	5.3	3.1-7.5	4.7	3.3-6.0
Effective Carries (%)	81.7	76.3-87.1	87.6	84.3-90.9	85.1	82.1-88.1
Tackles Made / Game	4.5	3.1-5.9	4.4	3.2-5.6	4.4	3.6-5.3
Tackles Made (%)	59.5	48.9-70.1	68.6	64.3-73.0	64.8	59.8-69.8
Effective Tackles / Game	0.6	0.2-1.1	0.9	0.5-1.3	0.8	0.5-1.1
Effective Tackles (%)	13.0	5.1-20.9	20.8	13.9-27.7	17.5	12.5-22.5
Ruck (Arrivals) / Game	3.8	2.4-5.2	13.7	10.5-16.9	9.5	6.5-12.5
Ruck (Clearing) / Game	1.7	0.8-26	5.3	3.8-6.7	3.8	2.6-5.0
Effective Rucks / Game	1.2	0.6-1.8	3.7	2.8-4.7	2.7	1.8-3.5
Effective Rucks (%)	64.6	38.7-90.5	75.9	70.3-81.4	71.1	61.0-81.3

Table 7.6 Individual player's tackle, ball-carry and ruck technique in training and matches (includes means and percentage (%) of training technique represented in match technique)

Player	Tackle Technique			Ball-Carry Technique			Ruck Technique		
	Training	Match	%	Training	Match	%	Training	Match	%
1	10.5	9.0	86	9.0	9.5	**106**	10.5	9.5	91
2	9.8	8.8	90	9.0	8.4	93	7.7	11.0	**143**
3	10.8	7.3	**68**	10.0	9.7	97	11.8	10.7	91
4	10.0	7.5	75	9.5	8.5	90	14.0	11.1	79
5	10.8	9.3	86	10.3	8.4	82	10.7	9.6	90
6	10.7	9.3	87	10.3	10.2	99	12.8	11.0	86
7	10.8	8.9	82	11.5	9.5	83	12.3	9.0	73
8	12.3	10.1	82	8.3	8.4	101	12.3	10.3	84
9	10.8	9.0	83	12.5	9.4	**75**	13.0	8.4	**65**
10	10.0	9.3	93	9.3	8.6	93	10.5	11.1	106
11	10.3	8.9	86	9.0	8.0	89	10.8	9.8	91
12	10.8	8.7	81	12.0	10.5	88	12.5	10.7	86
13	10.0	9.0	90	9.5	9.2	97	10.3	9.9	96
14	12.0	7.6	63	11.0	8.8	80	10.0	9.4	94
15	12.0	10.5	88	10.8	10.3	95	11.0	8.7	79
16	9.5	9.3	99	11.8	9.6	81	12.3	9.3	76
17	9.3	9.3	**100**	12.5	10.6	85	11.7	11.8	101
18	13.0	10.3	79	10.0	9.8	98	11.0	10.5	96
19	12.5	8.7	70	9.5	8.7	92	13.0	11.2	86
Total	**10.8**	**9.0**	**83**	**10.3**	**9.3**	**90**	**11.3**	**10.2**	**90**

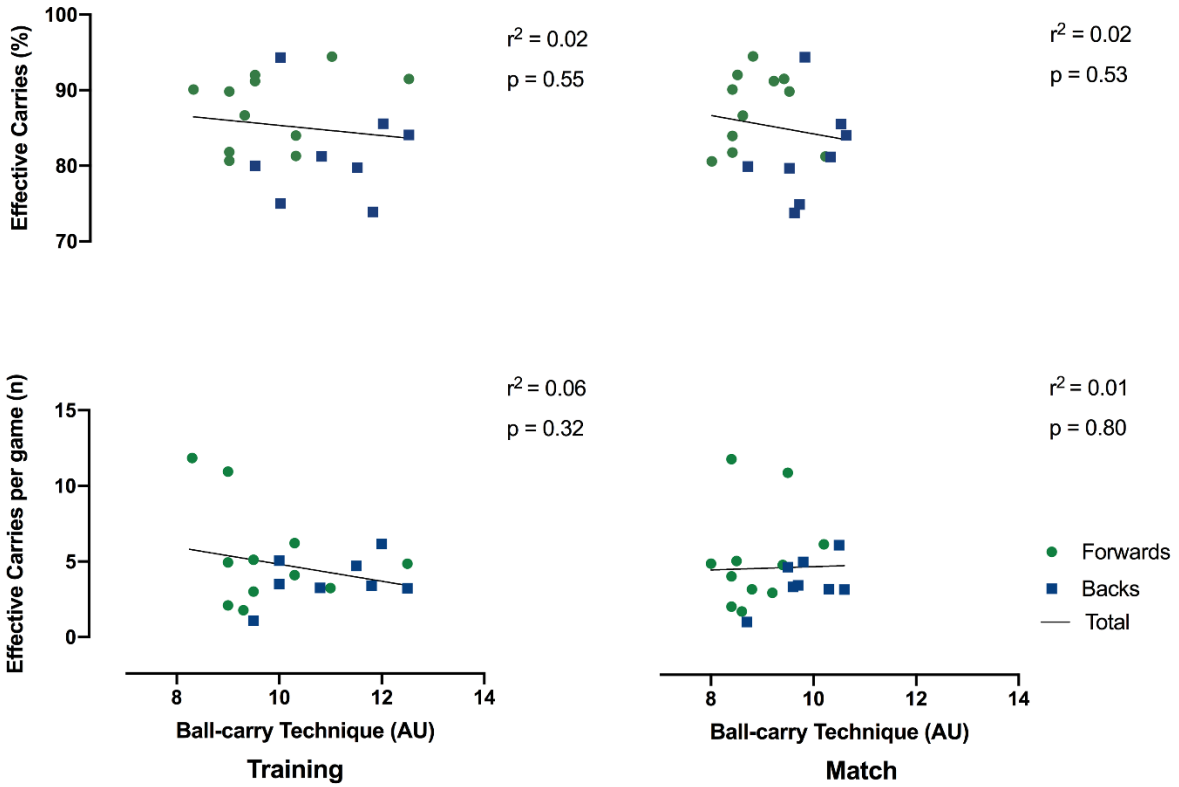

Figure 7.1 The relationship between ball-carry technique proficiency scores in training and in matches, and effective ball-carries made in matches. Individual scores for forwards and backs are shown. Coefficient of determination (r^2) and level of significance (p) are shown for the total sample (forwards and backs). Line represents the line of best fit.

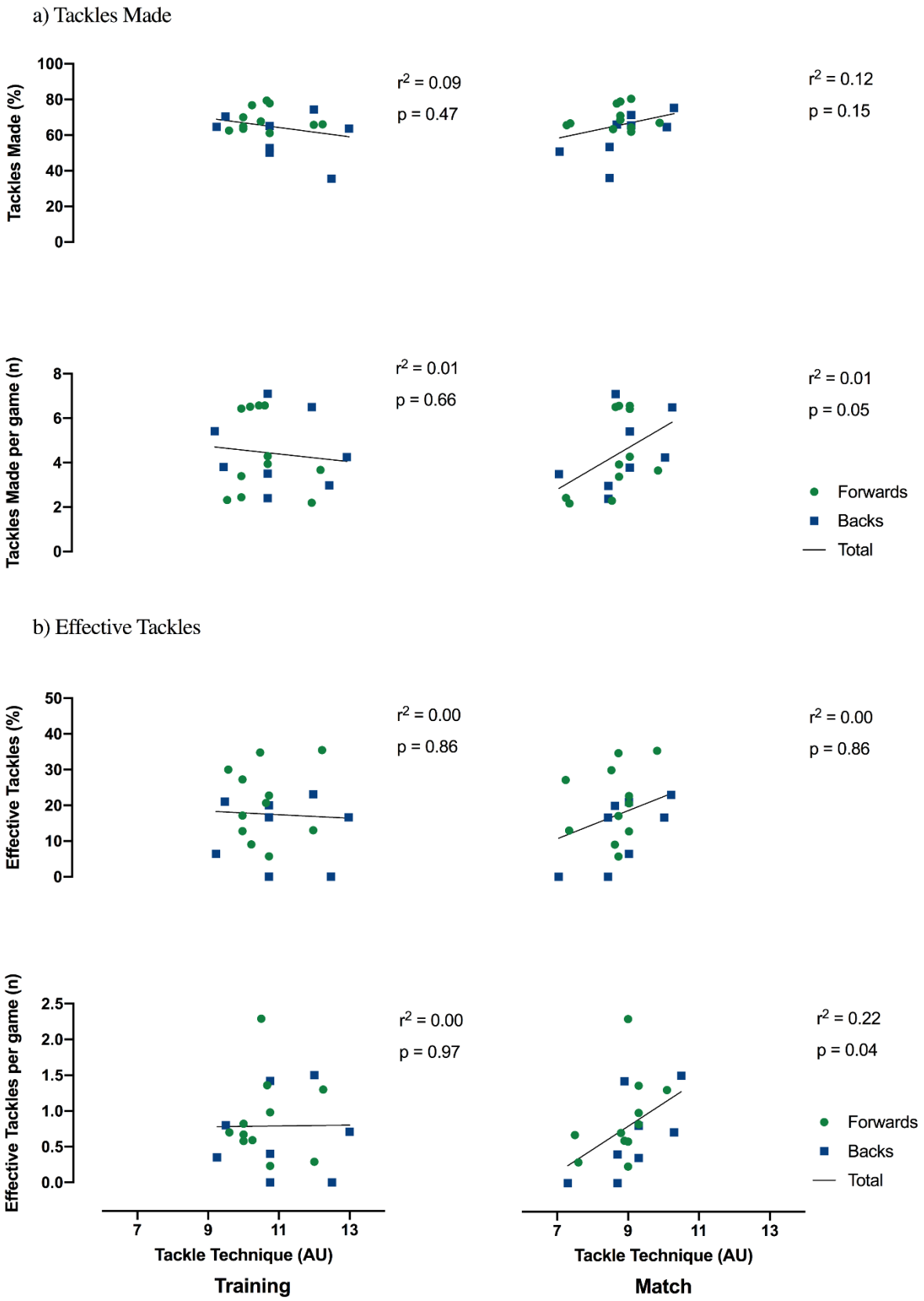

Figure 7.2 The relationship between tackle technique proficiency scores in training and in matches, and a) tackles made in matches, and b) effective tackles made in matches. Individual scores for forwards and backs are shown. Coefficient of determination (r^2) and level of significance (p) are shown for the total sample (forwards and backs). Line represents the line of best fit.

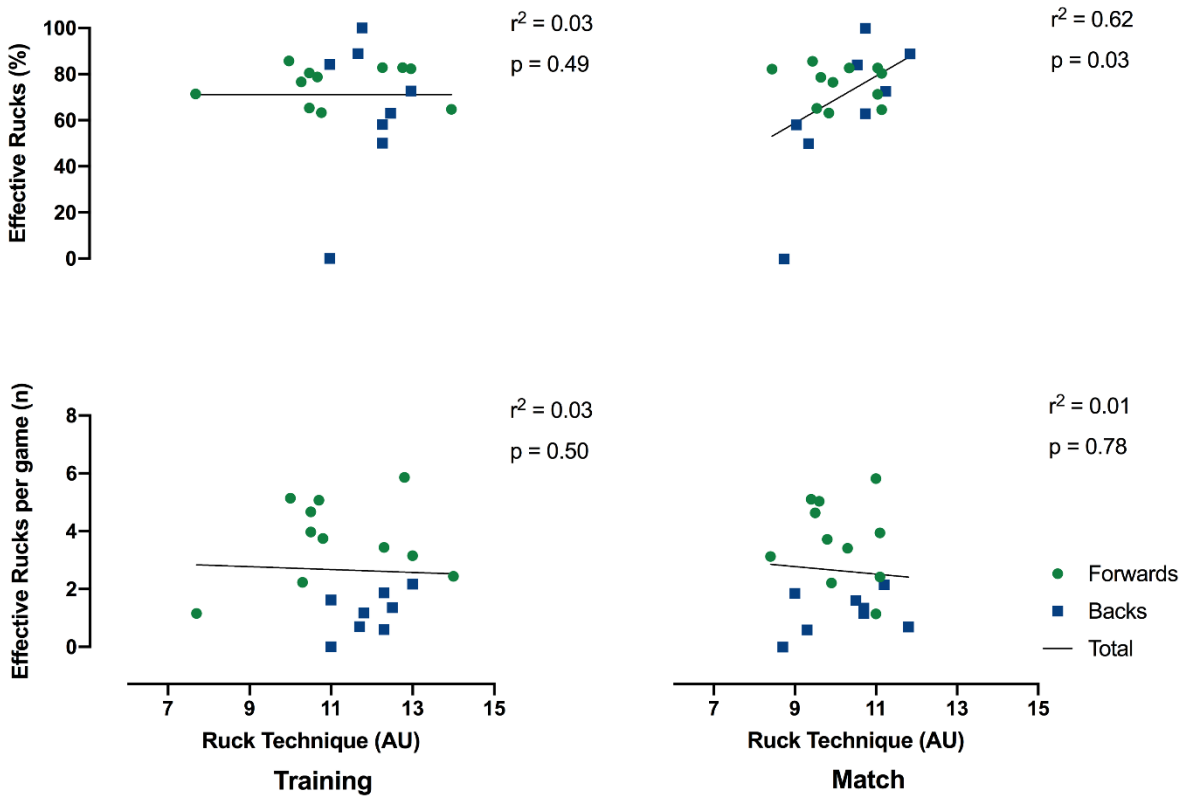

Figure 7.3 The relationship between ruck technique proficiency scores in training and in matches and effective rucks completed in matches. Individual scores for forwards and backs are shown. Coefficient of determination (r^2) and level of significance (p) are shown for the total sample (forwards and backs). Line represents the line of best fit.

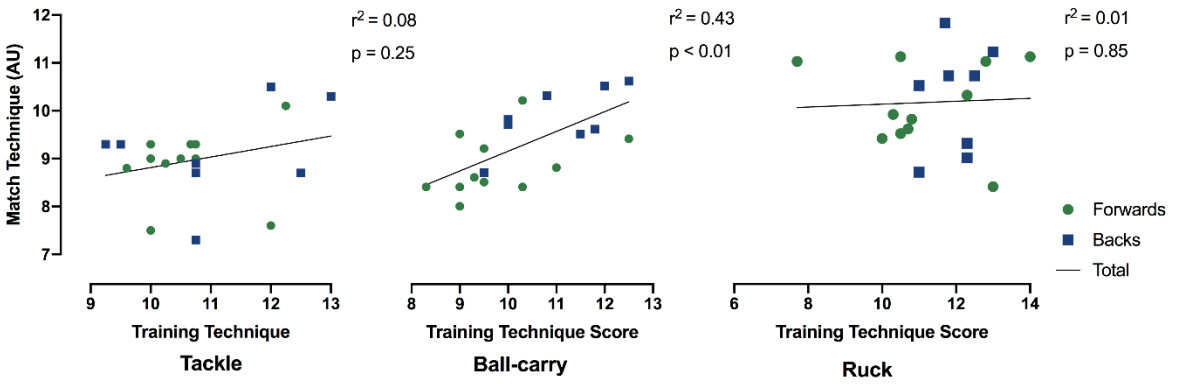

Figure 7.4 The relationship between tackle, ball-carry and ruck technique in training and matches. proficiency scores in training and in matches. Individual scores for forwards and backs are shown. Coefficient of determination (r^2) and level of significance (p) are shown for the total sample (forwards and backs). Line represents the line of best fit.

Discussion

The purpose of this study was to describe the relationship between contact technique proficiency in training and in matches and outcome measures of performance and contact injuries in matches. There were no correlations between contact technique measured in training and match characteristics. Tackle technique measured in matches was associated with the number of tackles made per a game, and the number of effective tackles made per game. Ball-carry technique measured in matches was associated with the percentage of rucks that were effective, and match ruck technique was associated with the, for all players, and the number of effective ruck engagements per game, for backs.

Players with better tackle and ruck technique in matches performed better in matches. Although contact technique scores were higher in training than matches, players' technique proficiency in training had no relationship to their match performance. There was also much variation in how the players' contact proficiency in training transferred to matches (Table 7.6). These findings show that although a player had good technique in a training drill, it did not guarantee that they would have good technique in matches and, subsequently, perform better in match activities. Research in rugby league have reported associations between tackling ability assessed in training and match performance, with players with better tackling ability involved in a greater proportion of successful and effective tackles (68, 165, 169). A key difference between the studies in rugby league and this study is that the rugby league players participated in technical contact training sessions prior to the training assessment (68, 165, 169). The degree to which training activities that represent match activities is important to ensure skills developed in training transfer to match performance (35, 148). In professional rugby union, only 24 minutes out of a possible 6 hours 48 minutes/player/week is spent in full-contact skills training (213). A study of rugby union junior players found that only 16% of training time (17

min) was spent on the tackle, and in most of these sessions low representative tackle training were used i.e. mainly tackle bag and tackle shield activities (90). Given that better technique is associated with better performance, and the evidence that poor technique is associated with a higher injury risk in matches (16, 86, 189), the findings of this study support recommendations that a greater proportion of training time is spent in contact technique training (90, 92, 213). Further research to evaluate the effectiveness of a contact technique training program on match technique and performance is also recommended.

There were no significant relationships between contact technique assessed in training or matches, and tackle or ruck related injuries. Similarly, studies in rugby league found no association between tackling ability assessed in training and tackle related match injuries (68, 69). There is, however, strong evidence that poor contact technique in matches is associated with higher injury risks in matches (16, 28, 33, 86, 189). These findings suggest that there may be other factors affecting a player's technique in an injurious event than their general contact technique ability. However, as the sample size of injuries in this study was relatively small, longitudinal studies over multiple seasons are required to gain a better understanding of the relationship between poor contact technique and contact-related injuries.

Tackle and ruck related injuries accounted for 59% of all injuries. This was similar to the proportion of tackle and ruck injuries in professional rugby union (158). The tackle injury incidence of 28.6 injuries/1000 hours was also similar to injury incidence rates in elite rugby union (29.2/1000hr) (220), but higher than the injury incidence rates in English amateur rugby (8.4) (149). Similarly, the ruck injury incidence of 7.1 was similar to elite rugby (5.0/1000hr) (220), but higher than English amateur rugby (1.6/1000hr) (220). The injury data collected in this study was limited, as it was from a single team in a single season and does not include

training injuries, yet it does provide insight into the injury profile of senior amateur South African rugby. However, longitudinal studies are recommended to adequately determine the injury risk and incidence rates in South African amateur rugby union.

Conclusion

This study described the relationship of tackle and ruck technique in training and matches and measures of match performance and match injuries. Contact technique assessed in matches was associated with match performance, with players with better technique in matches performing better in matches. Although players scored better in training than matches, contact technique in training had no effect on match performance. These findings highlight the importance of contact skill training to ensure skills developed in training are transferred to match performance. There were no significant associations between contact technique in training or matches, and contact related injuries in matches. These findings suggest that there may be other factors affecting a player's technique in an injurious event than their general contact technique ability. However, as the injury sample was relatively small, further research is recommended to gain a greater understanding of the relationship between contact technique and injuries in rugby union.

Chapter 8: Summary and Conclusions

Introduction

The aims of this thesis were to assess the validity and representativeness of a contact skill assessment tool, and to identify factors which affect the degree to which contact technique in training transfer to match technique. This information is important to allow coaches to develop effective contact techniques in training, to improve contact technique in matches and, ultimately, to improve match performance and reduce the risk of injury in contact. This thesis comprised five studies, each designed to answer specific questions, which contributed to fulfilling the aims of this thesis. The questions and corresponding answers are provided below.

Chapter 3:

Questions

Does the contact technique assessment tool have good construct validity? i.e. do the results discriminate between different levels of play?

What are the tackle, ball-carry and ruck technique scores of players in training at different levels of play?

Answers

Senior level players scored significantly higher than the academy level players in the tackle, ball-carry and ruck technique assessments. The differences between the levels of play show that the contact technique assessment tool has good construct validity. On average, senior players scored 10.1 in the tackle technique assessment, 10.2 in the ball-carry technique assessment and 11.2 the ruck technique assessment. Academy 1st and 2nd team players scored 8.9 and 8.6, 9.0 and 8.6, and 10.3 and 10.5 for the tackle, ball-carry and ruck technique assessments, respectively. These results provide reference data on tackle and ruck technique in training, at different levels of play.

Chapter 4:

Questions

What is the representative learning design of the contact technique drill?

Are tackle, ball-carry and ruck technique scores associated with the same performance outcomes in training and in matches?

Were there differences in the tackle ball-carry or ruck technique proficiency scores between contact events in training and contact events in matches?

Answers

Contact technique scores were associated with performance outcomes in training and matches. These findings demonstrate that the conditions created in the training drill adequately represented match conditions. However, there were differences between the contact technique scores in training and matches. Contact technique scores were lower in matches compared to training, demonstrating the importance of addressing any weaknesses in technique identified in training to improve players safety and performance in matches. The differences in technique between training and matches indicate that the drill may be too structured to fully represent the open nature of the tackle and ruck contests, and when technique has been sufficiently developed, technique be reassessed in less structured training environments to identify further weaknesses in contact technique proficiency.

Chapter 5:

Question

What is the relationship between physical qualities and tackle and ruck technique?

Answer

Seven physical qualities were moderately associated with tackle technique, including strength endurance, maximal strength, lower body power, agility and functional mobility. There was a large association between upper body power and ball-carry technique and a moderate association between height and agility and ruck technique. These findings highlight the important contribution of physical strength and conditioning to develop proficient contact technique.

Chapter 6:

Question

Does knowledge of the importance of tackle technique to improve performance or reduce the risk of injury translate to proper tackle technique execution?

Answer

There was a high level of awareness of the importance of tackle and ball-carry technique to improve performance and promote safety. Yet there were no meaningful associations between players' knowledge and their contact technique proficiency scores. These findings reveal a gap between players knowledge of the importance of proper tackle technique and their execution of proper tackle technique and support the need for contact skill training programmes in rugby union.

Chapter 7:

Questions

What is the relationship between a player's contact technique in matches and their match performance and injury risk?

Does good contact technique in training transfer to improved match performance and reduced injury risks?

Answers

Players with better technique in matches performed better in matches. Players with better ball-carry technique made more tackle breaks per game, players with better tackle technique missed fewer tackles per game, players with better ruck technique were effective at more rucks per game, and backs with better ruck technique were effective at greater percentage of rucks. There was no association between contact technique in matches or training and contact related injuries. Although players had higher tackle, ball-carry and ruck technique scores in training than matches, contact technique in training had no effect on match performance. There was also a large variation in the percentage of a player's training technique represented in their match technique. These findings highlight the importance of contact skill training to ensure skills developed in training are transferred to match performance

Practical Implications

This thesis demonstrated the validity of a tool to assess tackle and ruck technique in rugby union. The structured nature of the contact drill reduced the representativeness of the assessment tool, reflected in differences in technique scores between training and matches. However, the contact drill was able to identify weaknesses in tackle and ruck techniques, associated with injury risks, at all levels of play. Assessing and developing contact technique in a structured environment is, therefore, merited to improve weaknesses in technique proficiency before progressing to less structured environments. That declarative knowledge was not associated with technique, nor training technique in a structured drill with match performance, highlights the need for a contact technique training program to ensure contact technique developed in training transfers to match performance. Contact technique programs

should begin in a structured environment and progress to less structured environments that better represent match activities as players technique proficiency improves. Any contact technique program should be accompanied with a physical strength and conditioning program.

Strengths and Limitations of the Thesis

Throughout the thesis project we were privileged to have access to an academy of rugby players. This not only provided a statistically powerful sample size for the studies, but also allowed us to conduct our research in a real-world setting. However, a limitation of the thesis was that all the studies were conducted with amateur rugby players, thus its application to the professional level may be limited. Furthermore, although attempts were made to improve the ecological validity and representativeness of the assessment tool, we acknowledge that the drill only partially simulates a tackle and ruck match scenario.

Future Research

Future research should determine whether a training program for contact technique can improve the transfer of this technique to matches. Furthermore, longitudinal studies on the relationship between contact technique in training and matches, and contact-related research are recommended.

Three contact technique proficiencies were assessed in this thesis; front-on tackles, front-on ball-carries into contact, and ruck clearing. Developing technical criteria for other contact events, and designing drills to assess these events, would be of value to further assess and develop other contact events in rugby union.

Appendices

Appendix 2.1 Tackle techniques associated with injury prevention and performance in rugby union (including sevens)

Tackle	Injury Related Studies (n)					Performance Related Studies (n)			
	Studies	p < 0.05	p < 0.01	ES > 0.6	ES > 1.2	Studies	p < 0.05	p < 0.01	ES > 0.6
Pre-contact	2 (16, 33)		1 (33)	1 (33)		0			
Identify ball-carrier onto shoulder	4 (16, 33, 86, 182)		2 (33, 182)	2 (33, 182)		1 (179)			
Body position - upright to low (dipping)	**6 (16, 33, 86, 87, 182, 221)**		**1 (33)**	**2 (33, 86)**		**3 (85, 159, 179)**	**1 (179)**		
Back straight, centre of gravity ahead of support base	**4 (16, 33, 86, 182)**	**1 (182)**	**1 (33)**	**1 (33)**		**4 (85, 159, 179, 201)**	**1 (201)**	**1 (179)**	
Alignment square to ball-carrier	6 (16, 33, 86, 87, 173, 182)		1 (33)	1 (33)		1 (179)			
Head up and face forward	**7 (16, 33, 86, 87, 122, 173, 182)**	**1 (173)**	**1 (182)**		**1 (182)**	**3 (85, 159, 179)**	**1 (159)**	**1 (85)**	
Boxer stance - elbows low and close, hands up	5 (16, 33, 86, 87, 182)		1 (33)	1 (33)		3 (85, 159, 179)			
Shortening steps	**5 (16, 33, 86, 182, 183)**	**1 (183)**	**3 (16, 33, 182)**	**3 (16, 33, 86)**		**1 (179)**	**1 (179)**		
Approach from front/oblique	5 (16, 33, 86, 182, 183)	1 (16)				2 (85, 179)			
Contact	2 (16, 33)		1 (33)	1 (33)		0			
Explosiveness on contact	4 (16, 33, 86, 182)					1 (179)		1 (179)	
Contact with shoulder	**9 (15, 16, 33, 86, 87, 122, 125, 173, 182)**	**2 (15, 125)**	**1 (173)**			**2 (159, 179)**		**1 (159)**	
Contact in centre of gravity	**6 (16, 33, 86, 87, 173, 182)**		**1 (33)**	**1 (33)**		**4 (85, 91, 159, 179)**	**1 (159)**	**2 (85, 91)**	
Head placement on the correct side of ball-carrier	**9 (16, 33, 54, 86, 87, 122, 162, 182)**	**2 (54, 173)**	**4 (33, 162, 182, 183)**	**2 (33, 86)**	**1 (182)**	**3 (85, 159, 179)**		**1 (85)**	
Post contact	2 (16, 33)				1(16)	0			
Shoulder drive upon first contact	**4 (16, 33, 86, 182)**		**1 (33)**	**3 (16, 33, 86)**		**3 (85, 159, 179)**		**3 (85, 159, 179)**	
Leg drive upon contact	**8 (16, 33, 86, 122, 125, 173, 182, 221)**	**1 (125)**	**1 (33)**	**2 (33, 86)**		**5 (85, 91, 159, 179, 201)**	**2 (91, 159)**	**3 (85, 94, 179)**	**1 (94)**
Punch arms forward, wrap and pull (hit and stick)	**6 (16, 33, 86, 173, 182, 221)**	**1 (16)**	**2 (173, 182)**	**2 (16, 182)**		**3 (85, 159, 179)**	**2 (159, 179)**	**1 (85)**	
Release ball-carrier and compete for possession	**4 (16, 33, 86, 182)**		**1 (16)**		**1 (16)**	**1 (179)**	**1 (179)**		
Total	3 (16, 33, 86)		2 (16, 33)	2 (16, 33)		0			

Appendix 2.2 Ball-carry techniques associated with injury prevention and performance in rugby union

Ball-Carry	Injury Related Studies (n)					Performance Related Studies (n)				
	Studies	**p < 0.05**	**p < 0.01**	**ES > 0.6**	**ES > 1.2**	**Studies**	**p < 0.05**	**p < 0.01**	**ES > 0.6**	**ES > 1.2**
Pre-contact	2 (16, 33)		1 (33)	1 (33)		0				
Focus on tackler	7 (15, 16, 33, 86, 87, 125, 180)	1 (15)				1 (179)				
Body position - upright to low (dipping)	**4 (16, 33, 86, 180)**		**1 (33)**	**1 (33)**		**2 (179, 214)**		**1 (214)**		
Back straight, centre of gravity ahead of support base	4 (16, 33, 86, 180)		1 (33)	1 (86)	1 (33)	1 (179)				
Shift ball away from contact to correct arm	4 (16, 33, 86, 180)					1 (179)				
Head up, face forward	4 (16, 33, 86, 180)		1 (33)		1 (33)	1 (179)				
Shuffle or evasive manoeuvre	6 (16, 33, 86, 87, 173, 180)		1 ((173))			5 (85, 155, 159, 179, 215)		3 (155, 159, 215)		
Contact	2 (16, 33)		1 (33)		1 (33)	0				
Fend into contact	**6 (15, 16, 33, 86, 87, 180)**		**2 (33, 180)**	**2 (33, 180)**		**6 (85, 91, 94, 159, 179, 214)**	1 (179)	**4 (85, 91, 94, 214)**		**1 (94)**
Side-on into contact	4 (16, 33, 86, 180)		1 (33)	1 (33)		1 (179)				
Explosiveness on contact	**4 (16, 33, 86, 180)**	**1(180)**	**1 (33)**	**2 (33, 180)**		**1 (179)**	**1 (179)**	**1 (179)**		
Body position – from low up into contact	4 (16, 33, 86, 180)		1 (33)	1 (33)		1 (179)				
Ball in correct arm and protected	4 (16, 33, 86, 180)					1 (179)		1 (179)		
Post contact	2 (16, 33)		1 (33)	1 (33)	1 (16)	0				
Use of arm and/or shoulder to push tackler	4 (16, 33, 86, 180)		1 (33)	1 (33)		1 (179)				
Leg drive upon contact	**5 (16, 33, 86, 173, 180)**		**1 (33)**	**1 (33)**		**6 (85, 91, 94, 159, 179, 214)**		**3 (94, 179, 214)**	**2 (91, 179)**	**1 (94)**
Go to ground and present ball	**5** (16, 33, 86, 180, 221)		**1 (33)**	**1 (33)**		**3 (91, 94, 179)**	**1 (94)**		**2 (91, 94)**	
Total	3 (16, 33, 86)		2 (16, 33)	2 (16, 33)		0				

n: number of studies
ES: Effect size; 0.6-1.2 = moderate, >1.2 = large

Appendix 2.3 Tackle techniques associated with level of play in rugby league

Tackle	Level of play				
	Studies (n)	**p < 0.05**	**p < 0.01**	**ES > 0.6**	**ES > 1.2**
Watch target onto the shoulder	**4 (62, 63, 68, 167)**		**1 (63)**	**2 (62, 68)**	**1 (63)**
Centre of gravity ahead of support base	**4 (62, 63, 68, 167)**	**1 (63)**		**2 (63, 68)**	
Body position square and aligned	**4 (62, 63, 68, 167)**			**1 (167)**	**1 (63)**
Contact target with opposite shoulder to leading leg	0				
Contact with shoulder	4 (62, 63, 68, 167)				
Contact in centre of gravity	**4 (62, 63, 68, 167)**			**1 (63)**	**1 (68)**
Leg drive upon contact	**4 (62, 63, 68, 167)**	**1 (167)**		**2 (68, 167)**	**1 (62)**
Punch arms forward, wrap and pull (hit and stick)	0				
Total	6 (62, 63, 68, 136, 167, 168)	1 (136, 167)	1 (63)	1 (167)	4 (62, 63, 68, 168)

n: number of studies
ES: Effect size; 0.6-1.2 = moderate, >1.2 = large

Appendix 2.4 Factors associated with tackling ability in rugby league

Factors	Tackling Ability (Total Score)			
	Studies	**p < 0.05**	**p < 0.01**	**ES > 1.2**
Physical measurements				
Body composition	**8 (59, 60, 62, 63, 67, 167-169)**	**3 (60, 167, 168)**	**1 (63)**	
Lower body strength	**4 (61, 167-169)**		**2 (168, 169)**	
Upper body strength	5 (61, 165, 167-169)	1 (167)	1 (168)	
Lower body power	9 (59, 60, 62, 63, 67, 165, 167-169)	3 (62, 63, 165)		
Upper body power	5 (62, 165, 167-169)		1 (168)	
Agility	7 (59, 60, 62, 63, 67, 165, 169)	1 (59)		
Speed and Acceleration	7 (59-63, 67, 168)	2 (59, 62)	1 (63)	
Endurance	**2 (59, 67)**	**1 (59)**		
Experience	5 (60, 62, 63, 67, 68)	2(67, 68)	1 (63)	1 (68)
Match performance	5 (64, 68, 165, 166, 169)	3 (64, 68, 166)	2 (165, 169)	
Injury risk	2 (68, 69)			

n: number of studies
ES: Effect size; 0.6-1.2 = moderate, >1.2 = large

Appendix 3.1

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E52-24 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6626
Email: shuretta.thomas@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

18 May 2016

HREC REF: 811/2015

Dr S Hendricks
Sport Science Institute
Human Biology

Dear Dr Hendricks

PROJECT TITLE: ***THE RELIABILITY AND VALIDITY OF A SKILL ASSESSMENT PROTOCOL FOR RUGBY UNION (MSc (Med) candidate – Mr S den Hollander) Sub-study linked to 074/2015***

Thank you for your response to the Faculty of Health Sciences Human Research Ethics Committee dated 26 April 2016.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30th May 2017.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval before the research may occur.

The HREC acknowledge that the student, Steve den Hollander will also be involved in this study.

Yours sincerely

Signature Removed

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical

Appendix 4.1

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E52-24 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 404 7682
Email: nosi.tsama@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

18 September 2017

HREC REF: 666/2017

Dr S Hendricks
Human Biology
Exercise Science & Sports Medicine
Sports Science Institute

Dear Dr Hendricks

PROJECT TITLE: THE RELATIONSHIP BETWEEN SKILL PROFICIENCIES AND MATCH PERFORMANCE IN RUGBY UNION (PHD CANDIDATE- STEVEN DEN HOLLANDER)- LINKED TO 811/2015

Thank you for submitting study to the Faculty of Health Sciences Human Research Ethics Committee for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30th September 2018.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

We acknowledge that the student Steve den Hollander be involved in this study.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval before the research may occur.

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Yours sincerely

Signature Removed

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

Appendix 5.1

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E52-24 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 404 7682
Email: nosi.tsama@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

08 November 2017

HREC REF: 778/2017

Dr S Hendricks
Human Biology
Exercise Science & Sports Medicine

Dear Dr Hendricks

PROJECT TITLE: THE RELATIONSHIP BETWEEN PHYSIOLOGICAL MEASUREMENTS, ATTITUDES AND BEHAVIOURS AND SKILL QUALITIES IN RUGBY UNION- LINKED TO 811/2015 (PhD candidate- S DEN HOLLANDER)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30th November 2018.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

We acknowledge that the student Steve den Hollander will be involved in this study.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval before the research may occur.

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Yours sincerely

Signature Removed

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

Appendix 5.2

FUNCTIONAL MOBILITY ASSESSMENT

Proprioception

Single Leg Balance Eyes Closed

Instructions:

Stand on one leg, with feet facing forward. Slightly bend knee, keeping chest up and head looking forward. Place hands on hips. When you feel balanced, close your eyes to begin the time. Hold this position for 30 seconds. If you lose balance, open your eyes, reassume the position and continue the test. The test is repeated, standing on the opposite leg.

Faults:

1. Grips the toes throughout the balance. Intermittent gripping is permissible.
2. Does not load through the ball of the big toe.
3. Supporting leg rotates so pelvis is not square.
4. Unloaded leg rotates so that hip, knee and ankle are not in line in the frontal plane.
5. Legs abduct past 30º.
6. Forefoot or heel lifts from the floor.
7. Excessive trunk flexion towards the supporting leg.
8. Hip Adduction.
9. Hands lift from iliac crest.
10. Steps, stumbles or falls.
11. Any pain reported.
12. Multiple faults committed simultaneously are recorded as one fault only.

Mobility

Above Head Squat

Instructions:

Stand with your feet approximately 10cm apart, with feet slightly turned out. Keeping your chest up and head looking forward, hold a pole above the midline of your head with hands shoulder width apart. In this position, perform a squat, going as deep as you can. Throughout the movement, keep your heels on the floor and your hands directly in line with midline of your head. Hold this position for 3 seconds before returning to the start position.

Faults:

1. Grips the toes throughout the squat. Intermittent gripping is permissible.
2. Rotation or lateral translation of the pelvis to either side.
3. Forefoot or heel lifts from the floor.
4. Feet are forced into external rotation or the arch collapses.
5. Falls backwards.
6. Does not load through the ball of the big toe.
7. Valgus collapse of either knee.
8. Hands move forward, over the line of the toes.
9. Cannot achieve 120º of flexion at the knee. This should bring their bottom to within one hand length from the floor.
10. Any pain reported.

Multi-Segmental Lateral Flexion

Instructions:

Stand with your feet together and arms by your sides. Now slide your right hand down your right side. Hold for 2-3 seconds and then return to upright. Next repeat on your left side.

Faults:

1. Asymmetrical curve when comparing left to right.
2. No continuous curve from sacrum to cervical spine.
3. Any rotation in either the shoulders or the pelvis.
4. Any pain reported.

Spinal Extension

Instructions:

Stand with your shirt off and hands held together in front, with elbows extended. Reach your hands over your head leaning backwards as far as you can. (Assessor views from behind)

Faults:

1. Any pain reported.
2. Pinch point reported.
3. No hip extension - all lumbar spine
4. Any deviation to left or right
5. Rotation of pelvis

Stability

Single Leg Quarter Squat

Instructions:

Stand with feet approximately 10cm apart, with feet facing forward, hands on hips, chest up and head looking forward. Next, perform a single leg squat on the left leg, going approximately a quarter of the way down. Your right foot is to travel forward staying just above the floor. Perform the movement slowly in a controlled manner. Return to the start and repeat on the right leg.

Faults:

1. Grips the toes throughout the balance. Intermittent gripping is permissible.
2. Rotation of the pelvis to either side
3. Forefoot or heel lifts from the floor.
4. Hip Adduction or hip poke.
5. Steps, stumbles or falls.
6. Does not load through the ball of the big toe.
7. Excessive lateral flexion of the trunk in either direction.
8. Can't perform squat.
9. Any pain reported.

Glute bridge on bench

Instructions:

With feet on the ground, and knees bent at 90º, rest shoulders and head on a bench. Ensure that hips, knees and ankles are in alignment, and that heels are directly under the knees. Take your right leg off the floor and hold the position for 10 sec. Return to the start and repeat on the right leg (lift left leg off the floor).

Faults:

1. Foot turns out.
2. Pelvis drops.
3. Pelvis rotates.
4. Side of torso bends.
5. Alignment between hips, knees and ankles is not maintained.
6. Any pain reported.

Wide Leg press up plank single leg

Instructions:

Start in a push-up position, with hands directly under shoulder girdle, legs wider than shoulder width and knees locked. Plantarflex your left foot until it leaves the floor. Hold the position for 3-5 seconds. Dorsiflex the foot to return to the start position and repeat with the right foot.

Faults:

1. Cannot hold the correct start position with neutral spine.
2. Any pain reported.
3. Pelvis drops.
4. Pelvis rotates.
5. Loses neutral spine once foot leaves the floor.
6. Consistently bends knee.
7. Foot that is free from the floor drifts towards the midline of the body.

Movement Patterns

Bear Crawl

Instructions:

Start with your hands and feet in contact with the ground, with knees and hips at bent at 90º. Feet should be shoulder width apart, with hips aligned directly above knees and shoulders directly above hands. Crawl forward starting with your right hand and left foot, following with your left hand and right foot. Take four steps forward and four steps backwards.

Faults:

1. Asymmetry around pelvis
2. Unstable pelvis. Large movements although symmetrical
3. Hand and opposite foot placement not in time with each other
4. Can do forward but not back.
5. Move to the lateral border of the feet
6. Poor hip, knee, ankle and foot alignment
7. Lose neutral spine
8. Shoulders elevated towards ears.

Reverse Skydivers

Instructions:

Lay supine on the floor. Make your body as small as possible using the correct flexion technique outlined below. Hold this position for 5 sec. Thereafter, make your body as large as possible through the correct extension technique outlined below. Hold this position for 5 sec. Perform 3 repetitions of the movement pattern.

Correct Flexion Technique:

1. Toes in extension
2. Ankle dorsiflexed
3. Knee fully flexed
4. Hips fully flexed and adducted
5. Arms adducted
6. Elbows fully flexed
7. Wrists in fully flexed

Correct Extension Technique:

1. Toes pointed
2. Ankle plantar flexed
3. Knee fully extended
4. Hips abducted as far as possible
5. Lumbar spine little to no gap between the floor
6. Elbows fully extended
7. Wrists in relative extension
8. Fingers spread
9. Head relaxed on the floor
10. Arms and legs off the ground

Faults:

1. Not achieving any of the correct technique above repeatedly during the 3 attempts. An occasional mistake is permissible
2. Lack of symmetry in the sagittal plane
3. Inability to hold for the prescribed timings
4. Gross lack of co-ordination
5. Any pain reported at any time around any region of the body. Pay special attention to the lower back during the extension pattern.

Rolling Pattern

Instructions:

Lay on your back with your arms above your head, finger tips and feet together with knees locked. In this position, roll twice to your left and then twice to your right to return you to the start position. Keep your body as straight as possible throughout the movement and try to roll in a straight line.

Faults:

1. Ankles move apart
2. Knee, hip, shoulder do not form a straight line.
3. Fingertips come apart or do not remain above the head.
4. Limbs bend or form the foetal position.
5. Cannot roll in a straight line
6. Recruit the arms or legs to push off the floor to create the movement.
7. Head does not remain in line with the spine and/or rests on the floor.

Appendix 6.1

Investigation into the Tackle Contact Situation from the Perspective of Rugby Union Players

The tackle contact situation (which includes the ball-carrier and tackler) is a fundamental component of rugby and the ability to engage in tackle contact is a pre-requisite for participation. The purpose of this questionnaire is to gain insight into the:

- Knowledge and opinions of rugby players around the tackle contact situation, as a ball-carrier and tackler, in training and in matches.
- Training and match behaviours around the tackle contact situation

This information will prove invaluable in our understanding and development of better coaching strategies to improve the game of rugby union, and make it safer for all.

Player Information	**Date:** yyyy /mm/ dd
Surname	
First Names	
Club	
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)	Rugby Union *1 2 3 4 5 6 7 8 9 10 11 12 13 14 15*
What is the highest level you have played?	i.e., professional first-team, professional academy, club, province, country
What is the current level you playing this season)?	i.e., professional first-team, professional academy, club, province, country
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 two sections:

A. Training Questions
B. Match Questions

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

A. Training Questions

1. What do you think is the risk of injury for the different phases of play?					
	Very Low Risk	**Low Risk**	**Undecided**	**High risk**	**Very High Risk**
Scrum	1	2	3	4	5
Ball-carrying (Taking ball into contact)	1	2	3	4	5
Tackling	1	2	3	4	5
Line-out	1	2	3	4	5
Ruck	1	2	3	4	5
Maul	1	2	3	4	5
Catching and Passing (Ball Handling)	1	2	3	4	5
Falling to the ground	1	2	3	4	5
Other (specify):					

2. How important is being coached the proper technique to you for the following different phases of play?					
	Not at all important	**Not too important**	**Undecided**	**Somewhat important**	**Very important**
Scrum	1	2	3	4	5
Ball-carrying (Taking ball into contact)	1	2	3	4	5
Tackling	1	2	3	4	5
Line-out	1	2	3	4	5
Rucking	1	2	3	4	5
Maul	1	2	3	4	5
Catching and Passing (Ball Handling)	1	2	3	4	5
Falling to the ground	1	2	3	4	5

3. How important is coaching proper technique to you for the following?
(Assuming safety and performance are separate objectives)

	Not at all important	Not too important	Undecided	Somewhat important	Very important
Ball-carrying					
Safety *(Lowering the risk of injury)*	1	2	3	4	5
Improved performance *(Dominating the contact point and progressing the ball towards the try-line)*	1	2	3	4	5
Tackling					
Safety *(Lowering the risk of injury)*	1	2	3	4	5
Improved performance *(Dominating the contact point and progressing the ball towards the try-line)*	1	2	3	4	5

4. How important are the following for your tackling?

	Not at all important	Not too important	Undecided	Somewhat important	Very important
Physical conditioning	1	2	3	4	5
Mental conditioning	1	2	3	4	5

5. How important are the following for your ability to carry the ball into contact?

	Not at all important	Not too important	Undecided	Somewhat important	Very important
Physical conditioning	1	2	3	4	5
Mental conditioning	1	2	3	4	5

6. When doing a tackle contact 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
Ball-carrying					
Emphasising proper technique for safety *(Lowering the risk of injury)*	1	2	3	4	5
Emphasising proper technique to improve performance *(Dominating the contact point and preventing the ball from progressing towards the try-line)*	1	2	3	4	5
Tackling					
Emphasising proper technique for safety *(Lowering the risk of injury)*	1	2	3	4	5
Emphasising proper technique to improve performance *(Dominating the contact point and preventing the ball from progressing towards the try-line)*	1	2	3	4	5

7. How much did you learn about tackle contact 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	N/A	1	2	3	4	5
Under 13	N/A	1	2	3	4	5
Under 16	N/A	1	2	3	4	5
Under 19	N/A	1	2	3	4	5
Seniors	N/A	1	2	3	4	5

8. When coaching a front-on tackle drill in the last season, how much emphasis was placed on the following pointers for….? To indicate your answers make an X in the desired block						
Ball-carrying	**Not Familiar (NF)**	**Never**	**Rarely**	**Sometimes**	**Frequently**	**Always**
Pre-contact						
Eyes focused on tackler	NF	1	2	3	4	5
Shifting the ball away from contact	NF	1	2	3	4	5
Body position - upright to low body position	NF	1	2	3	4	5
Body position – Straight back	NF	1	2	3	4	5
Head up and forward, eyes open	NF	1	2	3	4	5
Shuffle or evasive manoeuvre	NF	1	2	3	4	5
Contact						
Fending into contact	NF	1	2	3	4	5
Side-on into contact	NF	1	2	3	4	5
Explosiveness on contact	NF	1	2	3	4	5
Body position - From a low body position up into contact	NF	1	2	3	4	5
Ball protection	NF	1	2	3	4	5
Post-contact						
Leg drive upon contact	NF	1	2	3	4	5
Arm and Shoulder usage	NF	1	2	3	4	5
Go to ground and present ball	NF	1	2	3	4	5
Tackling	**Not Familiar (NF)**	**Never**	**Rarely**	**Sometimes**	**Frequently**	**Always**
Pre-contact						
Identify/track ball-carrier onto shoulder	NF	1	2	3	4	5
Body position - upright to low (dipping)	NF	1	2	3	4	5
Straight back, centre of gravity forward support base	NF	1	2	3	4	5
Square to ball-carrier	NF	1	2	3	4	5
Boxer stance (elbows close, hands up)	NF	1	2	3	4	5
Head up and forward	NF	1	2	3	4	5
Shortening steps	NF	1	2	3	4	5
Approach from front/oblique	NF	1	2	3	4	5
Contact						
Explosiveness on contact	NF	1	2	3	4	5
Contact with shoulder opposite to leading leg	NF	1	2	3	4	5
Contact in centre of gravity	NF	1	2	3	4	5

Head placement on correct side of ball-carrier	NF	1	2	3	4	5
Post-contact						
Shoulder usage (drive into contact)	NF	1	2	3	4	5
Arm usage (punch forward and wrap i.e. hit-and-stick)	NF	1	2	3	4	5
Leg drive upon contact	NF	1	2	3	4	5
Release BC and compete for possession	NF	1	2	3	4	5

9. How important do you think the following technical components of ball-carrying and tackling are for preventing injuries?

To indicate your answers make an X in the desired block

Ball-carrying	**Not Familiar (NF)**	**Never**	**Rarely**	**Sometimes**	**Frequently**	**Always**
Pre-contact						
Eyes focused on tackler	NF	1	2	3	4	5
Shifting the ball away from contact	NF	1	2	3	4	5
Body position - upright to low body position	NF	1	2	3	4	5
Body position – Straight back	NF	1	2	3	4	5
Head up and forward, eyes open	NF	1	2	3	4	5
Shuffle or evasive manoeuvre	NF	1	2	3	4	5
Contact						
Fending into contact	NF	1	2	3	4	5
Side-on into contact	NF	1	2	3	4	5
Explosiveness on contact	NF	1	2	3	4	5
Body position - From a low body position up into contact	NF	1	2	3	4	5
Ball protection	NF	1	2	3	4	5
Post-contact						
Leg drive upon contact	NF	1	2	3	4	5
Arm and Shoulder usage	NF	1	2	3	4	5
Go to ground and present ball	NF	1	2	3	4	5
Tackling	**Not Familiar (NF)**	**Never**	**Rarely**	**Sometimes**	**Frequently**	**Always**
Pre-contact						
Identify/track ball-carrier onto shoulder	NF	1	2	3	4	5
Body position - upright to low (dipping)	NF	1	2	3	4	5
Straight back, centre of gravity forward support base	NF	1	2	3	4	5
Square to ball-carrier	NF	1	2	3	4	5
Boxer stance (elbows close, hands up)	NF	1	2	3	4	5
Head up and forward	NF	1	2	3	4	5
Shortening steps	NF	1	2	3	4	5
Approach from front/oblique	NF	1	2	3	4	5
Contact						
Explosiveness on contact	NF	1	2	3	4	5
Contact with shoulder opposite to leading leg	NF	1	2	3	4	5
Contact in centre of gravity	NF	1	2	3	4	5

Head placement on correct side of ball-carrier	NF	1	2	3	4	5
Post-contact						
Shoulder usage (drive into contact)	NF	1	2	3	4	5
Arm usage (punch forward and wrap i.e. hit-and-stick)	NF	1	2	3	4	5
Leg drive upon contact	NF	1	2	3	4	5
Release BC and compete for possession	NF	1	2	3	4	5

10. How important do you think the following technical components of ball-carrying and tackling are for winning the tackle contest?

To indicate your answers make an X in the desired block

Ball-carrying	**Not Familiar (NF)**	**Never**	**Rarely**	**Sometimes**	**Frequently**	**Always**
Pre-contact						
Eyes focused on tackler	NF	1	2	3	4	5
Shifting the ball away from contact	NF	1	2	3	4	5
Body position - upright to low body position	NF	1	2	3	4	5
Body position – Straight back	NF	1	2	3	4	5
Head up and forward, eyes open	NF	1	2	3	4	5
Shuffle or evasive manoeuvre	NF	1	2	3	4	5
Contact						
Fending into contact	NF	1	2	3	4	5
Side-on into contact	NF	1	2	3	4	5
Explosiveness on contact	NF	1	2	3	4	5
Body position - From a low body position up into contact	NF	1	2	3	4	5
Ball protection	NF	1	2	3	4	5
Post-contact						
Leg drive upon contact	NF	1	2	3	4	5
Arm and Shoulder usage	NF	1	2	3	4	5
Go to ground and present ball	NF	1	2	3	4	5
Tackling	**Not Familiar (NF)**	**Never**	**Rarely**	**Sometimes**	**Frequently**	**Always**
Pre-contact						
Identify/track ball-carrier onto shoulder	NF	1	2	3	4	5
Body position - upright to low (dipping)	NF	1	2	3	4	5
Straight back, centre of gravity forward support base	NF	1	2	3	4	5
Square to ball-carrier	NF	1	2	3	4	5
Boxer stance (elbows close, hands up)	NF	1	2	3	4	5
Head up and forward	NF	1	2	3	4	5
Shortening steps	NF	1	2	3	4	5
Approach from front/oblique	NF	1	2	3	4	5
Contact						
Explosiveness on contact	NF	1	2	3	4	5
Contact with shoulder opposite to leading leg	NF	1	2	3	4	5
Contact in centre of gravity	NF	1	2	3	4	5

Head placement on correct side of ball-carrier	NF	1	2	3	4	5
Post-contact						
Shoulder usage (drive into contact)	NF	1	2	3	4	5
Arm usage (punch forward and wrap i.e. hit-and-stick)	NF	1	2	3	4	5
Leg drive upon contact	NF	1	2	3	4	5
Release BC and compete for possession	NF	1	2	3	4	5

B. Match Questions

1. What is important to you when entering a tackle contact situation 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
Dominating the contact point at all costs	1	2	3	4	5
Your own safety (lowering your risk of getting injured)	1	2	3	4	5
Safety of the opponent (lowering the risk of the opponent getting injured)	1	2	3	4	5
Safety of both you and the opponent	1	2	3	4	5
Winning Territory	1	2	3	4	5
Playing the ball only (maintaining or regaining possession of the ball)	1	2	3	4	5
Leg drive after contact	1	2	3	4	5
Further Comment (Any additional information regarding this question):					

2. Please rate your enjoyment when carrying the ball into contact **To indicate your answers make an X in the desired block**											
Not at all	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Very Much**

3. Please rate your enjoyment when making a tackle **To indicate your answers make an X in the desired block**											
Not at all	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Very Much**

4. Please rate how motivated you are to carry the ball into contact **To indicate your answers make an X in the desired block**											
Not at all	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Very Much**

5. Please rate how motivated you are to tackle To indicate your answers make an X in the desired block										
Not at all	1	2	3	4	5	6	7	8	9	10	Very Much

How much do you agree with the following statements?				
6. Techniques that reduce the risk of injury (safe techniques), can also improve performance?				
Not at all	A little	A fair amount	Much	Very Much

7. Techniques that improve performance, can also reduce the risk of injury?				
Not at all	A little	A fair amount	Much	Very Much

8. If the latest scientific data showed a new, improved way to train tackle contact technique for safety, would you use it?				
Not at all	A little	A fair amount	Much	Very Much

9. If the latest scientific data showed a new, improved way to train tackle contact technique to improve performance, would you use it?				
Not at all	A little	A fair amount	Much	Very Much

Thank You for Your Participation!

Appendix 7.1

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E53-46 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
Email: sumayah.ariefdien@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

27 September 2018

HREC REF: 604/2018

Dr S Hendricks
Division of Exercise Science & Sports Medicine
SSISA
Boundary Road, Newlands

Dear Dr Hendricks

PROJECT TITLE: THE RELATIONSHIP BETWEEN CONTACT TECHNIQUE MEASURED IN TRAINING AND CONTACT TECHNIQUE AND INJURIES IN MATCHES (SUB-STUDY LINKED TO 666/2017)-BSc Candidate - Ms C. Ponce

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee (HREC) for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30 September 2019.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

We acknowledge that the student: Ms Chanda Ponce will also be involved in this study.

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

Signature Removed

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

Reference List

1. Ali A. Measuring soccer skill performance: a review. *Scand J Med Sci Sports* 21: 170-183, 2011.
2. Attwood MJ, Roberts SP, Trewartha G, England M, and Stokes KA. Association of the Functional Movement Screen with match-injury burden in men's community rugby union. *J Sports Sci* 37: 1365-1374, 2019.
3. Austin D, Gabbett T, and Jenkins D. The physical demands of Super 14 rugby union. *J Sci Med Sport* 14: 259-263, 2011.
4. Austin D, Gabbett T, and Jenkins D. Repeated high-intensity exercise in professional rugby union. *J Sports Sci* 29: 1105-1112, 2011.
5. Austin D, Gabbett T, and Jenkins D. Tackling in a professional rugby league. *J Strength Cond Res* 25: 1659-1663, 2011.
6. Bahr R and Holme I. Risk factors for sports injuries--a methodological approach. *Br J Sports Med* 37: 384-392, 2003.
7. Bartlett R. *Sports biomechanics reducing injury and improving performance.* London: Routledge, 2002.
8. Bishop D. An applied research model for the sport sciences. *Sports Med* 38: 253-263, 2008.
9. Bishop L and Barnes A. Performance indicators that discriminate winning and losing in the knockout stages of the 2011 Rugby World Cup. *Int J Perf Anal Spor* 13: 149-159, 2013.
10. Blair J., Czaja RF, and Blair EA. *Designing surveys: A guide to decisions and procedures.* Thousand Oaks, California: Sage Publications, 2013.
11. Boddington M and Lambert M. Quantitative and qualitative evaluation of scoring opportunities by South Africa in World Cup Rugby 2003. *Int J Perf Anal Spor* 4: 32-35, 2004.

12. Borrie A, Jonsson GK, and Magnusson MS. Temporal pattern analysis and its applicability in sport: an explanation and exemplar data. *J Sports Sci* 20: 845-852, 2002.

13. Bremner S, Robinson G, and Williams MD. A retrospective evaluation of team performance indicators in rugby union. *Int J Perf Anal Spor* 13: 461-473, 2013.

14. Brown JC, Verhagen E, Viljoen W, Readhead C, Van Mechelen W, Hendricks S, and Lambert MI. The incidence and severity of injuries at the 2011 South African Rugby Union (SARU) Youth Week tournaments. *S Afr J Sports Med* 24, 2012.

15. Burger N, Lambert MI, Viljoen W, Brown JC, Readhead C, den Hollander S, and Hendricks S. Mechanisms and factors associated with tackle-related injuries in South African youth rugby union players. *Am J Sports Med* 45: 278-285, 2017.

16. Burger N, Lambert MI, Viljoen W, Brown JC, Readhead C, and Hendricks S. Tackle technique and tackle-related injuries in high-level South African Rugby Union under-18 players: real-match video analysis. *Br J Sports Med* 50: 932-938, 2016.

17. Calder JM and Durbach IN. Decision support for evaluating player performance in rugby union. *Int J Sports Sci Coa* 10: 21-37, 2015.

18. Carling C, Wright C, Nelson LJ, and Bradley PS. Comment on 'Performance analysis in football: a critical review and implications for future research'. *J Sports Sci* 32: 2-7, 2014.

19. Chiwaridzo M, Ferguson GD, and Smits-Engelsman BCM. Anthropometric, physiological characteristics and rugby-specific game skills discriminating Zimbabwean under-16 male adolescent rugby players by level of competition. *BMJ Open Sport Exerc Med* 5: e000576, 2019.

20. Chiwaridzo M, Ferguson GD, and Smits-Engelsman BCM. Qualities or skills discriminating under 19 rugby players by playing standards: a comparative analysis of elite, sub-elite and non-rugby players using the SCRuM test battery. *BMC Res Notes* 12: 536, 2019.

21. Chiwaridzo M, Ferguson GD, and Smits-Engelsman BCM. Anthropometric, physiological characteristics and rugby-specific game skills of schoolboy players of different age categories and playing standards. *BMC Sports Sci Med Rehabil* 12: 3, 2020.

22. Chiwaridzo M, Oorschot S, Dambi JM, Ferguson GD, Bonney E, Mudawarima T, Tadyanemhandu C, and Smits-Engelsman BCM. A systematic review investigating measurement properties of physiological tests in rugby. *BMC Sports Sci Med Rehabil* 9: 24, 2017.

23. Coetzee B and van den Berg PH. Game analysis of the eight top ranked tertiary institution rugby teams in South Africa. *J Hum Mov Stud* 52: 49-63, 2007.

24. Cohen J. *Statistical power analysis for the behavioral sciences.* New York: Taylor & Francis, 2013.

25. Conserve DF, Teti M, Shin G, Iwelunmor J, Handler L, and Maman S. A systematic rview and nrrative snthesis of iterventions for parental human immunodeficiency virus disclosure. *Front Public Health* 5: 187, 2017.

26. Correia V, Araujo D, Craig C, and Passos P. Prospective information for pass decisional behavior in rugby union. *Hum Mov Sci* 30: 984-997, 2011.

27. Correia V, Araujo D, Davids K, Fernandes O, and Fonseca S. Territorial gain dynamics regulates success in attacking sub-phases of team sports. *Psychol Sport Exerc* 12: 662-669, 2011.

28. Cross MJ, Tucker R, Raftery M, Hester B, Williams S, Stokes KA, Ranson C, Mathema P, and Kemp S. Tackling concussion in professional rugby union: a case-control study of tackle-based risk factors and recommendations for primary prevention. *Br J Sports Med*, 2017.

29. Cruz-Ferreira A, Cruz-Ferreira E, Santiago L, and Taborda Barata L. Epidemiology of injuries in senior male rugby union sevens: a systematic review. *Phys Sportsmed* 45: 41-48, 2016.

30. Cummins C and Orr R. Collision characteristics of shoulder charge tackles in elite rugby league. *Int J Perf Anal Spor* 15: 1090-1101, 2015.

31. Cunningham DJ, Shearer DA, Drawer S, Pollard B, Cook CJ, Bennett M, Russell M, and Kilduff LP. Relationships between physical qualities and key performance indicators during match-play in senior international rugby union players. *PLoS One* 13: e0202811, 2018.

32. Cureton T. *Physical fitness of champions.* Urbana, IL: University of Illinois Press., 1951.

33. Davidow D, Quarrie K, Viljoen W, Burger N, Readhead C, Lambert M, Jones B, and Hendricks S. Tackle technique of rugby union players during head impact tackles compared to injury free tackles. *J Sci Med Sport* 21: 1025-1031, 2018.

34. Davidow D, Redman M, Lambert M, Burger N, Smith M, Jones B, and Hendricks S. The effect of physical fatigue on tackling technique in Rugby Union. *J Sci Med Sport*, 2020.

35. Davids K, Button C, and Bennett S. *Dynamics of skill acquisition: a constraints-led approach.* Human Kinetics, 2008.

36. den Hollander S, Brown J, Lambert M, Treu P, and Hendricks S. Skills associated with line breaks in elite rugby union. *J Sports Sci Med* 15: 501-508, 2016.

37. den Hollander S, Lambert M, Jones B, and Hendricks S. Tackle and ruck technique proficiency within academy and senior club rugby union. *J Sports Sci* 37: 2578-2587, 2019.

38. Deutsch MU, Kearney GA, and Rehrer NJ. Time - motion analysis of professional rugby union players during match-play. *J Sports Sci* 25: 461-472, 2007.

39. Deutsch MU, Maw GJ, Jenkins D, and Reaburn P. Heart rate, blood lactate and kinematic data of elite colts (under-19) rugby union players during competition. *J Sports Sci* 16: 561-570, 1998.

40. Diedrick E and van Rooyen M. Line break situations in international rugby. *Int J Perf Anal Spor* 11: 522-534, 2011.

41. Dobbin N, Hunwicks R, Highton J, and Twist C. A reliable testing battery for assessing physical qualities of elite academy rugby league players. *J Strength Cond Res* 32: 3232-3238, 2018.

42. Durandt J, Du Toit S, Borresen J, Hew-Butler T, Masimla H, Jakoet I, and Lambert M. Fitness and body composition profiling of elite junior South African rugby players. *S Afr J Sports Med* 18, 2006.

43. Duthie G, Pyne D, and Hooper S. Applied physiology and game analysis of rugby union. *Sports Med* 33: 973-991, 2003.

44. Duthie G, Pyne D, and Hooper S. Reliability of video-based time motion analysis of rugby. *J Hum Mov Stud* 44: 261-272, 2003.

45. Duthie G, Pyne D, and Hooper S. Time motion analysis of 2001 and 2002 super 12 rugby. *J Sports Sci* 23: 523-530, 2005.

46. Duthie GM, Pyne DB, Marsh DJ, and Hooper SL. Sprint patterns in rugby union players during competition. *J Strength Cond Res* 20: 208-214, 2006.

47. Eaves JS, Hughes DM, and Lamb LK. The consequences of the introduction of professional playing status on game action variables in international Northern Hemisphere rugby union football. *Int J Perf Anal Spor* 5: 58-86, 2005.

48. Eaves S and Hughes M. Patterns of play of international rugby union teams before and after the introduction of professional status. *Int J Perf Anal Spor* 3: 103-111, 2003.

49. Egger M, Juni P, Bartlett C, Holenstein F, and Sterne J. How important are comprehensive literature searches and the assessment of trial quality in systematic reviews? Empirical study. *Health Technol Assess* 7: 1-76, 2003.

50. Evans L and O'Donoghue P. The effectiveness of the chop tackle in elite and semi-professional rugby union. *Int J Perf Anal Spor* 13: 602-611, 2013.

51. Farrow D and Robertson S. Development of a skill acquisition periodisation framework for high-performance sport. *Sports Med* 47: 1043-1054, 2017.

52. Fraas MR and Burchiel J. A systematic review of education programmes to prevent concussion in rugby union. *Eur J Sport Sci* 16: 1212-1218, 2016.

53. Franks IM and Hughes MD. *Notational analysis of sport.* London: Routledge, 2004.

54. Fuller CW, Ashton T, Brooks JH, Cancea RJ, Hall J, and Kemp SP. Injury risks associated with tackling in rugby union. *Br J Sports Med* 44: 159-167, 2010.

55. Fuller CW, Brooks JH, Cancea RJ, Hall J, and Kemp SP. Contact events in rugby union and their propensity to cause injury. *Br J Sports Med* 41: 862-867, 2007.

56. Fuller CW, Jones R, and Fuller AD. Defining a safe player run-off zone around rugby union playing areas. *Inj Prev* 21: 309-313, 2015.

57. Fuller CW, Molloy MG, Bagate C, Bahr R, Brooks JH, Donson H, Kemp SP, McCrory P, McIntosh AS, Meeuwisse WH, Quarrie KL, Raftery M, and Wiley P. Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *Br J Sports Med* 41: 328-331, 2007.

58. Fuller CW, Taylor A, Kemp SP, and Raftery M. Rugby World Cup 2015: World Rugby injury surveillance study. *Br J Sports Med* 51: 51-57, 2017.

59. Gabbett TJ. Influence of fatigue on tackling technique in rugby league players. *J Strength Cond Res* 22: 625-632, 2008.

60. Gabbett TJ. Physiological and anthropometric correlates of tackling ability in rugby league players. *J Strength Cond Res* 23: 540-548, 2009.

61. Gabbett TJ. Influence of fatigue on tackling ability in rugby league players: role of muscular strength, endurance, and aerobic qualities. *PLoS One* 11: e0163161, 2016.

62. Gabbett TJ, Jenkins DG, and Abernethy B. Physiological and anthropometric correlates of tackling ability in junior elite and subelite rugby league players. *J Strength Cond Res* 24: 2989-2995, 2010.

63. Gabbett TJ, Jenkins DG, and Abernethy B. Correlates of tackling ability in high-performance rugby league players. *J Strength Cond Res* 25: 72-79, 2011.

64. Gabbett TJ, Jenkins DG, and Abernethy B. Relationships between physiological, anthropometric, and skill qualities and playing performance in professional rugby league players. *J Sports Sci* 29: 1655-1664, 2011.

65. Gabbett TJ, Jenkins DG, and Abernethy B. Relative importance of physiological, anthropometric, and skill qualities to team selection in professional rugby league. *J Sports Sci* 29: 1453-1461, 2011.

66. Gabbett TJ and Kelly J. Does Fast Defensive Line Speed Influence Tackling Proficiency in Collision Sport Athletes? *Int J Sports Sci Coa* 2: 467-472, 2007.

67. Gabbett TJ, Kelly J, and Pezet T. Relationship between physical fitness and playing ability in rugby league players. *J Strength Cond Res* 21: 1126-1133, 2007.

68. Gabbett TJ and Ryan P. Tackling technique, injury risk, and playing performance in high-performance collision sport athletes. *Int J Sports Sci Coa* 4: 521-533, 2009.

69. Gabbett TJ, Ullah S, Jenkins D, and Abernethy B. Skill qualities as risk factors for contact injury in professional rugby league players. *J Sports Sci* 30: 1421-1427, 2012.

70. Garganta J. Trends of tactical performance analysis in team sports: bridging the gap between research, training and competition. *Rev Port Ciênc Desporto* 9: 81-89, 2009.

71. Garraway WM, Lee AJ, Macleod DA, Telfer JW, Deary IJ, and Murray GD. Factors influencing tackle injuries in rugby union football. *Br J Sports Med* 33: 37-41, 1999.

72. George TM, Olsen PD, Kimber NE, Shearman JP, Hamilton JG, and Hamlin MJ. The effect of altitude and travel on rugby union performance: Analysis of the 2012 Super Rugby Competition. *J Strength Cond Res* 29: 3360-3366, 2015.

73. Gianotti SM, Quarrie KL, and Hume PA. Evaluation of RugbySmart: a rugby union community injury prevention programme. *J Sci Med Sport* 12: 371-375, 2009.

74. Glazier PS. Game, set and match? Substantive issues and future directions in performance analysis. *Sports Med* 40: 625-634, 2010.

75. Grant MJ and Booth A. A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Info Libr J* 26: 91-108, 2009.

76. Gregson W, Drust B, Atkinson G, and Salvo VD. Match-to-match variability of high-speed activities in premier league soccer. *Int J Sports Med* 31: 237-242, 2010.

77. Hartwig TB, Naughton G, and Searl J. Motion analyses of adolescent rugby union players: a comparison of training and game demands. *J Strength Cond Res* 25: 966-972, 2011.

78. Hendricks S, den Hollander S, and Lambert M. Coaching behaviours and learning resources; influence on rugby players' attitudes towards injury prevention and performance in the tackle. *Sci Med Football*: 1-5, 2019.

79. Hendricks S, den Hollander S, Tam N, Brown J, and Lambert M. The relationships between rugby players' tackle training attitudes and behaviour and their match tackle attitudes and behaviour. *BMJ Open Sport Exerc Med* 1: e000046, 2015.

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

81. Hendricks S, Karpul D, and Lambert M. Momentum and kinetic energy before the tackle in rugby union. *J Sports Sci Med* 13: 557-563, 2014.

82. Hendricks S, Karpul D, Nicolls F, and Lambert M. Velocity and acceleration before contact in the tackle during rugby union matches. *J Sports Sci* 30: 1215-1224, 2012.

83. Hendricks S and Lambert M. Tackling in rugby: coaching strategies for effective technique and injury prevention. *Int J Sports Sci Coa* 5: 117-135, 2010.

84. Hendricks S, Lambert M, Masimla H, and Durandt J. Measuring skill in rugby union and rugby league as part of the standard team testing battery. *Int J Sports Sci Coa* 10: 949-965, 2015.

85. Hendricks S, Matthews B, Roode B, and Lambert M. Tackler characteristics associated with tackle performance in rugby union. *Eur J Sport Sci* 14: 753-762, 2014.

86. Hendricks S, O'Connor S, Lambert M, Brown J, Burger N, Mc Fie S, Readhead C, and Viljoen W. Contact technique and concussions in the South African under-18 Coca-Cola Craven Week Rugby tournament. *Eur J Sport Sci* 15: 557-564, 2015.

87. Hendricks S, O'Connor S, Lambert M, Brown JC, Burger N, Mc Fie S, Readhead C, and Viljoen W. Video analysis of concussion injury mechanism in under-18 rugby. *BMJ Open Sport Exerc Med* 2: e000053, 2016.

88. Hendricks S, Roode B, Matthews B, and Lambert M. Defensive strategies in rugby union. *Percept Mot Skills* 117: 1107-1129, 2013.

89. Hendricks S and Sarembock M. Attitudes and behaviours of top-level junior rugby union coaches towards the coaching of proper contact technique in the tackle – a pilot study. *S Afr J Sports Med* 25, 2013.

90. Hendricks S, Sarembock M, Jones B, Till K, and Lambert M. The tackle in South African youth rugby union – Gap between coaches' knowledge and training behaviour. *Int J Sports Sci Coa* 12: 708-715, 2017.

91. Hendricks S, Sin DW, van Niekerk T, den Hollander S, Brown J, Maree W, Treu P, and Lambert M. Technical determinants of tackle and ruck performance in International Rugby Sevens. *Eur J Sport Sci*: 1-12, 2019.

92. Hendricks S, Till K, Brown JC, and Jones B. Rugby union needs a contact skill-training programme. *Br J Sports Med* 51: 829-830, 2017.

93. Hendricks S, Till K, Oliver JL, Johnston RD, Attwood M, Brown J, Drake D, MacLeod S, Mellalieu SD, Treu P, and Jones B. Technical skill training framework and skill load measurements for the rugby union tackle. *Strength Cond J* 40: 44-59, 2018.

94. Hendricks S, van Niekerk T, Sin DW, Lambert M, den Hollander S, Brown J, Maree W, Treu P, Till K, and Jones B. Technical determinants of tackle and ruck performance in International rugby union. *J Sports Sci* 36: 522-528, 2018.

95. Higham DG, Hopkins WG, Pyne DB, and Anson JM. Relationships between rugby sevens performance indicators and international tournament outcomes. *J Quant Anal Sports* 10, 2014.

96. Holt NL and Tamminen KA. Improving grounded theory research in sport and exercise psychology: Further reflections as a response to Mike Weed. *Psychol Sport Exerc* 11: 405-413, 2010.

97. Hopkins WG. Estimating sample size for mgnitude-based inferences. *Sportscience* 10: 63-70, 2006.

98. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3-13, 2009.

99. Jackson RC. Pre-performance routine consistency: temporal analysis of goal kicking in the Rugby Union World Cup. *J Sports Sci* 21: 803-814, 2003.

100. Jackson RC and Baker JS. Routines, rituals, and rugby: Case study of a world class goal kicker. *Sport Psychol* 15: 48-65, 2001.

101. James N, Mellalieu SD, and Jones NM. The development of position-specific performance indicators in professional rugby union. *J Sports Sci* 23: 63-72, 2005.

102. Jones MR, West DJ, Harrington BJ, Cook CJ, Bracken RM, Shearer DA, and Kilduff LP. Match play performance characteristics that predict post-match creatine kinase responses in professional rugby union players. *BMC Sports Sci Med Rehabil* 6: 38, 2014.

103. Jones NMP, Mellalieu SD, and James N. Team performance indicators as a function of winning and losing in rugby union. *Int J Perf Anal Spor* 4: 61-71, 2004.

104. Kemp SP, Hudson Z, Brooks JH, and Fuller CW. The epidemiology of head injuries in English professional rugby union. *Clin J Sport Med* 18: 227-234, 2008.

105. Kerr HA, Ledet EH, Ata A, Newitt JL, Santa Barbara M, Kahanda M, and Sperry Schlueter E. Does instructional video footage improve tackle technique? *Int J Sports Sci Coa* 13: 3-15, 2017.

106. Kim JW, Ritter FE, and Koubek RJ. An integrated theory for improved skill acquisition and retention in the three stages of learning. *Theor Issues Ergon Sci* 14: 22-37, 2013.

107. King D, Hume PA, and Clark T. Video analysis of tackles in professional rugby league matches by player position, tackle height and tackle location. *Int J Perf Anal Spor* 10: 241-254, 2010.

108. King D, Hume PA, and Clark T. Nature of tackles that result in injury in professional rugby league. *Res Sports Med* 20: 86-104, 2012.

109. Knudson DV. *Qualitative diagnosis of human movement: Improving performance in sport and exercise.* Human Kinetics, 2013.

110. Kraak W, Coetzee F, and Venter R. Analysis of the general match profile of international rugby union between 2007 and 2013. *Int J Perf Anal Spor* 17: 303-318, 2017.

111. Kraak WJ and Welman KE. Ruck-play as performance indicator during the 2010 Six Nations Championship. *Int J Sports Sci Coa* 9: 525-541, 2014.

112. Lacome M, Piscione J, Hager JP, and Bourdin M. A new approach to quantifying physical demand in rugby union. *J Sports Sci* 32: 290-300, 2014.

113. Lacome M, Piscione J, Hager JP, and Carling C. Analysis of running and technical performance in substitute players in international male rugby union competition. *Int J Sports Physiol Perform* 11: 783-792, 2016.

114. Lacome M, Piscione J, Hager JP, and Carling C. Fluctuations in running and skill-related performance in elite rugby union match-play. *Eur J Sport Sci* 17: 132-143, 2017.

115. Laird P and Lorimer R. An examination of try scoring in rugby union: a review of international rugby statistics. *Int J Perf Anal Spor* 4: 72-80, 2004.

116. le Gall F, Carling C, Williams M, and Reilly T. Anthropometric and fitness characteristics of international, professional and amateur male graduate soccer players from an elite youth academy. *J Sci Med Sport* 13: 90-95, 2010.

117. Lees A. Technique analysis in sports: a critical review. *J Sports Sci* 20: 813-828, 2002.

118. Lim E, Lay B, Dawson B, Wallman K, and Anderson S. Predicting try scoring in super 14 rugby union - the development of a superior attacking team scoring system. *Int J Perf Anal Spor* 11: 464-475, 2011.

119. Lindsay A, Draper N, Lewis J, Gieseg SP, and Gill N. Positional demands of professional rugby. *Eur J Sport Sci* 15: 480-487, 2015.

120. Longo UG, Huijsmans PE, Maffulli N, Denaro V, and De Beer JF. Video analysis of the mechanisms of shoulder dislocation in four elite rugby players. *J Orthop Sci* 16: 389-397, 2011.

121. Mackenzie R and Cushion C. Performance analysis in football: a critical review and implications for future research. *J Sports Sci* 31: 639-676, 2013.

122. Maki N, Kawasaki T, Mochizuki T, Ota C, Yoneda T, Urayama S, and Kaneko K. Video analysis of primary shoulder dislocations in rugby tackles. *Orthop J Sports Med* 5: 2325967117712951, 2017.

123. McGarry T, Anderson DI, Wallace SA, Hughes MD, and Franks IM. Sport competition as a dynamical self-organizing system. *J Sports Sci* 20: 771-781, 2002.

124. McIntosh AS, McCrory P, and Comerford J. The dynamics of concussive head impacts in rugby and Australian rules football. *Med Sci Sports Exerc* 32: 1980-1984, 2000.

125. McIntosh AS, Savage TN, McCrory P, Frechede BO, and Wolfe R. Tackle characteristics and injury in a cross section of rugby union football. *Med Sci Sports Exerc* 42: 977-984, 2010.

126. McKenzie AD, Holmyard DJ, and Docherty D. Quantitative analysis of rugby: factors associated with success. *J Hum Mov Stud* 17: 101-113, 1989.

127. McLean DA. Analysis of the physical demands of international rugby union. *J Sports Sci* 10: 285-296, 1992.

128. McLellan CP, Lovell DI, and Gass GC. Performance analysis of elite rugby league match play using global positioning systems. *J Strength Cond Res* 25: 1703-1710, 2011.

129. Meir R, Diesel W, and Archer E. Developing a prehabilitation program in a collision sport: A model developed within English premiership rugby union football. *Strength Cond J* 29: 50-62, 2007.

130. Mellalieu S, Trewartha G, and Stokes K. Science and rugby union. *J Sports Sci* 26: 791-794, 2008.

131. Montgomery C, Blackburn J, Withers D, Tierney G, Moran C, and Simms C. Mechanisms of ACL injury in professional rugby union: a systematic video analysis of 36 cases. *Br J Sports Med* 52: 994-1001, 2018.

132. O'Donoghue P. *Research methods for sports performance analysis.* Taylor & Francis, 2009.

133. Oorschot S, Chiwaridzo M, and Smits-Engelsman B. Psychometric evaluation of commonly used game-specific skills tests in rugby: A systematic review. *BMJ Open Sport Exerc Med* 3: e000281, 2017.

134. Ortega E, Villarejo D, and Palao JM. Differences in game statistics between winning and losing rugby teams in the Six Nations Tournament. *J Sports Sci Med* 8: 523-527, 2009.

135. Otte FW, Millar S-K, and Klatt S. Skill training periodization in "Specialist" sports coaching - An introduction of the "PoST" framework for skill development. *Front Sports Act Living* 1, 2019.

136. Pearce LA, Sinclair WH, Leicht AS, and Woods CT. Passing and tackling qualities discriminate developmental level in a rugby league talent pathway. *Int J Perf Anal Spor* 19: 985-998, 2019.

137. Pinder RA, Davids K, Renshaw I, and Araujo D. Representative learning design and functionality of research and practice in sport. *J Sport Exerc Psychol* 33: 146-155, 2011.

138. Popay J, Roberts H, Sowden A, Petticre M, Arai L, Rogers M, Roen K, Duffy S, Ottavio S, and Britten N. Guidance on the conduct of narrative synthesis in systematic reviews,

in: *A Product from the ESRC Methods Programme Version*. Bailrigg: Lancaster University, 2006, pp 1-92.

139. Posthumus M and Viljoen W. BokSmart: Safe and effective techniques in rugby union. *S Afr J Sports Med* 20: 64-70, 2008.

140. Praxedes A, Del Villar F, Pizarro D, and Moreno A. The impact of nonlinear pedagogy on decision-making and execution in youth soccer players according to game actions. *J Hum Kinet* 62: 185-198, 2018.

141. Prim S, van Rooyen M, and Lambert M. A comparison of performance indicators between the four South African teams and the winners of the 2005 Super 12 Rugby competition. What separates top from bottom? *Int J Perf Anal Spor* 6: 126-133, 2006.

142. Pulling C and Stenning M. Offloads in rugby union: Northern and Southern Hemisphere international teams. *Int J Perf Anal Spor* 15: 217-228, 2015.

143. Quarrie KL and Hopkins WG. Changes in player characteristics and match activities in Bledisloe Cup rugby union from 1972 to 2004. *J Sports Sci* 25: 895-903, 2007.

144. Quarrie KL and Hopkins WG. Tackle injuries in professional rugby union. *Am J Sports Med* 36: 1705-1716, 2008.

145. Quarrie KL and Hopkins WG. Evaluation of goal kicking performance in international rugby union matches. *J Sci Med Sport* 18: 195-198, 2015.

146. Quarrie KL, Hopkins WG, Anthony MJ, and Gill ND. Positional demands of international rugby union: evaluation of player actions and movements. *J Sci Med Sport* 16: 353-359, 2013.

147. Reardon C, Tobin DP, Tierney P, and Delahunt E. Collision count in rugby union: A comparison of micro-technology and video analysis methods. *J Sports Sci* 35: 2028-2034, 2017.

148. Renshaw I and Chow JY. A constraint-led approach to sport and physical education pedagogy. *Phys Educ Sport Pedagogy* 24: 103-116, 2018.

149. Roberts SP, Trewartha G, England M, and Stokes KA. Collapsed scrums and collision tackles: what is the injury risk? *Br J Sports Med* 49: 536-540, 2015.

150. Roberts SP, Trewartha G, Higgitt RJ, El-Abd J, and Stokes KA. The physical demands of elite English rugby union. *J Sports Sci* 26: 825-833, 2008.

151. Robertson SJ, Burnett AF, and Cochrane J. Tests examining skill outcomes in sport: a systematic review of measurement properties and feasibility. *Sports Med* 44: 501-518, 2014.

152. Ross A, Gill N, Cronin J, and Malcata R. The relationship between physical characteristics and match performance in rugby sevens. *Eur J Sport Sci* 15: 565-571, 2015.

153. https://www.rugby-league.com/the_rfl/welfare/concussion/prevention. Accessed 22/06/2020.

154. Sasaki K, Furukawa T, Murakami J, Shimozono H, Nagamatsu M, Miyao M, Yamamoto T, Watanabe I, Yasugahira H, Saito T, Ueno Y, Katsuta T, and Kono I. Scoring profiles and defense performance analysis in rugby union. *Int J Perf Anal Spor* 7: 46-53, 2007.

155. Sayers MGL and Washington-King J. Characteristics of effective ball carries in Super 12 rugby. *Int J Perf Anal Spor* 5: 92-106, 2005.

156. Schoeman R, Coetzee D, and Schall R. Positional tackle and collision rates in Super Rugby. *Int J Perf Anal Spor* 15: 1022-1036, 2015.

157. Schoeman R and Coetzee DF. Time-motion analysis: Discriminating between winning and losing teams in professional rugby. *S Afr J Res Sport Ph* 36: 167-178, 2014.

158. Schwellnus MP, Jordaan E, Janse van Rensburg C, Bayne H, Derman W, Readhead C, Collins R, Kourie A, Suter J, and Strauss O. Match injury incidence during the Super Rugby tournament is high: a prospective cohort study over five seasons involving 93 641 player-hours. *Br J Sports Med* 53: 620-627, 2019.

159. Sewry N, Lambert M, Roode B, Matthews B, and Hendricks S. The relationship between playing situation, defence and tackle technique in rugby union. *Int J Sports Sci Coa* 10: 1115-1128, 2015.

160. Smart D, Hopkins WG, Quarrie KL, and Gill N. The relationship between physical fitness and game behaviours in rugby union players. *Eur J Sport Sci* 14 Suppl 1: S8-17, 2014.

161. Smart DJ, Gill ND, Beaven CM, Cook CJ, and Blazevich AJ. The relationship between changes in interstitial creatine kinase and game-related impacts in rugby union. *Br J Sports Med* 42: 198-201, 2008.

162. Sobue S, Kawasaki T, Hasegawa Y, Shiota Y, Ota C, Yoneda T, Tahara S, Maki N, Matsuura T, Sekiguchi M, Itoigawa Y, Tateishi T, and Kaneko K. Tackler's head position relative to the ball carrier is highly correlated with head and neck injuries in rugby. *Br J Sports Med* 52: 353-358, 2018.

163. Spencer K and Brady H. Examining the effects of a variation to the ruck law in rugby union. *J Hum Sport Exerc* 10: 550-562, 2015.

164. Speranza MJA, Gabbett TJ, Greene DA, Johnston RD, and Sheppard JM. Changes in rugby league tackling ability during a competitive season: the relationship with strength and power qualities. *J Strength Cond Res* 31: 3311-3318, 2017.

165. Speranza MJA, Gabbett TJ, Greene DA, Johnston RD, and Townshend AD. Tackle characteristics and outcomes in match-play rugby league: the relationship with tackle ability and physical qualities. *Sci Med Football* 1: 265-271, 2017.

166. Speranza MJA, Gabbett TJ, Greene DA, Johnston RD, and Townshend AD. Relationship between 2 standardized tackling proficiency tests and rugby league match-play tackle performance. *Int J Sports Physiol Perform* 13: 770-776, 2018.

167. Speranza MJA, Gabbett TJ, Greene DA, Johnston RD, Townshend AD, and O'Farrell B. An alternative test of tackling ability in rugby league players. *Int J Sports Physiol Perform* 13: 347-352, 2018.

168. Speranza MJA, Gabbett TJ, Johnston RD, and Sheppard JM. Muscular strength and power correlates of tackling ability in semiprofessional rugby league players. *J Strength Cond Res* 29: 2071-2078, 2015.

169. Speranza MJA, Gabbett TJ, Johnston RD, and Sheppard JM. Relationship between a standardized tackling proficiency test and match-play tackle performance in semiprofessional rugby league players. *Int J Sports Physiol Perform* 10: 754-760, 2015.

170. Speranza MJA, Gabbett TJ, Johnston RD, and Sheppard JM. Effect of strength and power training on tackling ability in semiprofessional rugby league players. *J Strength Cond Res* 30: 336-343, 2016.

171. Steenbergen B, van der Kamp J, Verneau M, Jongbloed-Pereboom M, and Masters RS. Implicit and explicit learning: applications from basic research to sports for individuals with impaired movement dynamics. *Disabil Rehabil* 32: 1509-1516, 2010.

172. Stewart AD, Marfell-Jones M, Olds T, and De Ridder J. *International standards for anthropometric assessment.* International Society for the Advancement of Kinanthropometry, 2011.

173. Suzuki K, Nagai S, Iwai K, Furukawa T, Mukai N, Miyakawa S, and Takemura M. Characteristics and factors of concussion events for tacklers in collegiate rugby union. *Scand J Med Sci Sports* 30: 185-192, 2020.

174. Swaby R, Jones PA, and Comfort P. Relationship between maximum aerobic speed performance and distance covered in rugby union games. *J Strength Cond Res* 30: 2788–2793, 2016.

175. Taylor AE, Kemp S, Trewartha G, and Stokes KA. Scrum injury risk in English professional rugby union. *Br J Sports Med* 48: 1066-1068, 2014.

176. Tee JC, Klingbiel JF, Collins R, Lambert MI, and Coopoo Y. Preseason functional movement screen component tests predict severe contact injuries in professional rugby union players. *J Strength Cond Res* 30: 3194-3203, 2016.

177. Thomas GL and Wilson MR. Playing by the rules: a developmentally appropriate introduction to rugby union. *Int J Sports Sci Coa* 10: 413-423, 2015.

178. Thomas KT and Thomas JR. Developing expertise in sport: The relation of knowledge and performance. *Int J Sport Psychol* 25: 295-312, 1994.

179. Tierney GJ, Denvir K, Farrell G, and Simms CK. The effect of technique on tackle gainline success outcomes in elite level rugby union. *Int J Sports Sci Coa* 13: 16-25, 2017.

180. Tierney GJ, Denvir K, Farrell G, and Simms CK. Does ball carrier technique influence tackler head injury assessment risk in elite rugby union? *J Sports Sci*: 1-6, 2018.

181. Tierney GJ, Denvir K, Farrell G, and Simms CK. Does player time-in-game affect tackle technique in elite level rugby union? *J Sci Med Sport* 21: 221-225, 2018.

182. Tierney GJ, Denvir K, Farrell G, and Simms CK. The effect of tackler technique on head injury assessment risk in elite rugby union. *Med Sci Sports Exerc* 50: 603-608, 2018.

183. Tierney GJ, Lawler J, Denvir K, McQuilkin K, and Simms CK. Risks associated with significant head impact events in elite rugby union. *Brain Inj* 30: 1350-1361, 2016.

184. Till K, Cobley S, O'Hara J, Morley D, Chapman C, and Cooke C. Retrospective analysis of anthropometric and fitness characteristics associated with long-term career progression in Rugby League. *J Sci Med Sport* 18: 310-314, 2015.

185. Till K and Jones B. Monitoring anthropometry and fitness using maturity groups within youth rugby league. *J Strength Cond Res* 29: 730-736, 2015.

186. Till K, Jones B, and Geeson-Brown T. Do physical qualities influence the attainment of professional status within elite 16-19 year old rugby league players? *J Sci Med Sport* 19: 585-589, 2016.

187. Till K, Scantlebury S, and Jones B. Anthropometric and physical qualities of elite male youth rugby league players. *Sports Med* 47: 2171-2186, 2017.

188. Tucker R, Raftery M, Fuller GW, Hester B, Kemp S, and Cross MJ. A video analysis of head injuries satisfying the criteria for a head injury assessment in professional Rugby Union: a prospective cohort study. *Br J Sports Med* 51: 1147-1151, 2017.

189. Tucker R, Raftery M, Kemp S, Brown J, Fuller G, Hester B, Cross M, and Quarrie K. Risk factors for head injury events in professional rugby union: a video analysis of 464 head injury events to inform proposed injury prevention strategies. *Br J Sports Med* 51: 1152-1157, 2017.

190. Tucker R, Raftery M, and Verhagen E. Injury risk and a tackle ban in youth Rugby Union: reviewing the evidence and searching for targeted, effective interventions. A critical review. *Br J Sports Med* 50: 921-925, 2016.

191. Ullah S, Gabbett TJ, and Finch CF. Statistical modelling for recurrent events: an application to sports injuries. *Br J Sports Med* 48: 1287-1293, 2014.

192. Usman J, McIntosh AS, Quarrie K, and Targett S. Shoulder injuries in elite rugby union football matches: Epidemiology and mechanisms. *J Sci Med Sport* 18: 529-533, 2015.

193. Vahed Y, Kraak W, and Venter R. The effect of the law changes on time variables of the South African Currie Cup Tournament during 2007 and 2013. *Int J Perf Anal Spor* 14: 866-883, 2014.

194. Vahed Y, Kraak W, and Venter R. Changes on the match profile of the South African Currie Cup tournament during 2007 and 2013. *Int J Sports Sci Coa* 11: 85-97, 2016.

195. van Rooyen KM. A statistical analysis of tackling performance during international rugby union matches from 2011. *Int J Perf Anal Spor* 12: 517-530, 2012.

196. van Rooyen KM, Diedrick E, and Noakes DT. Ruck frequency as a predictor of success in the 2007 Rugby World Cup tournament. *Int J Perf Anal Spor* 10: 33-46, 2010.

197. van Rooyen KM, Lambert IM, and Noakes DT. A retrospective analysis of the IRB statistics and video analysis of match play to explain the performance of four teams in the 2003 Rugby World Cup. *Int J Perf Anal Spor* 6: 57-72, 2006.

198. van Rooyen KM and Noakes DT. An analysis of the movements, both duration and field location, of 4 teams in the 2003 Rugby World Cup. *Int J Perf Anal Spor* 6: 40-56, 2006.

199. van Rooyen KM and Noakes DT. Movement time as a predictor of success in the 2003 Rugby World Cup Tournament. *Int J Perf Anal Spor* 6: 30-39, 2006.

200. van Rooyen M, Rock K, Prim S, and Lambert M. The quantification of contacts with impact during professional rugby matches. *Int J Perf Anal Spor* 8: 113-126, 2008.

201. van Rooyen M, Yasin N, and Viljoen W. Characteristics of an 'effective' tackle outcome in Six Nations rugby. *Eur J Sport Sci* 14: 123-129, 2014.

202. Vaz L, Carreras D, and Kraak W. Analysis of the effect of alternating home and away field advantage during the Six Nations Rugby Championship. *Int J Perf Anal Spor* 12: 593-607, 2012.

203. Vaz L, Mouchet A, Carreras D, and Morente H. The importance of rugby game-related statistics to discriminate winners and losers at the elite level competitions in close and balanced games. *Int J Perf Anal Spor* 11: 130-141, 2011.

204. Vaz L, Van Rooyen M, and Sampaio J. Rugby game-related statistics that discriminate between winning and losing teams in IRB and Super twelve close games. *J Sports Sci Med* 9: 51-55, 2010.

205. Vaz L, Vasilica I, Kraak W, and Arrones LS. Comparison of scoring profile and game related statistics of the two finalist during the different stages of the 2011 Rugby World Cup. *Int J Perf Anal Spor* 15: 967-982, 2015.

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

207. Viljoen W and Patricios J. BokSmart - implementing a National Rugby Safety Programme. *Br J Sports Med* 46: 692-693, 2012.

208. Villarejo D, Palao J-M, Ortega E, Gomez-Ruano M-Á, and Kraak W. Match-related statistics discriminating between playing positions during the men's 2011 Rugby World Cup. *Int J Perf Anal Spor* 15: 97-111, 2015.

209. Villarejo D, Palao JM, and Toro EO. Match profiles for establishing position specific rehabilitation for rugby union players. *Int J Perf Anal Spor* 13: 567-571, 2013.

210. Virr JL, Game A, Bell GJ, and Syrotuik D. Physiological demands of women's rugby union: time-motion analysis and heart rate response. *J Sports Sci* 32: 239-247, 2014.

211. Viviers PL, Viljoen JT, and Derman W. A review of a decade of rugby union injury epidemiology: 2007-2017. *Sports Health* 10: 223-227, 2018.

212. Watson N, Durbach I, Hendricks S, and Stewart T. On the validity of team performance indicators in rugby union. *Int J Perf Anal Spor* 17: 609-621, 2017.

213. West SW, Williams S, Kemp S, Cross M, McKay C, Fuller C, Taylor A, Brooks JH, and Stokes K. Patterns of training volume and injury risk in elite rugby union: an analysis of 1.5 million hours of training exposure over eleven seasons. *J Sports Sci* In Press, 2019.

214. Wheeler K and Sayers M. Contact skills predicting tackle-breaks in rugby union. *Int J Sports Sci Coa* 4: 535-544, 2009.

215. Wheeler KW, Askew CD, and Sayers MG. Effective attacking strategies in rugby union. *Eur J Sport Sci* 10: 237-242, 2010.

216. Wheeler KW, Mills D, Lyons K, and Harrinton W. Effective defensive strategies at the ruck contest in rugby union. *Int J Sports Sci Coa* 8: 481-491, 2013.

217. Williams AM and Hodges NJ. Practice, instruction and skill acquisition in soccer: challenging tradition. *J Sports Sci* 23: 637-650, 2005.

218. Williams J, Hughes M, and O'Donoghue P. The effect of rule changes on match and ball in play time in rugby union. *Int J Perf Anal Spor* 5: 1-11, 2005.

219. Williams S, Trewartha G, Kemp S, and Stokes K. A meta-analysis of injuries in senior men's professional Rugby Union. *Sports Med* 43: 1043-1055, 2013.

220. Williams S, Trewartha G, Kemp SP, Michell R, and Stokes KA. The influence of an artificial playing surface on injury risk and perceptions of muscle soreness in elite Rugby Union. *Scand J Med Sci Sports* 26: 101-108, 2016.

221. Wilson BD, Quarrie KL, Milburn PD, and Chalmers DJ. The nature and circumstances of tackle injuries in rugby union. *J Sci Med Sport* 2: 153-162, 1999.

222. World Rugby. Year in review. Dublin: World Rugby, 2018.

223. World Rugby. Laws of the game: rugby union. Dublin, Ireland: World Rugby, 2019.

224. Ziv G and Lidor R. On-field performances of rugby union players - A review. *J Strength Cond Res* 30: 881-892, 2016.