BMJ Open Sport & Exercise Medicine

Lay of the land: narrative synthesis of tackle research in rugby union and rugby sevens

Nicholas Burger ,[1] Mike Lambert ,[1,2] Sharief Hendricks [1,3]

To cite: Burger N, Lambert M, Hendricks S. Lay of the land: narrative synthesis of tackle research in rugby union and rugby sevens. *BMJ Open Sport & Exercise Medicine* 2020;**6**:e000645. doi:10.1136/bmjsem-2019-000645

► Additional material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/bmjsem-2019-000645).

Accepted 22 March 2020

[1]Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Cape Town, Western Cape, South Africa
[2]Department of Public and Occupational Health and the EMGO Institute for Health and Care Research, VU University Medical Center, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands
[3]Institute for Sport, Physical Activity and Leisure, Centre for Sport Performance, School of Sport, Fairfax Hall, Headingley Campus, Leeds Beckett University, Leeds, UK

Correspondence to
Dr Sharief Hendricks;
sharief.hendricks01@gmail.com

ABSTRACT

Objectives The purpose of this review was to synthesise both injury prevention and performance tackle-related research to provide rugby stakeholders with information on tackle injury epidemiology, including tackle injury risk factors and performance determinants, and to discuss potential preventative measures.

Design Systematic review and narrative synthesis.

Data sources PubMed, Scopus and Web of Science.

Eligibility criteria Limited to peer-reviewed English-only publications between January 1995 and October 2018.

Results A total of 317 studies were identified, with 177 in rugby union and 13 were in rugby sevens. The tackle accounted for more than 50% of all injuries in rugby union and rugby sevens, both at the professional level and at the lower levels, with the rate of tackle injuries higher at the professional level (mean 32/1000 player-hours) compared with the lower levels (mean 17/1000 player-hours). A player's tackle actions and technical ability were identified as major risk factors for injury and a key determinant of performance.

Summary/conclusion Evidence-based education, progressive tackle technique training with a high potential to transfer and law changes have been proposed as key modifiers of player tackle actions and technical ability. Conceivably, all three modifiers working in unison (as opposed to separately) will have a higher potential at reducing tackle injury risk while enhancing performance. With the guidance of tackle injury and performance studies, as well as stakeholder engagement, experiential and explorative tackle research has the potential to inspire innovative injury prevention and performance strategies.

What is known

- The physical and dynamic nature of rugby union and rugby sevens exposes players to high risk of injury.
- The tackle is the contact event that has the highest injury incidence.
- To effectively reduce the risk of injury and optimise performance, it is recommended a sport injury prevention or sport performance process model be followed.

What this study adds

- Tackle injury rates are higher at the professional level compared with the lower levels.
- Tackle injury frequencies are similar between the ball carrier and tackler.
- A major risk factor for tackle injury and a key determinant of tackle performance is the player's technical ability.
- A player's technical ability can be improved through *boosting* coaching competencies. An example of such a coaching competency is how to monitor and progress tackle training to ensure optimum transfer to matches.

INTRODUCTION

The physical and dynamic nature of rugby union and rugby sevens expose players to high risk of injury. The majority of injuries in these rugby codes, at all levels, occur during the contact events: the tackle, ruck, maul, line-out and scrums.[1–4] The tackle is the contact event that has the highest injury incidence (injuries per 1000 player-hours), while the ruck and scrum have the second and third highest injury incidences, respectively.[1–4]Also, while the majority of spinal cord injuries occur in the scrum, the tackle has the highest incidence for the most severe injuries.[5] During the tackle, both the player in possession of the ball (ball carrier) and the player(s) attempting to contest the ball and territory (tacklers) are at risk of injury,[6–9] although the mechanisms of injury may differ.[10 11] Although the tackle is a high-injury risk contest, the ability to repeatedly win the contest is also a key performance indicator, with successful teams winning more tackles.[12]

To effectively reduce the risk of injury and optimise performance, it is recommended a sport injury prevention or sport performance process model such as the Translating Research into Injury Prevention Practice (TRIPP) model[13] (involving six stages) or the Applied Research Model for the Sport Sciences[14] (involving eight stages) be followed. These models outline a sequence of stages that need to be completed to ensure

the uptake and sustainability of an injury prevention or performance initiative in the 'real world'.[13] The first stage proposes establishing the extent of the injury problem through injury surveillance studies. Thereafter, the aim is to understand why and how these injuries occur, that is, identifying injury risk factors (stage 2). Stage 3 seeks to develop potential preventive measures for testing in ideal or controlled conditions (stage 4). Stage 5 aims to understand the implementation context, and the final stage (stage 6) monitors the effectiveness of the preventive measure in the real world.

Owing to the high risk of injury and performance demands, the tackle has been a research focus within rugby compared with other contact events.[15] Seemingly, each of these studies have contributed to a stage in the injury prevention or performance process models. However, these studies have not been consolidated to determine the state of tackle-related research at each stage for both injury prevention and performance. For instance, while systematic reviews on injury rates in rugby union and rugby sevens have been published[1–4] to address stage 1 of injury prevention models, and despite knowing the high incidence of tackle injury, no review to date has synthesised tackle injury frequencies and rates by playing levels and competition, and by role (ball carrier or tackler). Therefore, using the first three stages of the TRIPP model[13] as a guide, the purpose of this review was to consolidate both injury prevention and performance tackle-related research. The intention of this review was to synthesise both injury prevention and performance tackle-related research to provide rugby stakeholders with information on tackle injury epidemiology, including tackle injury risk factors and performance determinants, and to discuss measures that may improve tackle performance and reduce the risk of tackle injuries.

METHODS

A narrative synthesis format was chosen to review and synthesise the pool of literature. A narrative synthesis is an 'approach to the systematic review and synthesis of findings from multiple studies that relies primarily on the use of words and texts to summarise and explain the finding of the synthesis'.[16 17] Narrative syntheses can be used to review and assess quantitative and qualitative data and, in contrast to 'narrative reviews' and 'evidence syntheses', involve a systematic and predefined search strategy with a focus on producing a more textual synthesis versus other types of systematic reviews such as quantitative meta-analyses.

Search strategy

A search was conducted for published studies that reported on tackle-specific factors in rugby union and rugby sevens (rugby league studies were included in the search but removed at the final stage of the selection process). Three electronic databases (PubMed, Scopus and Web of Science) were searched using the keyword combinations 'rugby' AND 'contact', 'rugby' AND 'tackle', and 'rugby' AND 'union' OR 'league' OR 'sevens' AND 'injur*'.

Eligibility criteria

The search was limited to peer-reviewed English-only publications between January 1995 (the advent of professionalism in rugby union) and October 2018. Articles that involved quantitative data on rugby union or rugby sevens (including all ages and levels of play, and male and female players) were included. Only studies that included tackle-related testing protocols and match or training data (pertaining to tacklers and/or ball carriers) were included. The studies had to clearly define the tackle or ball carry as part of their analysis and not group the tackle into general contact/collision data.

Overall and/or time-loss tackle injury rates (only studies reporting number of injuries per 1000 exposure) and frequencies (percentages) were tabulated according to rugby code and level of play (tables 1–3). A time-loss injury was defined as an injury that resulted in a player being absent from normal match/training/recreational activities for more than 24 hours or 7 days (depending on the specific study's definition) after the incident. Medical attention injuries were injuries that required treatment from a doctor/healthcare professional but resulted in no time away from normal match/training/recreational activities. Overall injuries included both medical attention and time-loss injury events. Injury case studies specific to tackle events were also reviewed (see online supplementary appendix 1). Overall tackle numbers and rates (only studies reporting total number of tackles per match, and/or number of tackles per game or per minute) were tabulated in tables 4 and 5. Narrative literature reviews, systematic reviews, meta-analyses, editorials, journal letters, book chapters, conference proceedings, discussions and qualitative research studies were excluded from the analysis. All other quantitative study types and case studies were accepted for review.

Screening process

A five-step approach was followed to identify the final group of articles that would eventually be included in the final review (figure 1). Two authors (NB and SH) independently screened the titles using the eligibility criteria. The reliability of the authors was assessed by comparing the results of the title-screening process. Disparities in the results were discussed and resolved by the authors. NB continued the screening process of the abstracts and full-text articles. The articles were excluded at each step if they met the exclusion criteria or did not meet the inclusion criteria.

Data interpretation

Only the main findings (relating to tackle events) from each study were presented in this review. Confidence intervals (90% or 95% CIs) and standard deviations (±SDs) were provided in the tables, depending on their availability. All values and percentages were rounded off

Table 1 Tackle-related injury frequencies and rates in professional rugby union

Study	Cohort	Injury definition	Injury frequency	Injury rate
Jakoet and Noakes[145]	1995 RWC teams	Overall and time-loss (>1 day)	56% (29% tackled, 27% tackling)	N/A
Targett[146]	Super 12 team	Time-loss (>2 training sessions, >1 match)	46%	N/A
Doyle and George[147]	England Women's team	Overall and time-loss (>1 day)	30% tackling	N/A
Best *et al*[23]	2003 RWC teams	Overall and time-loss (>1 day)	40% (19% tackled, 21% tackling)	38.9/1000 hours (18.7/1000 hours tackled [95% CI 12.6 to 24.7]; 20.2/1000 hours tackling [95% CI 13.9 to 26.5])
Brooks *et al*[148]	England 2003 RWC team	Time-loss (>1 day)	36% (23% tackled, 13% tackling)	50/1000 hours (tackled only)
Holtzhausen *et al*[149]	Super 12 South African teams	Time-loss (>1 day or special treatment)	61% (46% tackled, 15% tackling)	33.8/1000 hours (25.7/1000 hours tackled, 8.1/1000 hours tackling)
Fuller *et al*[20]	English Premiership teams	Time-loss (>1 day)	63%	33.9/1000 hours (95% CI 30.3 to 37.9)
Fuller *et al*[24]	2007 RWC teams	Time-loss (>1 day)	N/A	29.2/1000 hours (22.4/1000 hours tackled [95% CI 16.6 to 30.2]; 6.8/1000 hours tackling [95% CI 3.9 to 11.7])
Quarrie and Hopkins[10]	Professional New Zealand men's teams	Overall and time-loss (>1 day)	N/A	12.2/1000 hours (5.8/1000 hours tackled [90% CI 4.9 to 6.8]; 6.4/1000 hours tackling [90% CI 5.5 to 7.5])
Schick *et al*[150]	2006 Women's RWC teams	Time-loss (>1 day)	63% (36% tackled, 27% tackling)	N/A
Fuller *et al*[151]	Super 14 teams	Overall and time-loss (>1 day)	68% (41% tackled [95% CI 35.5 to 47.2]; 27% tackling [95% CI 21.5 to 32])	N/A
Fuller *et al*[151]	Vodacom Cup teams	Overall and time-loss (>1 day)	64% (33% tackled [95% CI 21.3 to 44.3]; tackling 31% [95% CI 19.9 to 42.6])	N/A
Taylor *et al*[27]	2010 Women's RWC teams	Time-loss (>1 day)	38% (33% tackled [95% CI 18.5 to 48.1]; 5% tackling [95% CI 0 to 12.1])	N/A
Fuller *et al*[25]	2011 RWC teams	Time-loss (>1 day)	44%	40.1/1000 hours (21.9/1000 hours tackled [95% CI 16.2 to 29.6]; 18.2/1000 hours tackling [95% CI 13.1 to 25.4])
Schwellnus *et al*[8]	Super Rugby South African teams	Time-loss (>1 day)	49% (23% tackled, 26% tackling)	N/A
Fuller *et al*[26]	2015 RWC teams	Time-loss (>1 day)	46% (25% tackled [95% CI 18.2 to 31.2]; 21% tackling [95% CI 15.0 to 27.3])	N/A
Williams *et al*[152]	English Premiership team	Overall and time-loss (>1 day)	N/A	29.2/1000 hours (18.0/1000 hours tackled; 11.2/1000 tackling)
Schwellnus *et al*[153]	Super Rugby South African teams	Time-loss (>1 day)	54% (23% tackled, 27% tackling, 4% unspecified)	N/A

Continued

Table 1 Continued

Study	Cohort	Injury definition	Injury frequency	Injury rate
Ranson *et al*[51]	UK club teams	Time-loss (>1 day)	N/A	39.7/1000 hours (17.7/1000 hours tackled [90% CI 14.5 to 21.5]; 22/1000 tackling [90% CI 18.4 to 26.2])

N/A, not applicable; RWC, Rugby World Cup.

to a maximum of two decimal places where necessary. Results are organised according to the first three stages of the TRIPP model.

RESULTS

Injury epidemiology and tackle frequencies

General rugby union and sevens injury studies provided details pertaining to one or more tackle-related factors, including but not limited to injury rates, player injured (ie, ball carrier or tackler), player position (eg, forward or back), injury location (eg, head/neck, lower-limb or upper-limb), injury type/diagnosis (eg, concussion, fracture or bruise/contusion), tackle direction (eg, front-on or from behind) and player running speed prior to injury.[6–11 18–52] The tackle consistently accounted for more than 50% of all injuries in rugby union and rugby sevens, both at the professional level and at the lower levels. The rate of tackle injuries are higher at the professional level (mean 32/1000 player-hours) compared with the lower levels (mean 17/1000 player-hours). At all levels, the frequency of injury between the ball carrier and tackler were not largely dissimilar.

Certain studies also focused on niche areas including head injuries and concussions,[31 40 53–70] spinal and neck injuries,[71–79] shoulder injuries,[34 80–88] knee and ankle injuries,[89–93] and the influence of tackle technique on injuries.[61 64 65 69 94–96] Overall and time-loss injury frequencies and rates for rugby union (tables 1 and 2) and sevens (table 3) were tabulated (all injury types included). Tackle-related injury case studies were also summarised for all levels of rugby union and sevens from 1995 to 2018 (see online supplementary appendix 1).

The total number of tackles per match and tackle rates (tackles per game or per minute) for all levels of play for rugby union and sevens are summarised in tables 4 and 5, respectively. Successful and unsuccessful tackles were also included.

Injury risk factors and performance determinants

In matches, proper contact technique during the tackle, for both the ball carrier and tackler, has been identified as a key injury risk factor and performance determinant.[61 64 65 69 94–96] For example, ball carrier and tacklers that fail to 'leg drive' after contact have a higher risk of injury and a reduced chance of winning the tackle.[56 94 95 97] In another example, ball carriers fending the tackler on contact have a reduced risk of injury and are more likely to offload or break the tackle.[48 98] Not surprisingly, high, dangerous and illegal tackles are also a major risk factor for tackle injuries. A match contextual factor that has also been identified as a risk factor for injury is match quarter. Tackle injuries are reported to occur more frequently during the latter stages of matches,[15 16] which are attributed to a decrease in tackle technique. The physical and physiological demands of the tackle during matches, such as tackle velocity and muscle damage, have also been reported.[99–123]

Players' and coaches' knowledge, attitudes and behaviours pertaining to the tackle have been studied, including risk factors for injury and determinants of performance, both in training and matches.[68 124–130] For instance, players who rated tackle training to prevent injuries important (player attitude) and who spent more time on technique training to prevent injuries (player behaviour) reported safer behaviours for the tackle during matches. Also, coaches seem to be aware of the risk of injury in the tackle and the importance of coaching of proper technique.[131] However, this positive knowledge and attitudes from the coaches did not transfer into tackle training (coach behaviour).

Studying the tackle in controlled settings

Within lab settings, the physiological and biomechanical loads of the tackle have been studied.[99 101–113] These studies suggest that the movement patterns and the production of force are weaker on the non-dominant shoulder.[103 117] For example, Seminati *et al* reported a 13% higher impact force from the dominant shoulder.[132] Players seem to have poorer shoulder positional sense of their non-dominant shoulder while tackling[133] and adopt a more passive biomechanical strategy to generate the drive needed to stop a ball carrier.[132] As such, tackles on the dominant shoulder produce higher impact forces on contact, whereas the non-dominant shoulder produces force over longer durations.[132] In addition, tackles on the non-dominant shoulder were characterised by less control of head movement, which had a more flexed and laterally bent position compared with tackles on the dominant shoulder.[132]

DISCUSSION

It is well established that a player's tackle actions and technical ability are major risk factors for injury and key determinants of performance.[61 64 65 69 94–96] The question is how can we modify player action and improve tackle technique? One answer to this question is player, coach

Table 2 Tackle-related injury frequencies and rates in semiprofessional, amateur and youth rugby union

Study	Cohort	Injury definition	Injury frequency	Injury rate
Comstock and Fields[154]	USA women's teams	Overall and time-loss (>7 days)	58% (30% tackled, 28% tackling)	N/A
Collins *et al*[31]	Girls' US high school club teams	Time-loss (>1 day)	61% (29% tackled, 32% tackling)	N/A
Collins *et al*[31]	Boys' US high school club teams	Time-loss (>1 day)	59% (31% tackled, 28% tackling)	N/A
Kerr *et al*[7]	US collegiate teams (men)	Overall and time-loss (>1 day)	48%	8.2/1000 hours (4.53/1000 hours tackled, 3.62/1000 hours tackling)
Kerr *et al*[7]	US collegiate teams (women)	Overall and time-loss (>1 day)	53%	9.1/1000 hours (5.5/1000 hours tackled; 3.6/1000 hours tackling)
Schneiders *et al*[155]	New Zealand premier amateur club teams	Overall and time-loss (>1 day)	48% (19% tackled, 29% tackling)	N/A
Haseler *et al*[156]	English youth community club teams (9–17 years)	Time-loss (>1 day)	59%	14/1000 hours (95% CI 8.0 to 19.8)
Nicol *et al*[33]	Scottish school teams	Time-loss (>1 day)	62% (40% tackled, 22% tackling)	N/A
Fuller and Molloy[28]	International under-20 teams	Time-loss (>1 day)	45% (26% tackled, 19% tackling)	N/A
Palmer-Green *et al*[32]	English Premiership youth academy teams (16–18 years)	Time-loss (>1 day)	51% (30% tackled, 21% tackling)	21/1000 hours (12/1000 hours tackled [95% CI 8 to 17]; 9/1000 hours tackling [95% CI 5 to 13])
Palmer-Green *et al*[32]	English senior school teams (16–18 years)	Time-loss (>1 day)	57% (32% tackled, 25% tackling)	18/1000 hours (10/1000 hours tackled [95% CI 7 to 13]; 8/1000 hours tackling [95% CI 5 to 11])
Roberts *et al*[30]	English community-level teams	Time-loss (>7 days)	50%	8.4/1000 hours (95% CI 7.8 to 9.0) (4.8/1000 hours tackled [95% CI 4.3 to 5.2]; 3.6/1000 hours tackling [95% CI 3.2 to 4.0])
Archbold *et al*[157]	Irish grammar school teams (16.8±0.8 years)	Time-loss (>1 day)	48% (20% tackled, 28% tackling)	N/A
Swain *et al*[158]	Australian amateur club teams	Overall and time-loss (>1 day)	69% (34% tackled [95% CI 25.6 to 42.1]; 35% tackling [95% CI 26.4 to 42.9])	N/A
Burger *et al*[95]	South African under-18 provincial Craven Week teams	Overall and time-loss (>1 day)	50%	27/1000 hours (95% CI 21 to 33)
Burger *et al*[95]	South African under-18 provincial Craven Week teams	Time-loss (>1 day)	N/A	11/1000 hours (95% CI 8 to 15)
Leung *et al*[159]	Australian Associated Independent Colleges interschool competition teams: year 5 teams (9–10 year olds) to open grades (17–18 year olds)	Overall and time-loss (>1 day)	55% (27% tackled, 28% tackling)	N/A

Continued

Table 2 Continued

Study	Cohort	Injury definition	Injury frequency	Injury rate
Leung *et al*[132]	Australian greater private school competition teams: under-11 teams (10–11 year olds) to open grades (17–18 year olds)	Overall and time-loss (>1 day)	39%	N/A
Barden and Stokes[52]	English elite under-18 schoolboy teams: AASE league matches	Time-loss (>1 day)	N/A	42/1000 hours (95% CI 26 to 59) (20/1000 hours tackled [95% CI 9 to 32]; 22/1000 hours tackling [95% CI 10 to 34])
Barden and Stokes[52]	English elite under-18 schoolboy teams: general (non-AASE) matches	Time-loss (>1 day)	N/A	19/1000 hours (95% CI 12 to 25) (12/1000 hours tackled [95% CI 7 to 17]; 7/1000 hours tackling [95% CI 3 to 11])
Barden and Stokes[52]	English elite under-18 schoolboy teams (AASE and non-AASE matches)	Time-loss (>1 day)	55%	N/A
Sewry *et al*[160]	South African provincial Youth Week teams: under-13, under-16 and under-18	Time-loss (>1 day)	N/A	11.4/1000 hours (4/1000 hours tackled [95% CI 3.2 to 4.9]; 7.4/1000 hours tackling [95% CI 6.3 to 8.5])
Sewry *et al*[50]	South African Western Cape premier league under-16 school teams	Time-loss (>1 day)	N/A	18.3/1000 hours (11.3/1000 hours tackled [95% CI 5.2 to 17.5]; 7/100 hours tackling [95% CI 2.1 to 11.8])

AASE, Achieving Academic and Sporting Excellence; N/A, not applicable.

and referee education. Using evidence from tackle injury mechanism and performance determinant studies, national injury prevention programmes such as New Zealand's Rugby Smart and South Africa's BokSmart programmes aim to educate rugby stakeholders on safe and effective tackle techniques.[124 134] These educational tools are intended to modify player, coach and referee attitudes and behaviours, both in training and during matches. While these national injury prevention programmes have shown positive changes in player, coach and referee knowledge,[124 125] this may not be enough to drive positive behaviour change. Indeed, Hendricks *et al* showed that even though a sample of youth coaches were aware of the high risk of injury during the tackle and the importance of proper tackle technique, this knowledge did not transfer into their actual tackle training sessions.[131] Therefore, the next logical step is to apply the knowledge gained from tackle injury mechanism and performance determinant studies to improve tackle training.

The tackle is a highly technical and physical skill and, like any skill, should be developed though training.[15 135] Despite this, research comparing training and matches suggests that tackle contact preparation during training is not adequate to meet the demands of tackle contact during matches.[131 136 137] Implementation research in sport argues that the ability to coach technique depends on how competent the coaches believe they are to do so[138]; this is also true for coaching tackle technique.[131 136] From a behaviour change perspective, to increase the likelihood of a desired behaviour requires a specific action plan[139 140] and the fostering of competencies, a concept known as 'boosting'.[141] In line with these arguments, a group of rugby researchers and practitioners designed a tackle contact skill framework and training plan based on skill acquisition and skill development literature.[142] The framework describes measurements that can be used to monitor and progress tackle training to ensure optimum transfer to matches.[142] Although the efficacy and effectiveness of such a tackle training programme has yet to be studied, the framework and training plan serves as a starting point to design tackle training programmes and further develop tackle training concepts such as contact readiness (when introducing players to rugby), contact readiness as part of match warm-up, return to contact (for players returning from injury), contact capacity (maintaining proper technique while fatigued) and contact efficiency (highly proficient contact technique with minimal physical effort). Also, how other forms of physical preparation, for example, resistance training, influences tackle ability is yet to be investigated. Finally, most of what we know about tackle training is based on questionnaire studies; therefore, to better understand the implementation context, as well as

Table 3 Tackle-related injury frequencies and rates in rugby sevens (all levels of play)

Study	Cohort	Injury definition	Injury frequency	Injury rate
Fuller *et al*[161]	International World Sevens Series teams	Time-loss (>1 day)	52% (34% tackled, 18% tackling)	N/A
Lopez *et al*[46]	US amateur rugby union sevens teams (including women)	Overall and time-loss (>1 day)	75% (95% CI 60 to 85)	40.4/1000 hours (95% CI 28.6 to 55.6)
Fuller *et al*[44]	International World Sevens Series teams	Time-loss (>1 day)	54% (32% tackled [95% CI 27.1 to 37.6]; 22% tackling [95% CI 17.1 to 26.3])	N/A
Fuller *et al*[43]	International World Sevens Series teams	Time-loss (>1 day)	55% (33% tackled, 22% tackling)	N/A
Ma *et al*[47]	US women's rugby union sevens teams (under-19 to professional)	Time -loss (>1 day)	72%±8.5% (41% tackled, 31% tackling)	N/A
Rizi *et al*[162]	Hong Kong University rugby teams	Time-loss (>1 day)	65% (29% tackled, 29% tackling, 7% tackle collision, ie, no use of arm)	N/A
Cruz-Ferreira *et al*[163]	Tier 1 and tier 2 Portuguese national senior male rugby teams	Time-loss (>1 day)	57.1% (38.1% tackled [95% CI 17.6% to 60.0%]; 19% tackling [95% CI 4.8% to 38.1%])	N/A
Cruz-Ferreira *et al*[163]	Tier 1 Portuguese national senior male rugby Sevens teams	Time-loss (>1 day)	57.2% (42.9% tackled [95% CI 15.4% to 70.0%]; 14.3% tackling [95% CI 0% to 35.7%])	N/A
Cruz-Ferreira *et al*[163]	Tier 2 Portuguese national senior male rugby Sevens teams	Time-loss (>1 day)	57.2% (28.6% tackled [95% CI 0% to 66.7%]; 28.6% tackling [95% CI 0% to 66.7%])	N/A

N/A, not applicable.

barrier and facilitators to implementing a tackle training programme, coach engagement and systematic observations of tackle training sessions are required.

Another strategy to modify player tackle action during matches is through changing the laws of the game. To specifically reduce head injuries during the tackle, the sport's governing body, World Rugby, have recently recommended stronger sanctioning of reckless and high tackles and proposed a reduction in tackle height of a legal tackle,[61] from above the line of the shoulders to above the line of the armpit. These law changes are seemingly based on the behavioural principle known as 'nudging', that is, changing the external environment to achieve a predicable outcome.[141] Changing tackle laws also has a more immediate effect compared with education and training programmes. With that said, the actual effect of these law changes on tackle injury risk and player tackle actions is yet to be published.

Although results from lab-based studies may have limited applicability to match situations due to its controlled nature, studying the tackle in the lab allows for experiential and explorative study designs. Experiential and explorative study designs may offer deeper insights into the demands and movement patterns of the tackle (eg, tackle biomechanics),[103] as well as test the effects of different conditions (eg, physical fatigue) and interventions (video feedback)[143] on tackle technique. Not all research on the tackle needs to have a direct application, and experiential and explorative work is important to inspire innovative tackle injury prevention and performance strategies.[144] Having said that, findings from tackle injury and performance studies in matches, as well stakeholder engagement, should guide the questions and design of lab-based studies.

CONCLUSION

The purpose of this review was to synthesise both injury prevention and performance tackle-related research to offer rugby stakeholders (researchers, practitioners, policymakers and coaches) with tackle-specific injury epidemiology and frequencies, an overview of tackle injury risk factors and performance determinants, discuss measures to improve tackle performance and reduce the risk of tackle injuries. The tackle consistently accounted for more than 50% of all injuries in rugby union and rugby sevens, both at the professional level and at the lower levels, with the rate of tackle injuries higher at the professional level (mean 32/1000 player-hours) compared with the lower levels (mean 17/1000 player-hours). Also, the frequencies of injury between the ball carrier and tackler were not largely dissimilar. A player's tackle actions and technical ability has been identified as a major risk factor for injury and a key determinant of performance. Evidence-based education has been used, and progressive tackle technique training with a high potential to transfer and law changes have been

Table 4 Tackle numbers and rates in rugby union (all levels of play)

Study	Cohort	Rate definition	Tackle rate
Duthie *et al*[164]	Super 12 teams	Tackling/game	Front-row forwards: 10±8 Back-row forwards: 13±5 Inside backs: 11±6 Outside backs: 7±4
Deutsch *et al*[165]	Super 12 team	Tackles (tackling and tackled)/game	Front-row forwards: 9.5±3 Back-row forwards: 23±6 Inside backs: 20±4.5 Outside backs: 11±6.5
Eaton and George[166]	English Premiership team	a) Tackling/game b) Tackled/game	Props: 8±4,[a] 5±3[b] Hooker: 8±4,[a] 7±4[b] Lock forwards: 11±3,[a] 4±2[b] Loose forwards: 13±6,[a] 8±5[b] Scrum halves: 11±4,[a] 9±4[b] Inside backs: 9±4,[a] 5±3[b] Outside backs: 6±3,[a] 5±3[b]
Fuller *et al*[20]	English Premiership teams	Total match tackles (tackling and tackled)	221 (95% CI 215.9 to 226.2)
Quarrie and Hopkins[167]	Bledisloe Cup teams	Total match tackles (tackling and tackled)	1995: 160±32 2004: 270±25
Roberts *et al*[168]	English Premiership team	Tackling/game	Tight forwards: 12±3 Loose forwards 16±4 Inside backs: 13±3 Outside backs: 8±2
Smart *et al*[99]	New Zealand National Provincial Championship team	a) Tackling/game b) Tackled/game	Forwards: 13.6±7.5,[a] 3.2±2.4[b] Backs: 6.5±4.7,[a] 0.7±0.9[b]
Austin *et al*[169]	Super 14 team	Tackles (tackling and tackled)/game	Front-row forwards: 20±4 Back-row forwards: 19±4 Inside backs: 25±13 Outside backs: 20±7
Coughlan *et al*[100]	International players (one forward and back)	a) Tackling/game b) Tackled/game	Forward: 10,[a] 5[b] Back: 12,[a] 4[b]
van Rooyen[170]	International teams	Total match tackles (tackling and tackled)	Six Nations: 165±28 Tri Nations:141±24 2011 Rugby World Cup:156±47
Hendricks *et al*[171]	Super 14 teams	Total match tackles (tackling and tackled)	114±20
Villarejo *et al*[172]	2007 RWC teams	Tackling/game	Front-row forwards: 10.04 Lock forwards: 10.94 Back-row forwards: 14.25 Scrum halves: 12.48 Inside backs: 10.46 Outside backs: 5.9
Hendricks *et al*[98]	Super 14 teams	Total match tackles (tackling and tackled)	116±20
Jones *et al*[101]	European Cup team	a) Tackling/game b) Tackled/game	Forwards: 5±3,[a] 5±2[b] Backs: 4±3,[a] 5±3[b]

Continued

Table 4 Continued

Study	Cohort	Rate definition	Tackle rate
van Rooyen *et al*[173]	Six Nations team	Total match tackles (tackling and tackled)	191±32
Lindsay *et al*[174]	Super 15 team	c) Tackling/minute	Front-row forwards: 0.14±0.07,[c] 0.06±0.05[d]
		d) Tackled/minute	Lock forwards: 0.16±0.09,[c] 0.1±0.02[d]
			Loose forwards: 0.17±0.09,[c] 0.09±0.06[d]
			Inside backs: 0.14±0.12,[c] 0.11±0.07[d]
			Outside backs: 0.07±0.07,[c] 0.12±0.06[d]
Roberts *et al*[6]	Amateur English community-level teams	Total match tackles (tackling and tackled)	140.9 (95%CI 136.7 to 145.2)
Villarejo *et al*[175]	2011 RWC teams	Tackling/game	Front-row forwards: 9.96
			Lock forwards: 10.9
			Back-row forwards: 14.36
			Scrum halves: 12.44
			Inside backs: 10.35
			Outside backs: 5.95
Brown *et al*[176]	South African under-18 provincial Craven Week teams	Total match tackles (tackling and tackled)	123±17
Hendricks *et al*[97]	Six Nations teams	Total match tackles (tackling and tackled)	175±21
Hendricks *et al*[97]	Rugby Championship teams	Total match tackles (tackling and tackled)	154±36

[a], tackling/game; [b], tackled/game; [c], tackling/minute; [d], tackled/minute; RWC, Rugby World Cup.

proposed, as key modifiers of player tackle actions and technical ability. Conceivably, all three modifiers working in unison (as oppose to separately) will have a higher potential at reducing tackle injury risk while enhancing performance. With the guidance of tackle injury and performance studies, as well as stakeholder engagement, experiential and explorative tackle research also has potential to inspire innovative tackle injury prevention and performance strategies.

Twitter Nicholas Burger @it_is_burger, Mike Lambert @MikeLambert 01 and Sharief Hendricks @Sharief_H

Contributors NB conducted the search and review, NB and SH cowrote the first draft, and all authors provided input to the final version.

Table 5 Tackle numbers and rates in rugby sevens (all levels of play).

Study	Cohort	Rate definition	Tackle rate
Suarez-Arrones *et al*[177]	Professional Spanish League team	Tackles (tackling and tackled)/game	Forwards: 7.4±1.8 (first half: 3.3±1.3, second half: 4.1±1.8)
			Backs: 4.1±2.4 (first half: 2.3±1.8, second half: 1.9±1.4)
Ross *et al*[178]	New Zealand provincial rugby sevens championship teams	Tackling/minute	0.19±0.13
Ross *et al*[178]	International Sevens World Series team	Tackling/minute	0.2±0.15
Ross *et al*[179]	International Sevens World Series team	a) Tackling/game	Forwards: 2.68±2.59,[a] 1.59±2.24[b]
		b) Tackled/game	Backs: 2.41±2.52,[a] 1.79±2.85[b]

[a], tackling/game; [b], tackled/game.

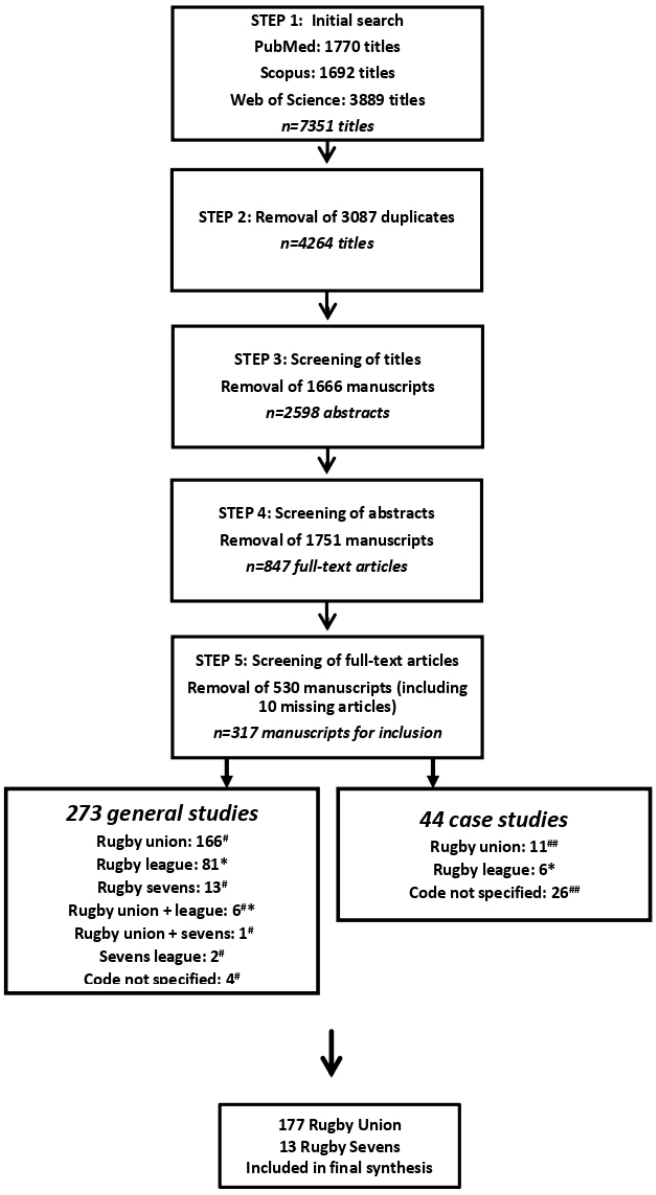

Figure 1 Summary of the literature screening process. #, manuscripts included in rugby union/sevens analysis; ##, manuscripts included in rugby union/sevens appendix; *, manuscripts included in separate rugby league analysis/ appendix.

Funding This work was supported by the UCT Faculty of Health Sciences Postgraduate Publication Incentive Award and the National Research Foundation (NRF).

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information.

ORCID iDs

Nicholas Burger http://orcid.org/0000-0002-0010-9212
Mike Lambert http://orcid.org/0000-0001-8979-1504
Sharief Hendricks http://orcid.org/0000-0002-3416-6266

REFERENCES

1 Williams S, Trewartha G, Kemp S, *et al*. A meta-analysis of injuries in senior men's professional rugby union. *Sports Med* 2013;43:1043–55.
2 Yeomans C, Kenny IC, Cahalan R, *et al*. The incidence of injury in amateur male rugby union: a systematic review and meta-analysis. *Sports Med* 2018;48:837–48.
3 Freitag A, Kirkwood G, Scharer S, *et al*. Systematic review of rugby injuries in children and adolescents under 21 years. *Br J Sports Med* 2015;49:511–9.
4 Cruz-Ferreira A, Cruz-Ferreira E, Santiago L, *et al*. Epidemiology of injuries in senior male rugby union sevens: a systematic review. *Phys Sportsmed* 2017;45:41–8.
5 Chan CW, Eng JJ, Tator CH, *et al*. Epidemiology of sport-related spinal cord injuries: a systematic review. *J Spinal Cord Med* 2016;39:255–64.
6 Roberts SP, Trewartha G, England M, *et al*. Collapsed scrums and collision tackles: what is the injury risk? *Br J Sports Med* 2015;49:536–40.
7 Kerr HA, Curtis C, Micheli LJ, *et al*. Collegiate rugby union injury patterns in New England: a prospective cohort study. *Br J Sports Med* 2008;42:595–603.
8 Schwellnus MP, Thomson A, Derman W, *et al*. More than 50% of players sustained a time-loss injury (>1 day of lost training or playing time) during the 2012 Super Rugby Union Tournament: a prospective cohort study of 17,340 player-hours. *Br J Sports Med* 2014;48:1306–15.
9 Burger N, Lambert MI, Viljoen W, *et al*. Tackle-related injury rates and nature of injuries in South African youth week tournament rugby union players (under-13 to under-18): an observational cohort study. *BMJ Open* 2014;4:e005556.
10 Quarrie KL, Hopkins WG. Tackle injuries in professional rugby union. *Am J Sports Med* 2008;36:1705–16.
11 Fuller CW, Ashton T, Brooks JHM, *et al*. Injury risks associated with tackling in rugby union. *Br J Sports Med* 2010;44:159–67.
12 Ortega E, Villarejo D, Palao JM. Differences in game statistics between winning and losing rugby teams in the six nations tournament. *J Sports Sci Med* 2009;8:523–7.
13 Finch C. A new framework for research leading to sports injury prevention. *J Sci Med Sport* 2006;9:3–9.
14 Bishop D. An applied research model for the sport sciences. *Sports Med* 2008;38:253–63.
15 Hendricks S, Till K, Brown JC, *et al*. Rugby Union needs a contact skill-training programme. *Br J Sports Med* 2017;51:829–30.
16 Popay J, Roberts H, Sowden A. *Guidance on the conduct of narrative synthesis in systematic reviews: a product from the ESRC methods programme*, 2006.
17 Druetz T, Siekmans K, Goossens S, *et al*. The community case management of pneumonia in Africa: a review of the evidence. *Health Policy Plan* 2015;30:253–66.
18 Garraway WM, Lee AJ, Macleod DA, *et al*. Factors influencing tackle injuries in rugby union football. *Br J Sports Med* 1999;33:37–41.
19 McIntosh AS, Savage TN, McCrory P, *et al*. Tackle characteristics and injury in a cross section of rugby union football. *Med Sci Sports Exerc* 2010;42:977–84.
20 Fuller CW, Brooks JHM, Cancea RJ, *et al*. Contact events in rugby union and their propensity to cause injury. *Br J Sports Med* 2007;41:862–7.
21 Brooks JHM, Fuller CW, Kemp SPT, *et al*. Epidemiology of injuries in English professional rugby union: Part 1 match injuries. *Br J Sports Med* 2005;39:757–66.
22 Brooks JHM, Kemp SPT. Injury-prevention priorities according to playing position in professional rugby union players. *Br J Sports Med* 2011;45:765–75.
23 Best JP, Mcintosh AS, Savage TN, *et al*. Injury surveillance project. *Br J Sports Med* 2003;2005:812–7.
24 Fuller CW, Laborde F, Leather RJ, *et al*. International rugby board rugby world cup 2007 injury surveillance study. *Br J Sports Med* 2008;42:452–9.
25 Fuller CW, Sheerin K, Targett S, *et al*. International rugby board injury surveillance study. *Br J Sports Med* 2011;2013:1184–91.
26 Fuller CW, Taylor A, Kemp SPT, *et al*. World rugby injury surveillance study. *Br J Sports Med* 2015;2016:1–7.

27 Taylor AE, Fuller CW, Molloy MG. Injury surveillance during the 2010 IRB women's rugby world cup. *Br J Sports Med* 2011;45:1243–5.
28 Fuller CW, Molloy MG, Marsalli M. Epidemiological study of injuries in men's international under-20 rugby union tournaments. *Clin J Sport Med* 2011;21:356–8.
29 Garraway WM, Lee AJ, Hutton SJ, *et al*. Impact of professionalism on injuries in rugby union. *Br J Sports Med* 2000;34:348–51.
30 Roberts SP, Trewartha G, England M, *et al*. Epidemiology of time-loss injuries in English community-level rugby union. *BMJ Open* 2013;3:e003998:1–8.
31 Collins CL, Micheli LJ, Yard EE, *et al*. Injuries sustained by high school rugby players in the United States, 2005-2006. *Arch Pediatr Adolesc Med* 2008;162:49–54.
32 Palmer-Green DS, Stokes KA, Fuller CW, *et al*. Match injuries in English youth Academy and schools rugby union: an epidemiological study. *Am J Sports Med* 2013;41:749–55.
33 Nicol A, Pollock A, Kirkwood G, *et al*. Rugby Union injuries in Scottish schools. *J Public Health* 2011;33:256–61.
34 Usman J, McIntosh AS, Usman MAS. Upper limb injury in rugby union football: results of a cohort study. *Br J Sports Med* 2013;47:374–9.
35 Babić Z, Misigoj-Duraković M, Matasić H, *et al*. Croatian rugby project. Part II: injuries. *J Sports Med Phys Fitness* 2001;41:392–8.
36 Brooks JHM, Fuller CW, Kemp SPT, *et al*. Epidemiology of injuries in English professional rugby union: Part 2 training injuries. *Br J Sports Med* 2005;39:767–75.
37 Palmer-Green DS, Stokes KA, Fuller CW, *et al*. Training activities and injuries in English youth Academy and schools rugby union. *Am J Sports Med* 2015;43:475–81.
38 Goodson A, Morgan M, Rajeswaran G, *et al*. Current management of Jersey finger in rugby players: case series and literature review. *Hand Surg* 2010;15:103–7.
39 Muller-Bolla M, Lupi-Pegurier L, Pedeutour P, *et al*. Orofacial trauma and rugby in France: epidemiological survey. *Dent Traumatol* 2003;19:183–92.
40 Kemp SPT, Hudson Z, Brooks JHM, *et al*. The epidemiology of head injuries in English professional rugby union. *Clin J Sport Med* 2008;18:227–34.
41 McIntosh AS, McCrory P, Finch CF, *et al*. Head, face and neck injury in youth rugby: incidence and risk factors. *Br J Sports Med* 2010;44:188–93.
42 Robertson GAJ, Wood AM, Heil K, *et al*. The epidemiology, morbidity and outcome of fractures in rugby union from a standard population. *Injury* 2014;45:677–83.
43 Fuller CW, Taylor AE, Raftery M. Should player fatigue be the focus of injury prevention strategies for international rugby sevens tournaments? *Br J Sports Med* 2016;50:682–7.
44 Fuller CW, Taylor AE, Raftery M. Does long-distance air travel associated with the Sevens world series increase players' risk of injury? *Br J Sports Med* 2015;49:458–64.
45 King DA, Gabbett TJ, Dreyer C, *et al*. Incidence of injuries in the New Zealand national rugby League sevens tournament. *J Sci Med Sport* 2006;9:110–8.
46 Lopez V, Galano GJ, Black CM, *et al*. Profile of an American amateur rugby union sevens series. *Am J Sports Med* 2012;40:179–84.
47 Ma R, Lopez V, Weinstein MG, *et al*. Injury profile of American women's Rugby-7s. *Med Sci Sports Exerc* 2016;48:1957–66.
48 Burger N, Lambert MI, Viljoen W, *et al*. Mechanisms and factors associated with tackle-related injuries in South African youth rugby union players. *Am J Sports Med* 2017;45:278–85.
49 Snodgrass SJ, Osmotherly PG, Reid SA, *et al*. Physical characteristics associated with neck pain and injury in rugby union players. *J Sports Med Phys Fitness* 2018;58:1474–81.
50 Sewry N, Verhagen E, Lambert M, *et al*. Seasonal time-loss match injury rates and burden in South African under-16 rugby teams. *J Sci Med Sport* 2019;22:54–8.
51 Ranson C, George J, Rafferty J, *et al*. Playing surface and UK professional rugby union injury risk. *J Sports Sci* 2018;36:2393–8.
52 Barden C, Stokes K. Epidemiology of injury in elite English Schoolboy rugby union: a 3-year study comparing different competitions. *J Athl Train* 2018;53:514–20.
53 Cross M, Kemp S, Smith A, *et al*. Professional Rugby Union players have a 60% greater risk of time loss injury after concussion: a 2-season prospective study of clinical outcomes. *Br J Sports Med* 2015;0:1–6.
54 Fuller CW, Taylor A, Raftery M. Epidemiology of concussion in men's elite Rugby-7s (Sevens world series) and Rugby-15s (rugby world cup, junior world Championship and rugby Trophy, Pacific nations cup and English Premiership). *Br J Sports Med* 2015;49:478–83.
55 Fuller GW, Kemp SPT, Decq P. The International rugby board (IRB) pitch side concussion assessment trial: a pilot test accuracy study. *Br J Sports Med* 2015;49:529–35.
56 Tierney GJ, Lawler J, Denvir K, *et al*. Risks associated with significant head impact events in elite rugby union. *Brain Inj* 2016;30:1350–61.
57 Delahunty SE, Delahunt E, Condon B, *et al*. Prevalence of and attitudes about concussion in Irish schools' rugby union players. *J Sch Health* 2015;85:17–26.
58 Lopez V, Ma R, Weinstein MG, *et al*. Concussive injuries in rugby 7S: an American experience and current review. *Med Sci Sports Exerc* 2016;48:1320–30.
59 Cross MJ, Tucker R, Raftery M, *et al*. Tackling concussion in professional rugby union: a case–control study of tackle-based risk factors and recommendations for primary prevention. *Br J Sports Med* 2017:1–6.
60 Tucker R, Raftery M, Fuller GW, *et al*. 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* 2017;51:1147–51.
61 Tucker R, Raftery M, Kemp S, *et al*. 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* 2017;51:1152–7.
62 Roberts SP, Trewartha G, England M, *et al*. Concussions and head injuries in English community rugby union match play. *Am J Sports Med* 2017;45:480–7.
63 Mc Fie S, Brown J, Hendricks S, *et al*. Incidence and factors associated with concussion injuries at the 2011 to 2014 South African rugby union youth week Tournaments. *Clin J Sport Med* 2016;26:398–404.
64 Tierney GJ, Denvir K, Farrell G, *et al*. Does ball carrier technique influence tackler head injury assessment risk in elite rugby union? *J Sports Sci* 2019;37:262–7.
65 Davidow D, Quarrie K, Viljoen W, *et al*. Tackle technique of rugby union players during head impact tackles compared to injury free tackles. *J Sci Med Sport* 2018;21:1025–31.
66 Tierney GJ, Simms CK. Can tackle height influence head injury assessment risk in elite rugby union? *J Sci Med Sport* 2018.
67 Fuller GW, Cross MJ, Stokes KA, *et al*. King-Devick concussion test performs poorly as a screening tool in elite rugby union players: a prospective cohort study of two screening tests versus a clinical reference standard. *Br J Sports Med* 2019;53:1526–32.
68 Clacy A, Goode N, Sharman R, *et al*. A knock to the system: a new sociotechnical systems approach to sport-related concussion. *J Sports Sci* 2017;35:2232–9.
69 Tierney GJ, Denvir K, Farrell G, *et al*. The effect of tackler technique on head injury assessment risk in elite rugby union. *Med Sci Sports Exerc* 2018;50:603–8.
70 Hendricks S, O'Connor S, Lambert M, *et al*. Video analysis of concussion injury mechanism in under-18 rugby. *BMJ Open Sport Exerc Med* 2016;2:e000053:1–11.
71 Fuller CW, Brooks JHM, Kemp SPT. Spinal injuries in professional rugby union: a prospective cohort study. *Clin J Sport Med* 2007;17:10–16.
72 Quarrie KL, Gianotti SM, Hopkins WG, *et al*. Effect of nationwide injury prevention programme on serious spinal injuries in New Zealand rugby union: ecological study. *BMJ* 2007;334:1150–3.
73 Carmody DJ, Taylor TKF, Parker DA, *et al*. Spinal cord injuries in Australian footballers 1997-2002. *Med J Aust* 2005;182:561–4.
74 Shelly MJ, Butler JS, Timlin M, *et al*. Spinal injuries in Irish rugby. *J Bone Joint Surg Br* 2006;88-B:771–5.
75 Dunn RN, van der Spuy DRugby and cervical spine injuries - has anything changed? A 5-year review in the Western Cape. *S Afr Med J* 2010;100:235–8.
76 Brown JC, Lambert MI, Verhagen E, *et al*. The incidence of rugby-related catastrophic injuries (including cardiac events) in South Africa from 2008 to 2011: a cohort study. *BMJ Open* 2013;3:e002475:1–10.
77 Maclean JGB, Hutchison JD. Serious neck injuries in U19 rugby union players: an audit of admissions to spinal injury units in Great britain and ireland. *Br J Sports Med* 2011:1–5.
78 Swain MS, Pollard HP, Bonello R. Incidence, severity, aetiology and type of neck injury in men's amateur rugby union: a prospective cohort study. *Chiropr Osteopat* 2010;18:1–12.
79 Badenhorst M, Verhagen E, Lambert MI, *et al*. '*In a blink of an eye your life can change*': experiences of players sustaining a rugby-related acute spinal cord injury. *Inj Prev* 2019;25:313-320.

80 Headey J, Brooks JHM, Kemp SPT. The epidemiology of shoulder injuries in English professional rugby union. *Am J Sports Med* 2007;35:1537–43.
81 Usman J, McIntosh AS, Quarrie K, *et al*. Shoulder injuries in elite rugby union football matches: epidemiology and mechanisms. *J Sci Med Sport* 2015;18:529–33.
82 Kawasaki T, Ota C, Urayama S, *et al*. Incidence of and risk factors for traumatic anterior shoulder dislocation: an epidemiologic study in high-school rugby players. *J Shoulder Elbow Surg* 2014;23:1624–30.
83 Bohu Y, Klouche S, Lefevre N, *et al*. The epidemiology of 1345 shoulder dislocations and subluxations in French rugby union players: a five-season prospective study from 2008 to 2013. *Br J Sports Med* 2015;49:1535–40.
84 Sundaram A, Bokor DJ, Davidson AS. Rugby Union on-field position and its relationship to shoulder injury leading to anterior reconstruction for instability. *J Sci Med Sport* 2011;14:111–4.
85 Lynch E, Lombard AJ, Coopoo Y, *et al*. Shoulder injury incidence and severity through identification of risk factors in rugby union players. *Pak J Med Sci* 2013;29:1400–5.
86 Singh VR, Trewartha G, Roberts SP, *et al*. Shoulder injuries in English community rugby union. *Int J Sports Med* 2016;37:659–64.
87 Larrain MV, Montenegro HJ, Mauas DM, *et al*. Arthroscopic management of traumatic anterior shoulder instability in collision athletes: analysis of 204 cases with a 4- to 9-year follow-up and results with the suture anchor technique. *Arthroscopy* 2006;22:1283–9.
88 Longo UG, Huijsmans PE, Maffulli N, *et al*. Video analysis of the mechanisms of shoulder dislocation in four elite rugby players. *J Orthop Sci* 2011;16:389–97.
89 Sankey RA, Brooks JHM, Kemp SPT, *et al*. The epidemiology of ankle injuries in professional rugby union players. *Am J Sports Med* 2008;36:2415–24.
90 Dallalana RJ, Brooks JHM, Kemp SPT, *et al*. The epidemiology of knee injuries in English professional rugby union. *Am J Sports Med* 2007;35:818–30.
91 Takazawa Y, Nagayama M, Ikeda H, *et al*. Anterior cruciate ligament injuries in elite and high school rugby players: a 11-year review. *Phys Sportsmed* 2016;44:53-8.
92 Viljoen W, Treu P, Swart B. SA Rugby BokSmart: Safe and Effective Techniques in Rugby—Practical Guidelines.. Available: http://www.sarugby.co.za/boksmart/pdf/BokSmart%25%0A20-%2520Safe%2520Rugby%2520Techniques%2520Practical%2520guidelines.pdf.2009 [Accessed 23 May 2012].
93 Montgomery C, Blackburn J, Withers D, *et al*. Mechanisms of ACL injury in professional rugby union: a systematic video analysis of 36 cases. *Br J Sports Med* 2018;52:994–1001.
94 Hendricks S, O'connor S, Lambert M, *et al*. Contact technique and concussions in the South African under-18 Coca-Cola Craven week rugby tournament. *Eur J Sport Sci* 2015;15:557–64.
95 Burger N, Lambert MI, Viljoen W, *et al*. Tackle technique and tackle-related injuries in high-level South African rugby union under-18 players: real-match video analysis. *Br J Sports Med* 2016;50:932–8.
96 Sobue S, Kawasaki T, Hasegawa Y, *et al*. Tackler's head position relative to the ball carrier is highly correlated with head and neck injuries in rugby. *Br J Sports Med* 2018;52:353–8.
97 Hendricks S, van Niekerk T, Sin DW, *et al*. Technical determinants of tackle and ruck performance in international rugby union. *J Sports Sci* 2018;36:522–8.
98 Hendricks S, Matthews B, Roode B, *et al*. Tackler characteristics associated with tackle performance in rugby union. *Eur J Sport Sci* 2014;14:753–62.
99 Smart DJ, Gill ND, Beaven CM, *et al*. The relationship between changes in interstitial creatine kinase and game-related impacts in rugby union. *Br J Sports Med* 2008;42:198–201.
100 Coughlan GF, Green BS, Pook PT, *et al*. Physical game demands in elite rugby union: a global positioning system analysis and possible implications for rehabilitation. *J Orthop Sports Phys Ther* 2011;41:600–5.
101 Jones MR, West DJ, Harrington BJ, *et al*. Match play performance characteristics that predict post-match creatine kinase responses in professional rugby union players. *BMC Sports Sci Med Rehabil* 2014;6:38.
102 Herrington L, Horsley I. Electromyographic analysis of selected shoulder muscles during a rugby football tackle. *BMC Sports Sci Med Rehabil* 2009;1:1–7.
103 Seminati E, Cazzola D, Preatoni E, *et al*. Specific tackling situations affect the biomechanical demands experienced by rugby union players. *Sports Biomech* 2017;16:58–75.
104 Horsley IG, Herrington LC, Rolf C. Does a slap lesion affect shoulder muscle recruitment as measured by EMG activity during a rugby tackle? *J Orthop Surg Res* 2010;5:1–10.
105 Morimoto K, Sakamoto M, Fukuhara T, *et al*. Electromyographic study of neck muscle activity according to head position in rugby tackles. *J Phys Ther Sci* 2013;25:563–6.
106 Takarada Y. Evaluation of muscle damage after a rugby match with special reference to tackle plays. *Br J Sports Med* 2003;37:416–9.
107 Cunniffe B, Hore AJ, Whitcombe DM, *et al*. Time course of changes in immuneoendocrine markers following an international rugby game. *Eur J Appl Physiol* 2010;108:113–22.
108 Pointon M, Duffield R. Cold water immersion recovery after simulated collision sport exercise. *Med Sci Sports Exerc* 2012;44:206–16.
109 Takeda M, Sato T, Hasegawa T, *et al*. The effects of cold water immersion after rugby training on muscle power and biochemical markers. *J Sports Sci Med* 2014;13:616–23.
110 Hinckson EA, Hamlin MJ, Wood MR, *et al*. Game performance and intermittent hypoxic training. *Br J Sports Med* 2007;41:537–9.
111 Hamlin MJ, Hinckson EA, Wood MR, *et al*. Simulated rugby performance at 1550-m altitude following adaptation to intermittent normobaric hypoxia. *J Sci Med Sport* 2008;11:593–9.
112 Stuart GR, Hopkins WG, Cook C, *et al*. Multiple effects of caffeine on simulated high-intensity team-sport performance. *Med Sci Sports Exerc* 2005;37:1998–2005.
113 Roe G, Darrall-Jones J, Till K, *et al*. The effect of physical contact on changes in fatigue markers following rugby union field-based training. *Eur J Sport Sci* 2017;17:647–55.
114 Wundersitz DW, Gastin PB, Robertson SJ, *et al*. Validity of a trunk-mounted accelerometer to measure physical collisions in contact sports. *Int J Sports Physiol Perform* 2015;10:681–6.
115 Hendricks S, Karpul D, Nicolls F, *et al*. Velocity and acceleration before contact in the tackle during rugby union matches. *J Sports Sci* 2012;30:1215–24.
116 Hendricks S, Karpul D, Lambert M. Momentum and kinetic energy before the tackle in rugby union. *J Sports Sci Med* 2014;13:557–63.
117 Usman J, McIntosh AS, Fréchède B. An investigation of shoulder forces in active shoulder tackles in rugby union football. *J Sci Med Sport* 2011;14:547–52.
118 Pain MTG, Tsui F, Cove S. In vivo determination of the effect of shoulder pads on tackling forces in rugby. *J Sports Sci* 2008;26:855–62.
119 Tierney GJ, Simms CK. The effects of tackle height on inertial loading of the head and neck in rugby union: a multibody model analysis. *Brain Inj* 2017;31:1925–31.
120 Ashworth B, Hogben P, Singh N, *et al*. The athletic shoulder (ash) test: reliability of a novel upper body isometric strength test in elite rugby players. *BMJ Open Sport Exerc Med* 2018;4:e000365.
121 Kawasaki T, Tanabe Y, Tanaka H, *et al*. Kinematics of rugby tackling: a pilot study with 3-dimensional motion analysis. *Am J Sports Med* 2018;46:2514–20.
122 MacLeod SJ, Hagan C, Egaña M, *et al*. The use of microtechnology to monitor collision performance in professional rugby union. *Int J Sports Physiol Perform* 2018;13:1075–82.
123 Tierney GJ, Richter C, Denvir K, *et al*. Could lowering the tackle height in rugby union reduce ball carrier inertial head kinematics? *J Biomech* 2018;72:29–36.
124 Gianotti SM, Quarrie KL, Hume PA. Evaluation of RugbySmart: a rugby union community injury prevention programme. *J Sci Med Sport* 2009;12:371–5.
125 Brown JC, Gardner-Lubbe S, Lambert MI, *et al*. The BokSmart intervention programme is associated with improvements in injury prevention behaviours of rugby union players: an ecological cross-sectional study. *Inj Prev* 2015;21:173–8.
126 Hendricks S, Jordaan E, Lambert M. Attitude and behaviour of junior rugby union players towards tackling during training and match play. *Saf Sci* 2012;50:266–84.
127 Hendricks S, den Hollander S, Tam N, *et al*. The relationships between rugby players' tackle training attitudes and behaviour and their match tackle attitudes and behaviour. *BMJ Open Sport Exerc Med* 2015:1–8.
128 Cooney M, Coleman F, Flynn A. A study of the knowledge that school rugby coaches have in the management and prevention of serious neck injury. *Ir Med J* 2000;93:171–4.
129 Carter AF, Muller R. A survey of injury knowledge and technical needs of junior rugby union coaches in Townsville (North Queensland). *J Sci Med Sport* 2008;11:167–73.
130 Brown JC, Gardner-Lubbe S, Lambert MI, *et al*. Coach-directed education is associated with injury-prevention behaviour in players: an ecological cross-sectional study. *Br J Sports Med* 2018;52:989–93.

131 Hendricks S, Sarembock M, Jones B, *et al*. The tackle in South African youth rugby union – gap between coaches' knowledge and training behaviour. *Int J Sports Sci Coach* 2017;12:708–15.
132 Leung FT, Franettovich Smith MM, Hides JA. Injuries in Australian school-level rugby union. *J Sports Sci* 2017;35:2088–92.
133 Morgan R, Herrington L. The effect of tackling on shoulder joint positioning sense in semi-professional rugby players. *Phys Ther Sport* 2014;15:176–80.
134 Viljoen W, Patricios J. BokSmart - implementing a National Rugby Safety Programme. *Br J Sports Med* 2012;46:692–3.
135 Hendricks S, Lambert MI. Theoretical model describing the relationship between the number of tackles in which a player engages, tackle injury risk and tackle performance. *J Sports Sci Med* 2014;13:715–7.
136 Hendricks S, 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 SM* 2013;25:8–11.
137 Campbell PG, Peake JM, Minett GM. The specificity of rugby union training sessions in preparation for match demands. *Int J Sports Physiol Perform* 2018;13:496–503.
138 White PE, Otago L, Saunders N, *et al*. Ensuring implementation success: how should coach injury prevention education be improved if we want coaches to deliver safety programmes during training sessions? *Br J Sports Med* 2014;48:402–3.
139 Leventhal H, Singer R, Jones S. Effects of fear and specificity of recommendation upon attitudes and behavior. *J Pers Soc Psychol* 1965;2:20–9.
140 Ross L, Nisbett R. *The Person and the Situation: Perspectives of Social Psychology*. London, United Kingdom: Pinter & Martin Publishers, 2011.
141 Hertwig R, Grüne-Yanoff T. Nudging and boosting: steering or empowering good decisions. *Perspect Psychol Sci* 2017;12:973–86.
142 Hendricks S, Till K, Oliver JL, *et al*. Technical skill training framework and skill load measurements for the rugby union tackle. *Strength Cond J* 2018;40:44–59.
143 Kerr HA, Ledet EH, Ata A, *et al*. Does instructional video footage improve tackle technique? *Int J Sports Sci Coach* 2018;13:3–15.
144 Stokes D. *Pasteur's Quadrant: Basic Science and Technological Innovation*. Brookings Institution Press, 2011.
145 Jakoet I, Noakes TD. A high rate of injury during the 1995 Rugby World Cup. *S Afr Med J* 1997;87:45–7.
146 Targett SG. Injuries in professional rugby union. *Clin J Sport Med* 1998;8:280–5.
147 Doyle C, George K. Injuries associated with elite participation in women's rugby over a competitive season: an initial investigation. *Physical Therapy in Sport* 2004;5:44–50.
148 Brooks JHM, Fuller CW, Kemp SPT, *et al*. A prospective study of injuries and training amongst the England 2003 Rugby World Cup squad. *Br J Sports Med* 2005;39:288–93.
149 Holtzhausen LJ, Schwellnus MP, Jakoet I, *et al*. The incidence and nature of injuries in South African rugby players in the rugby Super 12 competition. *S Afr Med J* 2006;96:1260–5.
150 Schick DM, Molloy MG, Wiley JP, *et al*. Women's Rugby World Cup. *Br J Sports Med* 2006;2008:447–51.
151 Fuller CW, Raftery M, Readhead C, *et al*. Impact of the International rugby board's experimental law variations on the incidence and nature of match injuries in southern hemisphere professional rugby union. *S Afr Med J* 2009;99:232–7.
152 Williams S, Trewartha G, Kemp SPT, *et al*. The influence of an artificial playing surface on injury risk and perceptions of muscle soreness in elite rugby union. *Scand J Med Sci Sports* 2016;26:101–8.
153 Schwellnus MP, Jordaan E, Janse van Rensburg C, *et al*. 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* 2019;53:620–7.
154 Comstock RD, Fields SK. The fair sex? foul play among female rugby players. *J Sci Med Sport* 2005;8:101–10.
155 Schneiders AG, Takemura M, Wassinger CA. A prospective epidemiological study of injuries to new Zealand premier club rugby union players. *Phys Ther Sport* 2009;10:85–90.
156 Haseler CM, Carmont MR, England M. The epidemiology of injuries in English youth community rugby union. *Br J Sports Med* 2010;44:1093–9.
157 Archbold HAP, Rankin AT, Webb M, *et al*. RISUS study: rugby injury surveillance in Ulster schools. *Br J Sports Med* 2017;51:600–6.
158 Swain MS, Lystad RP, Henschke N, *et al*. Match injuries in amateur rugby union: a prospective cohort study - FICS Biennial Symposium Second Prize Research Award. *Chiropr Man Therap* 2016;24:1–8.
159 Leung FT, Franettovich Smith MM, Brown M, *et al*. Epidemiology of injuries in Australian school level rugby union. *J Sci Med Sport* 2017;20:740–4.
160 Sewry N, Verhagen E, Lambert M, *et al*. Trends in time-loss injuries during the 2011-2016 South African rugby youth weeks. *Scand J Med Sci Sports* 2018;28:2066–73.
161 Fuller CW, Taylor A, Molloy MG. Epidemiological study of injuries in international rugby sevens. *Clin J Sport Med* 2010;20:179–84.
115 Rizi RM, Yeung SS, Stewart NJ, *et al*. Risk factors that predict severe injuries in university rugby sevens players. *J Sci Med Sport* 2017;20:648–52.
163 Cruz-Ferreira AM, Cruz-Ferreira EM, Silva JD, *et al*. Epidemiology of injuries in Portuguese senior male rugby union sevens: a cohort prospective study. *Phys Sportsmed* 2018;46:255–61.
164 Duthie G, Pyne D, Hooper S. Time motion analysis of 2001 and 2002 Super 12 rugby. *J Sports Sci* 2005;23:523–30.
165 Deutsch MU, Kearney GA, Rehrer NJ. Time-Motion analysis of professional rugby union players during match-play. *J Sports Sci* 2006.
166 Eaton C, George K. Position specific rehabilitation for rugby union players. Part I: empirical movement analysis data. *Physical Therapy in Sport* 2006;7:22–9.
167 Quarrie KL, Hopkins WG. Changes in player characteristics and match activities in Bledisloe cup rugby union from 1972 to 2004. *J Sports Sci* 2007;25:895–903.
168 Roberts SP, Trewartha G, Higgitt RJ, *et al*. The physical demands of elite English rugby union. *J Sports Sci* 2008;26:825–33.
169 Austin D, Gabbett T, Jenkins D. The physical demands of Super 14 rugby union. *J Sci Med Sport* 2011;14:259–63.
170 van Rooyen KM. A statistical analysis of tackling performance during international rugby union matches from 2011. *Int J Perform Anal Sport* 2012;12:517–30.
171 Hendricks S, Roode B, Matthews B, *et al*. Defensive strategies in rugby union. *Percept Mot Skills* 2013;117:65–87.
172 Villarejo D, Palao JM, Toro EO. Match profiles for establishing position specific rehabilitation for rugby union players. *Int J Perform Anal Sport* 2013;13:567–71.
173 van Rooyen M, Yasin N, Viljoen W. Characteristics of an 'effective' tackle outcome in Six Nations rugby. *Eur J Sport Sci* 2014;14:123–9.
174 Lindsay A, Draper N, Lewis J, *et al*. Positional demands of professional rugby. *Eur J Sport Sci* 2015;15:480–7.
175 Villarejo D, Palao J-M, Ortega E, *et al*. Match-related statistics discriminating between playing positions during the men's 2011 Rugby World Cup. *Int J Perform Anal Sport* 2015;15:97–111.
176 Brown JC, Boucher SJ, Lambert M, *et al*. Non-sanctioning of illegal tackles in South African youth community rugby. *J Sci Med Sport* 2018;21:631–4.
177 Suarez-Arrones L, Arenas C, López G, *et al*. Positional differences in match running performance and physical collisions in men rugby sevens. *Int J Sports Physiol Perform* 2014;9:316–23.
178 Ross A, Gill ND, Cronin JB. A comparison of the match demands of international and provincial rugby Sevens. *Int J Sports Physiol Perform* 2015;10:786–90.
179 Ross A, Gill N, Cronin J. The match demands of international rugby sevens. *J Sports Sci* 2015;33:1035–41.