The relationship between tackle technique and external load of a simulated tackle

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Thesis abstract

Background: Monitoring players in training and matches is important to ensure players are adequately prepared for competition demands, reducing injury risk and enhancing performance. In contact sports, collision monitoring however, remains a challenge. These challenges include how to quantify the demand of specific collision events such as the tackle, and how such quantities relate to the technical aspects of the event. Coaches play an essential role in the monitoring process, however, the research on coaches in collision sports is not well understood.

Objectives: The aim of this thesis is three-fold: (1) In chapter 2, the aim is to review and synthesise the current literature that quantifies collisions in rugby union and rugby sevens, (2) in chapter 3, the aim is to synthesise the current sport science and medicine literature on rugby union, rugby league, rugby sevens coaches, and (3) in chapter 4, the aim is to investigate the relationship between tackle technique and external load of a simulated tackle.

Methods: For chapter 2, a systematic review and meta-analysis was completed on the frequency and intensity of collisions in rugby union and rugby sevens. For the third chapter, a scoping review was completed on coach/coaching research in rugby union, rugby league, rugby sevens. For chapter 4, 20 players performed 12 tackles (6 tackles over 2 sessions). Each tackle was recorded by three cameras and a triaxial accelerometer housed in a player unit for analysis. Following the data collection, the tackles were split into three categories – low, medium, and high scoring tackles based on their tackle technique.

Results: Seventy-three studies (n = 73) were included in the final systematic review for chapter 2, with fifty-eight studies (n = 58, 79%) focusing on rugby union, and fifteen studies (n = 15, 21%) exploring rugby sevens. In rugby union, on average, a total of 22.0 (19.0 – 25.0 95%CI) scrums, 116.2 (62.7 – 169.7 95%CI) rucks, and 171.2 (140.5 - 201.8 95%CI) tackles occur per match. In sevens, on average 1.8 (1.7 – 2.0 95%CI) scrums, 4.8 (0 – 11.8 95%CI) rucks and 14.1 (0 – 32.8 95%CI) tackles occur per match. In chapter 3, a total of one hundred and one articles (n = 101) were included in the final review, which included a sum of 4233 participating coaches. The three main themes identified were Coach knowledge (n = 68, 68%), Coach pedagogies (n = 29, 29%) and Coach development (n = 4, 4%). For the study chapter, Power of the shoulder and *PlayerLoad*^{TM} at contact were significantly higher at contact for higher scoring tackles (low scoring tackles: 7.9 (5.3 - 10.5 95%CI) kW versus high scoring tackles: 27.8 (11.36 - 44.3 95%CI) kW). *PlayerLoad*^{TM} at contact also had the highest relative importance for tackle technique (Gini index: 25.4).

Conclusion: Per minute, rugby sevens players performed more tackles than rugby union players and forwards experienced more impacts and tackles than backs. The frequency and intensity of collisions in training and matches may lead to adaptations for a "collision-fit" player and lend itself to general training principles such as periodisation for optimum collision adaptation. When analysing the coaches' research, there is a positive trend in coach's knowledge of injuries, specifically concussions. Moving forward, continual practical educational input should be provided for our coaches to protect the welfare of our rugby players. Another finding was a shift from coach-centred learning to player-centred learning. Although, coaches are reluctant for this change it helps develop players to make their own decisions and read the game for themselves. When comparing differences in external load and tackle technique, the results suggest that players in the optimum position in the tackle at contact is suggested to produce more *power of the shoulder and PlayerLoad*™. Although, players produce higher force in the lower scoring tackles, it can be suggested that they are not executing the force in the correct way or place. *PlayerLoad*™ has been shown to be an important variable when monitoring tackle technique. Using external load measurements along with tackle technique assessments allows coaches to understand the dynamic nature of the tackle further resulting in the ability to optimise tackle training, monitor contact and preparing players for competition.

Acknowledgments

Dr Sharief Hendricks, thank you for all the patience, guidance, and support throughout my master's degree. I could not have picked a better supervisor. You go above and beyond for your students and I am very thankful for that. I am honoured to have worked and learnt from you throughout these years and will continue to in the future.

Catapult Sports, thank you for the use of your devices. Gordon Rennie, thank you for your guidance on the Catapult device and the variables we used.

Dr Amir Patel and Zubair Martin, thank you for all your support, help and data production throughout this thesis. There would be a big section of this thesis missing without your hard work.

I would like to acknowledge the University of Cape Town, and National Research Foundation (NRF) for the funding and support for this thesis. Without their financial support this thesis would not be possible.

To my family and friends, thank you for the support and putting up with my stress these last few years. To my parents and Brad Massardo, you are the best support system and thank you for the continual unconditional love and support. To my parents specifically, I dedicate this thesis to you.

Lastly, I would like to acknowledge my department, Division of Physiological Sciences. This department is the best environment to work in. I appreciate every smile and word of advice that I received along the way.

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Glossary

External or internal load: A physical or psychological stimulus experienced by players prior to, during and after participation of a training session or competition. Load creates a demand or stress (both physiological and psychological) and has internal and external components (1). External load are objective measures of the work performed by the player during training or matches whereas internal training can be defined as the relative biological (both physiological and psychological) stressors imposed on the athlete during training or matches (2).

Monitor: Monitoring athletes is measuring objective and subjective markers to assess the player's well-being and guide training and to detect any progression towards negative health outcomes and associated poor performance (3).

PlayerLoad™: *PlayerLoad™* is calculated as a modified vector magnitude, expressed as the square root of the sum of the squared instantaneous rate of change in acceleration, also known as jerk, in each of the three vectors - X, Y and Z axis - and divided by 100 (4–7).

Contact load: Physical stimulus experienced by players prior to, during and after contact activity specifically. Contact load creates a demand or stress (both physiological and psychological) and has internal and external components.

Collision: Collisions were broadly defined as any physical contact made with another player (teammate or opposition), which resulted in an alteration to the players momentum. This included collisions such as the tackle (tackling and being tackled), scrums, rucks and mauls (6,8). The terms 'collisions' and 'contacts' were used interchangeably through the thesis.

Chapter 1: Introduction and Scope of Thesis

1.1 Overview of rugby football

Rugby union is one of the most popular collision sports in the world, consisting of 9.6 million players (9). There are many different cohorts that fall under rugby football such as rugby union, rugby sevens and rugby league. Although these cohorts differ in rules, number of players and duration, they all are invasion sports characterized by frequent collisions and high-speed running (10,11). These collisions are a major component in rugby union and include rucks, scrums, mauls and tackles (12). The tackle is the most frequent collision in rugby union, rugby league and rugby sevens (13–15).

1.2 The tackle

The tackle can be defined as "any event where one or more tacklers (player or players making the tackle) attempt to stop or impede the ball-carrier (player carrying the ball) whether or not the ball carrier was brought to ground" (16,17). Understandably, due to its frequency, and dynamic and explosive nature, the tackle is the largest contributing event to rugby's high injury incidence and burden (18–21). For example, in senior professional male rugby union players, 29.0 injuries per 1000 player hours occur when being tackled, 19.0 injuries per 1000 player hours occur when tackling and 17.0 injuries per 1000 player hours occur in the ruck/maul (22). Although the tackle has a high injury incidence, winning the tackle is essential for team success (23). For instance, completing more tackles is a key performance indicator for winning the match (23). Despite the tackle being a key performance indicator and a high-risk injury event, not much is known about how we train, monitor and coach the tackle.

1.3 Proper tackle technique improves performance and safety

Poor tackle technique has been associated with an increase in risk of tackle injury and a decrease in tackle performance (13,16,24). In the literature, tackling technique has been analysed using the qualitative approach where a player's technique is scored using a list of observable actions that represents the model form of the movement, which were derived in training manuals and guidelines for coaches. That is, the technical criteria are currently used to coach the tackle. When scoring a player's technical proficiency, the player is either awarded one point if the action is performed correctly or zero points for an incorrect action throughout the tackle (16). The tackle event is also split into different phases – the preparation phase (pre-contact), the action phase (contact), and the follow through (post-contact). Each phase has a list of observational actions the ball carrier or tackler needs to perform to execute a correct, safe tackle. Using this technique scoring approach, studies have shown differences between injured and non-injured players, head impact events, playing levels and performance (25). To safely and effectively engage in the tackle, it is understood that both technique and physical conditioning are required (25). As such, studies in rugby union and rugby league have

also investigated the relationship between tackling proficiency and players physical qualities (26) and how tackling techniques changes during a fatigued state (27,28). Indeed, the tackle is a technical-physical contest. In 2020, Burger et al. (2020) also mentions the concept of contact efficiency. Contact efficiency refers to players who are highly technically proficient and therefore require minimal physical effort to succeed in the tackle (29). To date however, the physical external loads of different technical proficiency profiles have not been studied. Physical external load can be defined as objective measures of the work performed by the player such as speed or acceleration (1,2).

1.4 Monitoring contact load

To improve players performance and reduce injury risk, monitoring the training and match load has become an essential practice within high performance rugby (30–32)**.** These loads are divided into internal and external loads. External load are objective measures of the work performed by the player during training or matches (i.e., speed, acceleration), whereas internal load can be defined as the relative biological (both physiological and psychological) stressors imposed on the athlete during training or matches (i.e., heart rate, ratings of perceived exertion (RPE)) (2). Generally speaking, monitoring to date is largely focused on non-contact demands (33), however there has been a recent shift towards the monitoring of collisions in contact sports. For example, recently, World Rugby has proposed contact guidelines where players should be engaging in full contact training for 15 minutes, controlled contact for 40 minutes and live set piece training for 30 minutes a week (34). For such contact guidelines to be fulfilled, proper collision load monitoring is required. However, how collisions are quantified and what is known about these quantities in training and matches is not well understood.

1.5 Tackle-collision sport coaches

A key role player in the practice of monitoring, especially collision load monitoring, is the coach. The coach is responsible for creating a positive environment that fosters learning and player well-being (35). On the field, coaches provide players with the appropriate training stimulus to ensure players are mentally and physically prepared for competition, and optimally challenged to enhance their technical skill learning (36–38). Considering the high risk of tackle injury, tackle-collision sports have also targeted the coach as an important stakeholder in injury and concussion prevention (35). With the goal of preventing injury, improving performance, or developing the player (or a combination thereof), the research within tackle-collision sports to date have only been synthesised for player-focused studies. Coach-focused studies on the other hand, have not been consolidated and synthesised in a meaningful way to inform coaching practice and policy.

1.6 Objectives

The aim of this thesis is three-fold:

1) To synthesise the collision frequencies and intensities for rugby union and rugby sevens based on video-based analysis and microtechnology;
2) To synthesise the current literature on rugby union, rugby league and rugby sevens coaches; and
3) To investigate the relationship between tackle technique and external load of a simulated tackle.

Chapter 2: Quantifying Collision Frequency and Intensity in Rugby Union and Rugby Sevens: A Systematic Review

Published version

Paul L, Naughton M, Jones B, Davidow D, Patel A, Lambert M, et al. Quantifying Collision Frequency and Intensity in Rugby Union and Rugby Sevens: A Systematic Review. Sport Med - Open. 2022;8(1). https://doi.org/10.1186/s40798-021-00398-4

2.1 Introduction

Rugby union and rugby sevens are invasion team sports that are characterised by frequent high-speed running and physical collisions (10,11). Although the two rugby codes differ in match duration (rugby sevens = 14 min; rugby union = 80 min) and player numbers (rugby sevens = 7 players; rugby union = 15 players) (12,39–41), the type of collisions are similar (i.e., tackles, scrums, rucks and mauls) (12). Winning these collisions is associated with overall team success and player performance (23,42,43). For example, Ortega et al. (2009) identified that winning teams complete more tackles than losing teams (23). These collisions are also physically and technically demanding for players with an associated high injury incidence and burden (injury incidence rate X mean severity) (18,19,21,44). For instance, in senior professional male rugby union players, 29.0 injuries per 1000 player hours occur when being tackled, 19.0 injuries per 1000 player hours occur when tackling and 17.0 injuries per 1000 player hours occur in the ruck/maul (22). In rugby sevens, 40.4 injuries per 1000 player hours occur when tackling, with 1.2 injuries per 1000 player hours occurring in the mauls and scrums (45).

Given the high injury incidence and burden, and the positive performance outcomes associated with winning collisions in rugby union and sevens, it is important for coaches and practitioners to adequately prepare players for competition. To do this, they need to know the frequency and intensity of these collisions in both training and matches (37). In matches and training, the frequency and intensity of collisions have been quantified primarily using two methods: video-based analysis and microtechnology. Quantifying the frequency and intensity of collisions using video-based analysis requires the systematic observation and interpretation of video from matches and/or training (17,46). Analysing collisions can occur while the matches or training session(s) are underway, although most detailed analyses occur post-match (46). Previously, video-based analysis was the main method used to quantify collisions in both rugby cohorts (46). Quantifying collisions in this manner, however, is based on human observation, and as such, it is labour intensive and requires reliability checking to reduce bias and subjectivity (37). For these reasons, a shift to automated methods of collecting collision data through the use of microtechnology has occurred.

In sport, microtechnology typically incorporates GPS and micro-electrical mechanical systems (MEMs) that capture the external physical demands of competition and training (33). Commercially available microtechnology devices for team sports are designed to be unobstructive, so players can wear them during competition and training. One of the first studies using microtechnology to determine physical demands in rugby union was published in 2009 (47), and since then, research using these devices has grown (33). Initially, GPS was only used to provide information on distance and speed (48,49). Since then, MEMs have been built into GPS devices which now house triaxial accelerometers, gyroscopes and magnetometers (49). Triaxial accelerometers measure acceleration in three different axes

(anterior–posterior, medial–lateral and vertical) (37,49), and the sum of the acceleration in these three axes provides a vector magnitude (g force). This vector magnitude can be used to quantify the intensity of the collision (33,49). Each manufacturer has a different algorithm that is used to quantify collisions (50). As a consequence, validating collision metrics for these devices has been challenging (50). Although quantifying collisions using microtechnology may be more time efficient than video-based methods, the validity and reliability of microtechnology in rugby union and rugby sevens requires further investigation (37,51) due to the ambiguity in the current results (52).

To benefit coaches and practitioners, and aid injury prevention and injury management strategies, a synthesis of the frequency and intensity of collisions in rugby union and rugby sevens to date, both in training and matches, is required. For example, a coach who understands the positional match tackle frequencies and intensities can optimise tackle training sessions to meet those position specific match demands. Since one of the roles of coaches and practitioners is to ensure positive adaptations to training and reduce maladaptation, understanding the frequency and intensity of collisions may also aid optimising recovery between training and matches. Therefore, the aim of this systematic review to synthesise the collision frequencies and intensities for rugby union and rugby sevens based on video-based analysis and microtechnology.

2.2 Methods

2.2.1 Search Strategy

The search strategy was based on a similar systematic review in rugby league (37). The current systematic review was carried out in accordance with the PRISMA guidelines (53). The search was conducted from 1 January 1990 to 1 September 2021 on four different electronic databases (PubMed, Scopus, SPORTDiscus and Web of Science). The search used the following combined key terms for collisions ('tackl*' OR 'collision' OR 'impact*') AND ('dose' OR 'frequency' OR 'intensity' OR 'demands') AND rugby union ('rugby' OR 'rugby union' OR 'rugby sevens'). For example, in PubMed the search was (((tackl* OR collision OR impact* OR collisions)) AND (dose OR frequency OR intensity OR demands)) AND (rugby OR rugby union OR rugby sevens). The reference list of the final full-text articles (n = 73) were also examined.

2.2.2Selection of Studies

After consolidating the studies from the different electronic databases, LP removed the duplicates and screened the titles and abstracts (Figure 2.1) for eligibility before retrieving the full text (53). The review was registered with PROSPERO (registration number: CRD42020191112). The full text articles were further screened for eligibility by LP and MN. Any discrepancies in the screening process were discussed until agreed upon. A third researcher was available if consensus on the inclusion of an article

could not be reached; however, this was not required. The inclusion criteria were (i) any publication that quantified collisions in terms of frequency or intensity in rugby union and/or rugby sevens (ii) study participants within each study had to be over 18 years of age. When collisions were based on 'impact metrics', only impacts > 8 g were included in the data to eliminate possible confusion with running demands (i.e., high intensity accelerations or decelerations) unless stated otherwise (52). Publications from conferences and annual meetings were excluded. Only peer-reviewed publications were included. Any publication that could not be translated into English was excluded. Authors were contacted for detailed information if necessary. The final full-text articles went through the data extraction process.

Collisions were broadly defined as any physical contact made with another player (teammate or opposition), which resulted in an alteration to the player's momentum. This included collisions such as the tackle (tackling and being tackled), scrums, rucks and mauls (6,8). For this review the studies did not need to have a definition to be included.

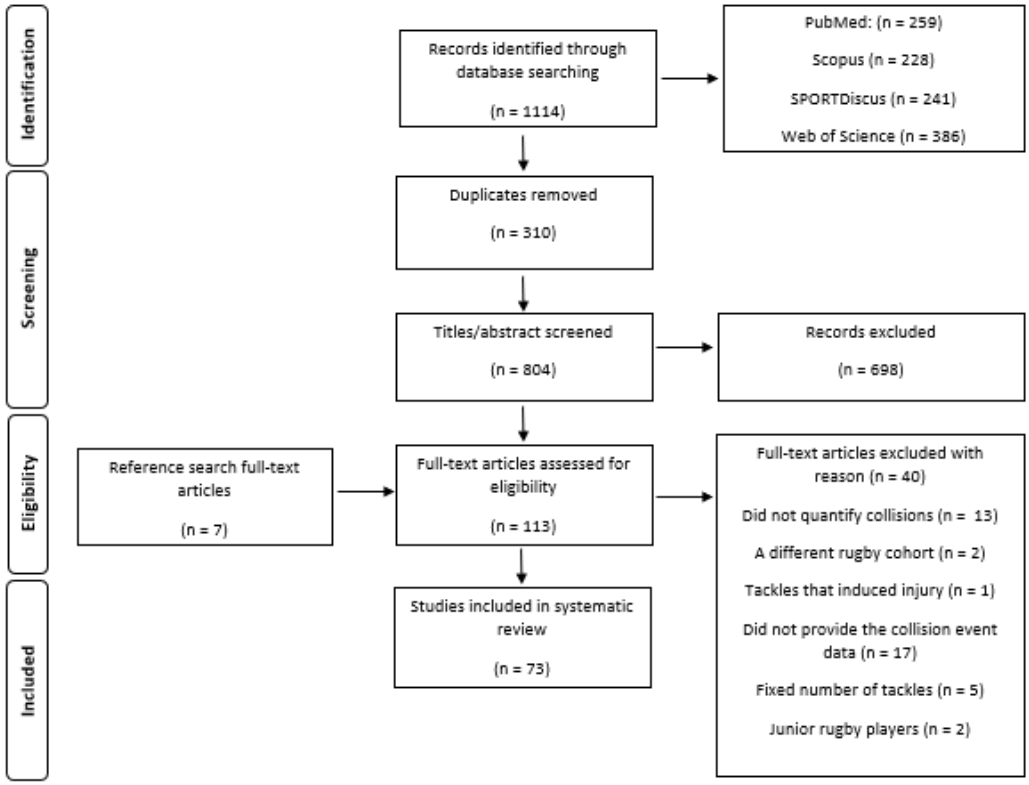

Figure 2.1 *Literature selection process for the systematic review*

2.2.3 Data Extraction

Data relating to participant characteristics (i.e., number, age, height, weight, level of competition, sex, cohort), context (i.e., match play or training), method used to quantify the collisions (i.e., video or microtechnology), the model and specifics of the device (i.e., Sampling rate, inertial sensors, number of files, software), video-based analysis characteristics (i.e., camera system, number of cameras, location of the devices and software), and collision characteristics were extracted from the final 73 full-text articles. Collision characteristics included type of collision, number of matches or training sessions, year of competition, absolute frequency (number), collisions in relation to playing time (number of collisions per minute) and the intensity of each collision. Collision intensity was commonly classified as *very heavy* (8–10 g), *severe* (> 10 g) or *another range* that was specific to the device based on the nature of the collision (54).

2.2.4 Assessment of Methodological Quality

The quality of the included studies was assessed using the checklist of Downs and Black's assessment of methodological quality (55). Questions 5, 8, 9, 13–15, 19, 21–28 were inapplicable due to the nature of the studies. The assessment was done by LP and MN (Additional file 1: Table S1). No studies were eliminated based on the methodological quality.

2.2.5 Data Analysis

All data were reported in the tables as mean ± standard deviation (SD) unless stated otherwise. Where possible, a meta-analysis (OpenMeta[Analyst]) was completed to produce a pooled mean and 95% confidence intervals (95%CI). An analysis was only conducted if there were at least two studies with mean and standard deviations. The DerSimonian-Laird continuous random-effects analysis method was used for the meta-analysis, with *I*-squared (*I*^2) used to assess the heterogeneity of the data. *I*^2 of 0–40% was considered low heterogeneity, 40–75%: moderate heterogeneity and > 70% was considered high heterogeneity (37). The forest plots (mean and 95% CI) presented the results of the meta-analysis.

2.3 Results

2.3.1 Identification of Studies

The literature search captured 1114 papers (Figure 2.1). After the screening process, 73 publications were included in the final review (13,20,54,56–64,38,65–74,39,75–84,41,85–94,42,95–104,47,105–114,50,115–117,51,52).

2.3.2 Study Characteristics

In total, 6212 participants were recorded throughout the seventy-three studies (Table 2.1). Fifteen studies explored rugby sevens (21%) (39,41,90,92–94,100,59–62,70,74,83,85) while fifty-eight studies investigated rugby union (79%) (13,20,57,58,63–69,71,38,72,73,75–82,42,84,86–89,91,95–98,47,99,101–109,50,110–117,51,52,54,56). Four studies (5%) focused on training (three in rugby union (57,102,112) and one in rugby sevens (70)), while two studies investigated training and matches in rugby union (4%) (38,66) and one in rugby sevens (1%) (74).

The other sixty-six studies (90%) focused on match-play only (13,20,56,58–65,67,39,68,69,71–73,75–79,41,80–89,42,90–99,47,100,101,103–110,50,111,113–117,51,52,54). The studies included, provincial (n = 10, % = 14), national (n = 8, % = 11), international (n = 38, % = 52), professional (n = 14, % = 19), experienced (n = 1, % = 1), novice (n = 4, % = 6) and collegiate players (n = 1, % = 1). Studies were recorded from the Super Rugby competition (54,56,65,67,72,73,78,82,95,97), Six Nations Championship (42,58,110), English Premiership (13,69,71,91), World Rugby Sevens World Series (39,74,94), Bledisloe Cup (86), Pro14 (50), and the Rugby World Cup (114,115).

Twenty-four studies used microtechnology as a method to record collision demands (33%) (47,54,76,81,82,84,85,98,99,102–104,57,105,106,113,117,59,60,62,66,70,71,74) and thirty-seven studies used video-based analysis (51%) (13,20,68,69,72,73,77,78,80,83,86,87,39,88,91–97,101,107,41,108–111,114–116,42,56,58,64,65,67) (Table 2.1). Twelve studies used both microtechnology and video-based analysis to capture collision demands (16%) (38,50,100,112,51,52,61,63,75,79,89,90). Seven studies (21%) used the GPSports' SPI Pro device (54,63,103–105,112,113) and GPSports' SPI HPU (38,59–62,66,82), 18% used Catapult Minimax S4 (57,70,75,76,79,81) and 12% used the StatSports GPS technology (52,71,84,106). Specifics of both the microtechnology device and software used are provided in Additional file: Table S2.2. Similarly, camera specifics and the video-based analysis system used can be found in Additional file: Table S2.3.

Table 2.1. *Characteristics of studies that were included.*

Study: Author (year)	Number of participants	Male or Female:	Participant competition level	Age (years): Mean±SD	Height (cm): Mean±SD	Body mass (kg): Mean±SD	Method of data capture:	Cohort:	Match-play/Training or both:
Austin et al. (2011) (56)	20	NR	Super 14	Front row forwards: 23 ± 2 Back row forwards: 26 ± 3 Inside backs: 22 ± 1 Outside backs: 24 ± 3	Front row forwards: 183 ± 2 Back row forwards: 183 ± 4 Inside backs: 179 ± 6 Outside backs: 182 ± 4	Front row forwards: 144 ± 4 Back row forwards: 103 ± 9 Inside backs: 87 ± 3 Outside backs: 100 ± 12	Video	Rugby union	Match-play
Bradley et al. (2015) (57)	44 (24 forwards, 20 backs)	NR	Elite	21 – 34	Forwards: 189±0.6 Backs: 183±0.5	Forwards: 110.1 ± 6.1 Backs: 92.1 ± 7	Microtechnology	Rugby union	Training
Bradley et al. (2017) (58)	NR	NR	Six Nation Championship	NR	NR	NR	Video	Rugby union	Match-play
Campbell et al. (2017) (38)	32	Male	Premier Grade Club	24 ± 4	177 ± 10	88 ± 20	Microtechnology and video	Rugby union	Both
Clarke et al. (2015) (59)	12 National 10 State	Female	State and National	National: 22.3 ± 2.5 Sate: 24.4 ± 4.3	National: 167 ± 0.4 State: 167 ± 0.3	National: 65.8 ± 4.6 State: 66.1 ± 7.9	Microtechnology	Sevens	Match-play
Clarke et al. (2015) (60)	12 National 10 State	Female	State and National	National: 22.3 ± 2.5 Sate: 24.4 ± 4.3	National: 167 ± 0.4 State: 167 ± 0.3	National: 65.8 ± 4.6 State: 66.1 ± 7.9	Microtechnology	Sevens	Match-play
Clarke et al. (2016) (61)	12 males 12 females	Male and Female	International	Male: 24.1 ± 3.2 Female: 22.8 ± 3.6	Male: 184 ± 0.8 Female: 169 ± 0.2	Male: 92 ± 6.9 Female: 68.6 ± 4.4	Microtechnology and video	Sevens	Match-play
Clarke et al. (2017) (62)	64	Male and Female	Domestic and international	NR	Senior Male: 181 ± 0.5 Elite Male: 184 ± 0.7 Senior Female: 170 ± 0.7 Elite Female: 169 ± 0.2	Senior Male: 88.5 ± 10.2 Elite Male: 92 ± 6.9 Senior Female: 70.4 ± 9.3 Elite Female: 68.6 ± 4.4	Microtechnology	Sevens	Match-play
Coughlan et al. (2011) (63)	2 (one forward, one back)	NR	International	30	Forward: 198 Back: 181	Forward: 111.8 Back: 94.9	Microtechnology and video	Rugby union	Match-play
Cunniffe et al. (2009) (47)	3	NR	Elite	25 ± 3.6	193.3 ± 9.7	104.6 ± 10.4	Microtechnology	Rugby union	Match-play
Deutsch et al. (1998) (64)	24	Male	Under 19	18.4 ± 0.5	185 ± 7	8.7 ± 9.9	Video	Rugby union	Match-play
Deutsch et al. (2007) (65)	Forwards: 16 Backs: 13	NR	Super 12	NR	NR	NR	Video	Rugby union	Match-play

Dubois et al. (2020) (66)	14 Forwards: 6 Backs: 8	NR	Professional	26.9 ± 1.9	185 ± 7.9	97.6 ± 13.2	Microtechnology	Rugby union	Both
Duthie et al. (2005) (67)	47	NR	Super 12	NR	NR	NR	Video	Rugby union	Match-play
Eaton et al. (2006) (68)	35	NR	Professional	20 - 34 years	NR	NR	Video	Rugby union	Match-play
Fuller et al. (2007) (13)	645	NR	English Premiership	NR	NR	NR	Video	Rugby union	Match-play
Fuller et al. (2008) (69)	645	NR	English Premiership	NR	NR	NR	Video	Rugby union	Match-play
Gibson et al. (2015) (70)	12	Male	International	27.8 ± 3.9	177.8 ± 5.9	81 ± 8.3	Microtechnology	Sevens	Training
Grainger et al. (2018) (71)	38	NR	English Premiership	26.4 ± 4.7	182.3 ± 30.2	100 ± 11	Microtechnology	Rugby union	Match-play
Hendricks et al. (2013) (72)	NR	NR	Super 14	NR	NR	NR	Video	Rugby union	Match-play
Hendricks et al. (2014) (73)	NR	NR	Super 14	NR	NR	NR	Video	Rugby union	Match-play
Hendricks et al. (2018) (42)	NR	NR	Six Nations and Championship	NR	NR	NR	Video	Rugby union	Match-play
Hendricks et al. (2019) (39)	NR	NR	Rugby Sevens World Series	NR	NR	NR	Video	Sevens	Match-play
Higham et al. (2014) (41)	196	Male	International	NR	NR	NR	Video	Sevens	Match-play
Higham et al. (2016) (74)	42	Male	International (World Rugby Sevens World Series and Federation of Oceania Rugby Unions Oceania Sevens Championship)	Forwards: 21.6 ± 2.4 Backs: 21 ± 2.2	Forwards: 185 ± 0.5 Backs: 181 ± 0.6	Forwards: 95.8 ± 6.7 Backs: 86.2 ± 5.6	Microtechnology	Sevens	Both
Jones et al. (2014) (75)	28	Male	European Cup	Forwards: 26.7 ± 2.8 Backs:23.4 ± 2.6	NR	Forwards: 111.6 ± 5.7 Backs: 94.2 ± 7.9	Microtechnology and video	Rugby union	Match-play
Jones et al. (2015) (76)	33	NR	Professional	25 ± 4	NR	104 ± 10.6	Microtechnology	Rugby union	Match-play
Lacome et al. (2016) (77)	375	Male	International	NR	NR	NR	Video	Rugby union	Match-play
Lindsay et al.	37	NR	Super 15	Front row: 26.6 ± 3.7	Front row: 186 ± 0.4	Front row: 112.1 ± 5.1	Video	Rugby union	Match-play

(2015) (78)				Locks: 23.7 ± 2.1 Loose forwards: 27 ± 4.4 Inside Backs: 27.5 ± 2.7 Outside Backs: 25.8 ± 1.3	Locks: 201 ± 0.5 Loose forwards: 188 ± 0.4 Inside Backs: 181 ± 0.2 Outside Backs: 189 ± 0.5	Locks: 112.3 ± 3.5 Loose forwards: 106.5 ± 2.3 Inside Backs: 92.9 ± 3 Outside Backs: 106.3 ± 13.7			
Lindsay et al. (2017) (79)	37	NR	Professional	26 ± 3.5	186 ± 0.7	104.5 ± 9.3	Microtechnology and video	Rugby union	Match-play
MacLeod et al. (2018) (52)	37	Male	Professional	27.9 ± 3.6	185.4 ± 7	103.1 ± 12.1	Microtechnology and video	Rugby union	Match-play
McIntosh et al. (2010) (80)	NR	NR	Club Level	NR	NR	NR	Video	Rugby union	Match-play
McLaren et al. (2015) (81)	28 Forwards: 15 Backs: 13	Male	Professional	27 ± 4	187 ± 8	101 ± 14	Microtechnology	Rugby union	Match-play
McLellan et al. (2013) (54)	5	Male	Super 15	Forwards: 23 ± 0.2 Backs: 22.3 ± 1.5	Forwards: 193 ± 6.1 Backs:187 ± 1.2	Forwards: 116 ± 1.4 Backs: 93.7 ± 1.5	Microtechnology	Rugby union	Match-play
Owen et al. (2015) (82)	33	Male	Super 14	25.2 ± 3.5	179.8 ± 33	101.2 ± 13.2	Microtechnology	Rugby union	Match-play
Peeters et al. (2019) (83)	15	Male	Elite	25.8 ± 3.6	182 ± 1	88.9 ± 13.5	Video	Sevens	Match-play
Pollard et al. (2018) (84)	22	Male	International	27 ± 2.9	187 ± 7	106.1 ± 14.1	Microtechnology	Rugby union	Match-play
Portillo et al. (2016) (85)	16	Female	National	23 ± 2	166 ± 7	66 ± 7	Microtechnology	Sevens	Match-play
Quarrie et al. (2007) (86)	NR	NR	Bledisloe Cup	NR	NR	NR	Video	Rugby union	Match-play
Quarrie et al. (2008) (87)	NR	NR	Professional	NR	NR	NR	Video	Rugby union	Match-play
Quarrie et al. (2012) (88)	763	NR	National	NR	NR	NR	Video	Rugby union	Match-play
Reardon et al. (2017) (51)	36	NR	Elite	Forwards: 27.2 ± 3.9 Backs 26.4 ± 5.1	Forwards: 188 ± 0.8 Backs: 181 ± 0.4	Forwards: 111.6 ± 9 Backs: 92 ± 7.4	Microtechnology and video	Rugby union	Match-play
Reardon et al. (2017) (89)	39	NR	Elite	27.2 ± 3.9	185 ± 4.3	99.2 ± 24.4	Microtechnology and video	Rugby union	Match-play
Reyneke et al. (2018) (90)	15	Female	International	24.3 ± 3.9	168 ± 7.1	67.5 ± 6.3	Microtechnology and video	Sevens	Match-play

Roberts et al. (2008) (91)	29 Forwards: 14 Backs: 15	NR	English Premiership	NR	NR	NR	Video	Rugby union	Match-play
Roberts et al. (2014) (20)	NR	Male	English community level (3 - 9)	NR	NR	NR	Video	Rugby union	Match-play
Ross et al. (2015) (92)	84	NR	International and Provincial	NR	NR	NR	Video	Sevens	Match-play
Ross et al. (2015) (93)	27	Male	International	Forwards: 24.4 ± 3.3 Backs:23.3 ± 2.9	Forwards: 188 ± 4.8 Backs: 183 ± 4.2	Forwards: 95.4 ± 6.3 Backs: 89.7 ± 5.9	Video	Sevens	Match-play
Ross et al. (2016) (94)	NR	NR	IRB Sevens World Series	NR	NR	NR	Video	Sevens	Match-play
Schoeman et al. (2015) (95)	15	NR	Super Rugby	NR	NR	NR	Video	Rugby union	Match-play
Smart et al. (2008) (96)	23	Male	New Zealand National Provincial Championship	25 ± 3	184 ± 9	99.2 ± 10.1	Video	Rugby union	Match-play
Smart et al. (2014) (97)	510	NR	Super 14	NR	NR	NR	Video	Rugby union	Match-play
Suarez-Arrones et al. (2012) (98)	9	NR	National	25.9 ± 4	181.5 ± 6.2	90.8 ± 4.8	Microtechnology	Rugby union	Match-play
Suarez-Arrones et al. (2013) (99)	8	Woman	National	Forwards: 26.6 ± 1.9 Backs: 27 ± 2.6	Forwards: 173.8 ± 5.9 Backs: 170 ± 2.3	Forwards: 76.8 ± 10.4 Backs: 68 ± 3.6	Microtechnology	Rugby union	Match-play
Suarez-Arrones et al. (2014) (100)	10	Male	National	27.4 ± 1.6	180.4 ± 7.8	87.9 ± 11	Microtechnology and video	Sevens	Match-play
Takarada (2003) (101)	14	NR	Elite	23 - 30	179.8 ± 1	87.4 ± 2.2	Video		Match-play
Takeda et al. (2014) (102)	20	Male	Collegiate	20 ± 0.6	174 ± 0.5	85.4 ± 2	Microtechnology	Rugby union	Training
Tee et al. (2015) (103)	19	NR	Professional	26 ± 2	186 ± 0.7	101.5 ± 12.2	Microtechnology	Rugby union	Match-play
Tee et al. (2017) (104)	19	NR	Professional	26 ± 2	186 ± 0.7	101.5 ± 12.2	Microtechnology	Rugby union	Match-play
Tee et al. (2020) (105)	19	NR	Professional	26 ± 2	186 ± 0.7	101.5 ± 12.2	Microtechnology	Rugby union	Match-play

Tierney et al. (2020) (50)	44		Guinness PRO14	25.7 ± 3.9	187.0 ± 7.6	102.6 ± 12.0	Microtechnology and video	Rugby union	Match-play
Tierney et al. (2021) (106)	118	Male	Elite	24.7 ± 4.1	186.5 ± 7.0	101.6 ± 12.2	Micotechnology	Rugby union	Match-play
Tucker et al. (2017) (107)	NR	NR	International and National	NR	NR	NR	Video	Rugby union	Match-play
Van Rooyen et al. (2008) (108)	10	NR	Professional	23 ± 3	184 ± 8	99 ± 15	Video	Rugby union	Match-play
Van Rooyen et al. (2012) (109)	NR	NR	International	NR	NR	NR	Video	Rugby union	Match-play
Van Rooyen et al. (2014) (110)	NR	NR	Six Nations	NR	NR	NR	Video	Rugby union	Match-play
Vaz et al. (2010) (111)	NR	NR	International Rugby Board competitions and Super 12	NR	NR	NR	Video	Rugby union	Match-play
Vaz et al. (2012) (112)	40	NR	Experienced and novice	21.6 ± 3.6	177.7 ± 7.4	81.2 ± 10.2	Microtechnology and video	Rugby union	Training
Venter et al. (2011) (113)	17	Male	Provincial	18.5 ± 0.5	183 ± 6	89.8 ± 10.8	Microtechnology	Rugby union	Match-play
Villarejo et al. (2013) (114)	626	NR	Rugby World Cup	NR	NR	NR	Video	Rugby union	Match-play
Villarejo et al. (2015) (115)	736	Male	Rugby World Cup	NR	NR	NR	Video	Rugby union	Match-play
Virr et al. (2014) (116)	38	Female	Premier division club level	24.1 ± 4	168.7 ± 6.5	73.4 ± 10.9	Video	Rugby union	Match-play
Yamamoto et al. (2020) (117)	298	Male	Elite	Forwards: 27.9 ± 3.0 Backs: 27.7 ± 2.7	Forwards: 183.1 ± 6.3 Backs: 173.9 ± 7.8	Forwards: 100.3 ± 7.2 Backs: 84.2 ± 11.8	Microtechnology	Rugby union	Match-play

NR= Not reported. SD = Standard Deviation

2.3.3 Microtechnology

2.3.3.1 Rugby Union Match-Play

Ten studies recorded collision frequency using microtechnology in match-play (14%) (47,50–52,63,75,76,81,106,113) (Table 2.2). Two studies in rugby union recorded collisions per match (50,63), while two recorded per position (51,52). One study recorded the impacts per min (0.7 ± 0.4 impacts per min) (81). Macleod et al. (2018) recorded the frequency of collisions per minute per position (52). Tackles per match (63,75) and impacts per match (75) for forwards and backs were recorded (47,63). Three studies recorded load per collision (52,63,106).

Sixteen studies recorded the intensity of collisions by using microtechnology (22%) (Table 2.3) (47,52,103–105,112,113,117,54,63,66,71,82,84,98,99). Forwards on average (frequency) experience 52.5 (29.8 – 75.2) *very heavy impacts* and 10.8 (4.4 – 17.1) *severe impacts* per match (Figure 2.2) (54,98,99). Backs experience on average 41.7 (26.4 – 57.0) *very heavy impacts* and 6.7 (5.1 – 8.4) *severe impacts* per match (54,98,99) (Figure 2.2). Three studies recorded the relative frequency of collisions by intensity (103–105). On average, forwards experience 9.1 (7.5 – 10.8) *impacts* > *5 g* per min (103,105) (Figure 2.3). Backs experience on average 9.5 (8.1 – 10.1) *impacts* > *5 g* per min (103,105). Note, Tee et al. study includes > 5 g impacts and > 8 g impacts (105). Players experienced the highest amount of contacts in the first 20 – 30 min of a match and the least amount of contacts between 60 and 70 min (104). Forwards experience more *very heavy* contacts in the second half of the match in comparison to the first half of the match. Backs experience fewer impacts in the second half of the match in comparison to the first half of the match (54). There was no difference in impacts > 8 g per min for backs and forwards across the match (103). Forwards experience more impacts > 5 g per min in 0 – 10 and 50 – 60 min and experienced the least amount in the 20 – 30 min, 40 – 50 min and 60 – 70 min intervals of the match. Backs experience more impacts > 5 g in the 0 – 10 min interval of the match and the 20 – 30 min interval of the match and the least in the 70 – 80 min interval (103).

Table 2.2. *Characteristics of collision frequency detected by microtechnology in rugby union and rugby sevens.*

Study: Author (year)	Number of Matches/Training Sessions	Type of Collisions:	Frequency definition:	Frequency of collisions: Mean±SD		Relative frequency of collisions: Mean±SD (no. per min)		Load (AU)	
Rugby union									
Bradley et al. (2015) (57)	Training sessions	Contact number	Weekly	Forwards: 80 ± 25 Backs: 50 ± 22		NR		NR	
Coughlan et al. (2011) (63)	1 match	Collisions	Number	Total: 1411 Forwards: 838 Backs: 573		NR		NR	
		Tackles	Total	Forwards: 10 Backs: 12					
		Average Body Load tackle against						Forwards: 8.4 G Backs: 7.8 G	
Cunniffe et al. (2009) (47)	1 match	Impacts	Total	Forwards:798 Backs: 1274		NR		NR	
Jones et al. (2014) (75)	4 matches			Forwards:	Backs:	NR		NR	
		Tackles	Per match	5 ± 3	4 ± 3				
		Contacts hit	Per match	15 ± 6	6 ± 4				
		Impacts	Total	25 ± 9	15 ± 7				
		Scrum	Per match	13 ± 5	0				
		Contacts	Total	31 ± 14	16 ± 7				
Jones et al. (2015) (76)	71 matches	Contacts	Per match	First half: 12.3 ± 9.5 Second half: 12.6 ± 9.8		NR		NR	
			0-10min	2.9 ± 2.5					
			10-20min	3.1 ± 3					
			20-30min	4.1 ± 4.6					
			30-40min	3.7 ± 5					
			40-50min	4 ± 3.8					
			50-60min	2.5 ± 2.2					
			60-70min	2.3 ± 2.1					
			70-80min	2.5 ± 2.4					
MacLeod et al. (2018) (52)	11 matches	Collisions	Number per game	Forwards: Prop:31 ± 6 Hooker: 33 ± 5 Second row: 35 ± 7 Back row: 35 ± 10	Backs: Half back:16 ± 5 Centre: 23 ± 5.4 Back three: 21 ± 5.8	Forwards: Prop:0.4 ± 0.1 Hooker: 0.38 ± 0.07 Second row:0.4 ± 0.1 Back row: 0.4 ± 0.2	Backs: Half back: 0.2 ± 0.1 Centre: 0.3 ± 0.07 Back three: 0.2 ± 0.08		
		Load per collision						Forwards: Prop:7.9 ± 1.4 Hooker: 7.7 ± 1.4 Second row:7.3 ± 1.4 Back row: 7.6 ± 1.6	Backs: Half back: 7.6 ± 1.4 Centre: 8.0 ± 1.4 Back three: 8.3 ± 1.6

McLaren et al. (2015) (81)	15 matches	Impacts	Total	Total: 50 ± 289 Forwards: 78 ± 18 Backs: 28 ± 12	Total: 0.7 ± 0.4 Forwards: 1 ± 0.3 Backs:1.1 ± 0.2	NR
Reardon et al. (2017) (51)	13 matches	Collisions	Total	Prop: 34 ± 11 Hooker: 33 ± 9 Second row: 35 ± 11 Back row: 44 ± 10 Scrum half: 11 ± 6 Out-half: 21 ± 7 Centre: 20 ± 5 Wing: 20 ± 5 Full back: 21 ± 6	NR	NR
Takeda et al. (2014) (102)	Training and simulated match	Tackles Contacts	Total number	37.6 ± 3 10.4 ± 2.5	NR	NR
Tierney et al. (2020) (50)	Match play	Collisions	Collisions per player per game	11	NR	NR
Tierney et al. (2021) (106)	Match play	Collision count Collision Load		0.4 ± 0.1	NR	NR 2.8±1.1
Venter et al. (2011) (113)	5 matches	Impacts	Total	Back row forwards: 683.4 ± 295 Outside Backs: 474.3 ± 81.9	NR	NR
Rugby sevens						
Clarke et al. (2015) (60)	3-6 matches	Impacts	Total	National: 7300 ± 2200 State: 5200 ± 2400	NR	NR
Clarke et al. (2016) (61)	2 matches	Collisions	NR	Men: 35 Women: 20	NR	NR
Gibson et al. (2015) (70)	3 weeks training	Tackles	Count	Week 1: 22.8 ± 10.6 Week 2: 14.6 ± 9.1 Week 3: 15.8 ± 5.7	NR	NR
Portillo et al. (2016) (85)	5 matches	Tackle Ruck Ball Carry	Number/min	NR	Tackle: 0.3 ± 0.1 Ruck: 0.3 ± 0.1 Ball Carry: 0.2 ± 0.1	NR
Suarez-Arrones et al. (2014) (100)	23 matches	Tackle	Whole match	Forwards: 7.4 ± 1.8 First half: 3.3 ± 1.3 Second half: 4.1 ± 1.8	NR	NR
			Whole match	Backs: 4.1 ± 2.4 First half: 2.3 ± 1.8 Second half: 1.9 ± 1.4		
		Ruck	Whole match	Forwards: 1 ± 1.1 First half: 0.4 ± 0.5 Second half: 0.6 ± 0.8		
			Whole match	Backs: 0.6 ± 0.9 First half: 0.3 ± 0.5 Second half: 0.4 ± 0.5		
		Scrums		Forwards: First half: 2.9 ± 0.7 Second half: 1 ± 0.8		

NR= Not reported. SD = Standard Deviation. AU = Arbitrary Units

Table 2.3. *Characteristics of collision intensity detected by microtechnology in rugby union and rugby sevens.*

Study: Author (year)	Type of Collisions:	Frequency of collisions by intensity: Mean±SD			Relative frequency of collisions by intensity: Mean±SD (no. per min)	
Rugby union						
Coughlan et al. (2011) (63)	Impacts	**Forwards**: Very heavy: 53 Severe: 10		**Backs**: Very Heavy: 40 Severe: 13	NR	
Cunniffe et al. (2009) (47)	Impacts	**Forwards:** Very heavy: 56 Severe: 13		**Backs:** Very heavy: 24 Severe: 4	NR	
Dubois et al. (2020) (66)	Impacts (>8g) weekly (game included)	**Forwards:** 23.7 ± 27	**Backs:** 26.7 ± 38.5		NR	
Grainger et al. (2018) (71)	Impacts	**Impacts G:** Impacts > 9.01: Impacts 9.01-11: Impacts 11.01-13: Impacts > 13:	**Forwards**: 229 ± 160 114 ± 79 48 ± 41 66 ± 44	**Backs**: 226 ± 151 118 ± 79 47 ± 38 59 ± 40	NR	
MacLeod et al. (2018) (52)	Impacts	Impacts (> 8g)	**Forwards**: Prop: 19.1 ± 7 Hooker: 19.6 ± 7.9 Second row: 17.7 ± 7.1 Back row: 18.7 ± 7.3	**Backs**: Half back: 17.8 ± 6.9 Centre: 19.1 ± 8 Back three: 20.4 ± 7.5	NR	
McLellan et al. (2013) (54)	Impacts	Impacts (g) Very heavy Severe	**Forwards:** **First half:** 35 ± 23 **Second half:** 37 ± 25 **Total match:** 70 ± 43 **First half:** 9 ± 3 **Second half:** 9 ± 6 **Total match:** 18 ± 7	**Backs:** **First half:** 32 ± 25 **Second half:** 24 ± 19 **Total match:** 54 ± 42 **First half:** 7 ± 4 **Second half:** 5 ± 4 **Total match:** 11 ± 6	NR	
Owen et al. (2015) (82)	Impacts (first half)	**Forwards**: Very heavy: 42 ± 21 Severe: 25 ± 11 High level: 120 ± 55		**Backs**: Very Heavy: 34 ± 18 Severe: 22 ± 12 High level: 99 ± 44	NR	
Pollard et al. (2018) (84)	Collisions	NR			**Mean of the whole match:** Forwards: 0.5 ± 0.1 Backs: 0.3 ± 0.1	
Suarez-Arrones et al. (2012) (98)	Impacts per match	**Forwards**: Very heavy: 66.6 ± 48 Severe: 10.4 ± 5		**Backs**: Very Heavy: 35.2 ± 26 Severe: 6.3 ± 4	NR	
Suarez-Arrones et al. (2013) (99)	Impacts for the match	**Forwards:** Very heavy: 39 ± 7.6 Severe: 5.2 ± 3.5		**Backs:** Very heavy: 51.6 ± 35.3 Severe: 6.3 ± 0.6	NR	
Tee et al. (2015) (103)	Impacts	NR			**Forwards**: Impacts > 5G: 10 ± 3 Impacts > 8G: 1.1 ± 0.5	**Backs**: Impacts > 5G: 9.5 ± 3.2 Impacts > 8G: 1.1 ± 0.4

Tee et al. (2017) (104)	Total impacts	NR		**Forwards**: Impacts > 5G: **First half:** 8.7 ± 2.4 Q1: 9.3 ± 4.5 Q2: 9.2 ± 2.4 Q3: 8.2 ± 3.7 Q4: 7.4 ± 2.1 **Second half:** 7.9 ± 3.2 Q1: 8.2 ± 3.7 Q2: 9.4 ± 4.8 Q3: 8.2 ± 3.1 Q4:8.7 ± 4 Impacts > 8G: **First half:** 0.8 ± 0.3 Q1: 0.8 ± 0.6 Q2: 0.9 ± 0.4 Q3: 0.6 ± 0.3 Q4: 0.8 ± 0.5 **Second half:** 0.7 ± 0.3 Q1: 0.8 ± 0.5 Q2: 0.8 ± 0.4 Q3: 0.7 ± 0.4 Q4: 0.8 ± 0.4	**Backs**: Impacts > 5G: **First half:** 10 ± 3.5 Q1: 10.4 ± 5.3 Q2: 10 ± 3.9 Q3:10.4 ± 4.1 Q4:9.6 ± 4.8 **Second half:** 9 ± 0.3 Q1: 9.7 ± 3.7 Q2: 9.4 ± 3.3 Q3:10 ± 3.6 Q4: 7.1 ± 4 Impacts > 8G: **First half:** 1.1 ± 0.3 Q1: 1 ± 0.5 Q2: 1.1 ± 0.4 Q3: 1.1 ± 0.4 Q4: 1.1 ± 0.7 **Second half:** 1.1 ± 0.4 Q1: 1.1 ± 0.5 Q2: 1.2 ± 0.6 Q3: 1.1 ± 0.5 Q4: 0.9 ± 0.7
Tee et al. (2020) (105)	Impacts per game (> 5 G)	NR		**Forwards:** 8.3 ± 2.7 Q1: 11 ± 5 Q2: 8 ± 2 Q3: 8 ± 4 Q4: 8 ± 3	**Backs:** 9.5 ± 3.1 Q1: 10 ± 4 Q2: 10 ± 4 Q3: 10 ± 3 Q4: 9 ± 3
Vaz et al. (2012) (112)	Impacts	**Novice:** Very heavy: 21.3 ± 17.1 Severe: 4.7 ± 9.1 189.8 ± 93.3	**Experienced:** Very heavy: 14 ± 10.4 Severe: 1.6 ± 2.4 182.5 ± 61.4	NR	
Venter et al. (2011) (113)	Impacts	**Severe impacts > 10G:** Front row forwards: 8 ± 4.6 Inside backs: 12.2 ± 3.2		NR	
Yamamoto et al. (2020) (117)	Impacts total	**Impacts 8.1 - 10 and > 10g:** (mean ± Standard error) Forwards: 202.3 ± 14.5 Props: 192.4 ± 17.6 Hooker: 197.2 ± 24.7 Locks: 225.4 ± 36 Flankers: 181.8 ± 11 No. 8: 196 ± 17.9 **Impacts > 10g:** (mean ± Standard error) Forwards: 48 ± 4.3 Props: 40.5 ± 7 Hooker: 20.5 ± 5.1 Locks: 57 ± 10.1 Flankers: 42.6 ± 3.8 No. 8: 50.2 ± 8.5	**Impacts 8.1 - 10 and > 10g:** (mean ± Standard error) Backs: 171.9 ± 6.3 Scrumhalf: 138.1 ± 31.4 Fly-half: 145.9 ± 14.9 Centres: 217.9 ± 11.2 Wings: 149.5 ± 8 Fullback: 168.5 ± 18.9 **Impacts > 10g:** (mean ± Standard error) Backs: 35.6 ± 2.1 Scrumhalf: 26.6 ± 7.6 Fly-half: 35.6 ± 6 Centres: 42.4 ± 4.8 Wings: 31.3 ± 2.7 Fullback: 36.5 ± 5.1	NR	
Rugby sevens					
Clarke et al. (2015) (59)	Impacts National: 5 - 6 games State: 4 - 6 games	**Day one:** **Impacts 8 - 10g:** National: 32 ± 14 State: 26 ± 18	**Day two:** **Impacts 8 - 10g:** National: 34 ± 24 State: 23 ± 17	NR	

		Impacts > 10g: National:15 ± 6 State: 12 ± 7	**Impacts > 10g:** National: 17 ± 9 State: 10 ± 5	
Clarke et al. (2015) (60)	Impacts	**Impacts > 10g:** National: 29 ± 11 State: 22 ± 11		NR
Clarke et al. (2017) (62)	Impacts	**Impacts > 10g Elite:** Male: 25 ± 11.2 Female: 12.6 ± 4.7 **Impacts > 10g Senior:** Male: 11.8 ± 6.6 Female: 10.2 ± 7.1		NR
Higham et al. (2016) (74)	Impacts during the 22 matches	NR		Forwards: 26.2 ± 10.7 Backs: 23.5 ± 9.6
Suarez-Arrones et al. (2014) (100)	Impacts	**Forwards:** **Very Heavy:** First half: 9 ± 5.1 Second half: 7 ± 3.7 **Severe:** First half: 0.7 ± 1 Second half: 1.4 ± 1.3 **Impacts > 7g:** Whole match: 45.1 ± 24.5	**Backs:** **Very Heavy:** First half: 8 ± 6.1 Second half: 6.6 ± 3.8 **Severe:** First half: 0.9 ± 1.1 Second half: 1.9 ± 1.8 **Impacts > 7g:** Whole match: 41.8 ± 20.7	NR

NR= Not reported. SD = Standard Deviation.

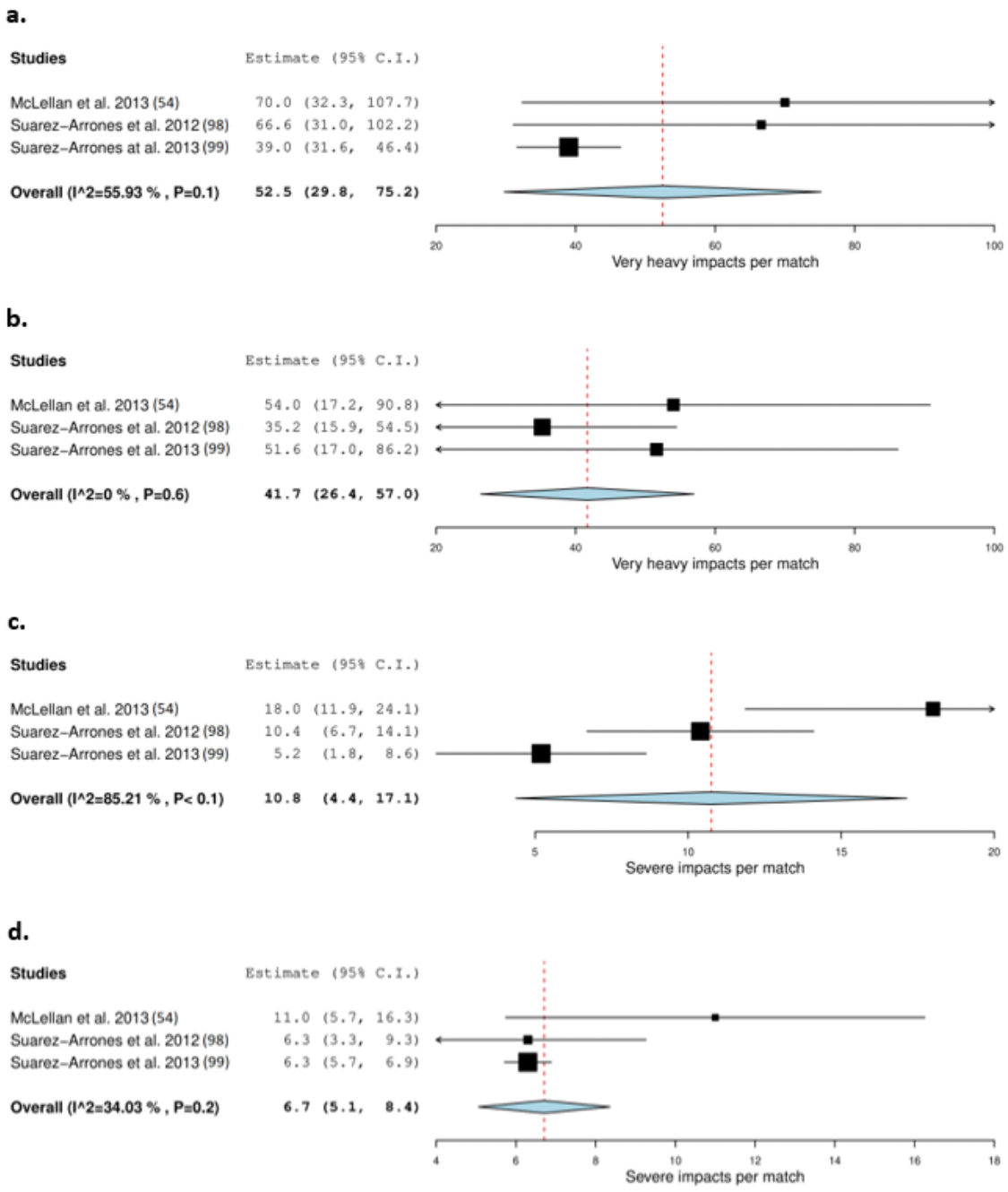

Figure. 2.2 *Meta-analysis of studies reporting absolute very heavy and severe impacts per match (n) from microtechnology in rugby union. The forest plot (mean and 95% confidence interval (95%CI)) presents the results of the meta-analysis of the pooled data estimates for the absolute very heavy and severe impact frequency for a forwards, b backs, c forwards and d backs. The squares and horizontal lines represent individual study mean and 95% CI and the diamond presents the pooled mean and 95% CI. The bigger the square the larger the sample size*

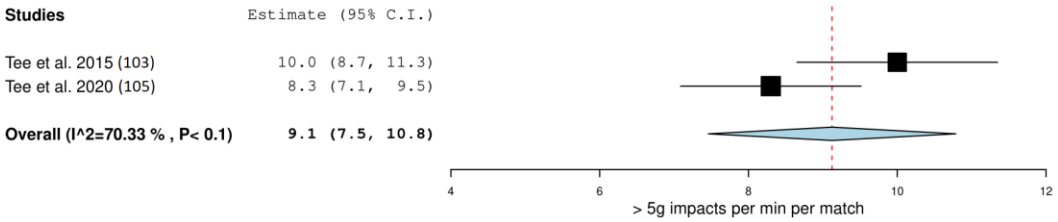

Figure. 2.3 *Meta-analysis of studies reporting relative > 5 g impacts frequency per match (n min^{-1}) from microtechnology in rugby union. The forest plot (mean and 95% confidence interval (95%CI)) presents the results of the meta-analysis of the pooled data estimates for the > 5 g impacts per min per match frequency for forwards. The squares and horizontal lines represent individual study mean and 95% CI and the diamond presents the pooled mean and 95% CI. The bigger the square the larger the sample size*

2.3.3.2 Rugby Union Training

Two studies recorded collision frequency using microtechnology during training (3%) (57,102). Bradley et al. (2015) recorded the contact number of weekly training sessions of forwards and backs. Note, match data were also included in this training week (57). Takeda et al. (2014) recorded 10.4 ± 2.5 tackles and 37.6 ± 3.0 contacts during a training simulated match (102).

2.3.3.3 Rugby Sevens Match-Play

Eight studies (11%) reported collision frequency using microtechnology during match-play (59–62,70,74,85,100). One study reported positional groupings (forwards and backs) (100), another study reported the level of play (60) and another study reported collision frequency by sex (61) (Table 2.2). Collision types included impacts, collisions, tackles, rucks, and scrums. Only one study recorded the relative frequency of tackles, ball carries in contact and rucks (85) and another study recorded relative frequency of impacts for forwards and backs (74). Of the eight studies, only five reported the intensity of collisions (63%) (Table 2.3) (59,60,62,74,100). Three studies recorded 16.9 (12.5–21.2) *impacts > 10 g* per match (Figure 2.4) (59,60,62).

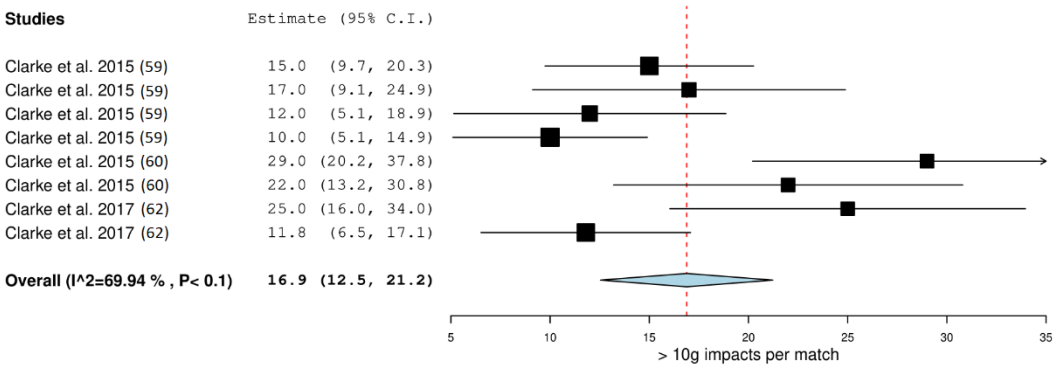

Figure. 2.4 *Meta-analysis of studies reporting absolute > 10 g impacts per match (n) from microtechnology in rugby sevens. The forest plot (mean and 95% confidence interval (CI)) presents the results of the meta-analysis of the pooled data estimates for the absolute > 10 g impacts frequency per match. The squares and horizontal lines represent individual study mean and 95% CI and the diamond presents the pooled mean and 95% CI. The bigger the square the larger the sample size*

2.3.3.4 Rugby Sevens Training

Only one study reported tackle frequency during training (on average 17.8 ± 4.4 tackles per week) (70).

2.3.4 Video-Based Analysis

2.3.4.1 Rugby Union Match-Play

Thirty-seven studies recorded the collision frequency using video-based analysis methods (51%) (13,20,68,69,72,73,75,77–80,86,38,87–89,91,95–97,101,107,108,42,109–112,114–116,51,56,58,64,65,67) (Table 2.4). Thirty-five studies were conducted during matches (95%) (13,20,69,72,73,75,77–80,86,87,42,88,89,91,95–97,101,107–109,51,110,111,114–116,56,58,64,65,67,68), one investigated training (3%) (112) and one study investigated matches and training (3%) (38). On average (frequency) a total of 22.0 (19.0 – 25.0) scrums (58,65,68,75,86,96,116), 116.2 (62.7 – 169.7) rucks (42,86), and 171 (140.5 – 201.8) tackles occur per match (Figure 2.5) (42,72,73,86,87,109–111). On average, forwards experience 12.8 (7.5 – 18.1) tackles (65,67,75,91,96) and backs experience 7.6 (4.3 – 10.9) tackles (Figure 2.6) (65,67,75,91,96). On average front row forwards perform 10.5 (5.7–15.2) tackles (38,56,67), back row forwards perform 15.9 (10.1 – 21.8) tackles (56,67), inside backs perform 17.2 (3.6 – 30.9) tackles (56,67) and outside backs perform 8.9 (2.0 – 15.7) tackles per match (Figure 2.7) (38,56,67). Props experience on average 5.5 (1.2 – 9.8) tackles per match (68,88), locks experience 4.5 (3.6– 5.4) tackles per match (68,88), hookers experience 6.3 (5.2–7.4) tackles (68,88) and scrum halves experience 6.4 (1.8 – 11.0) tackles per match (68,88) (Figure 2.8).

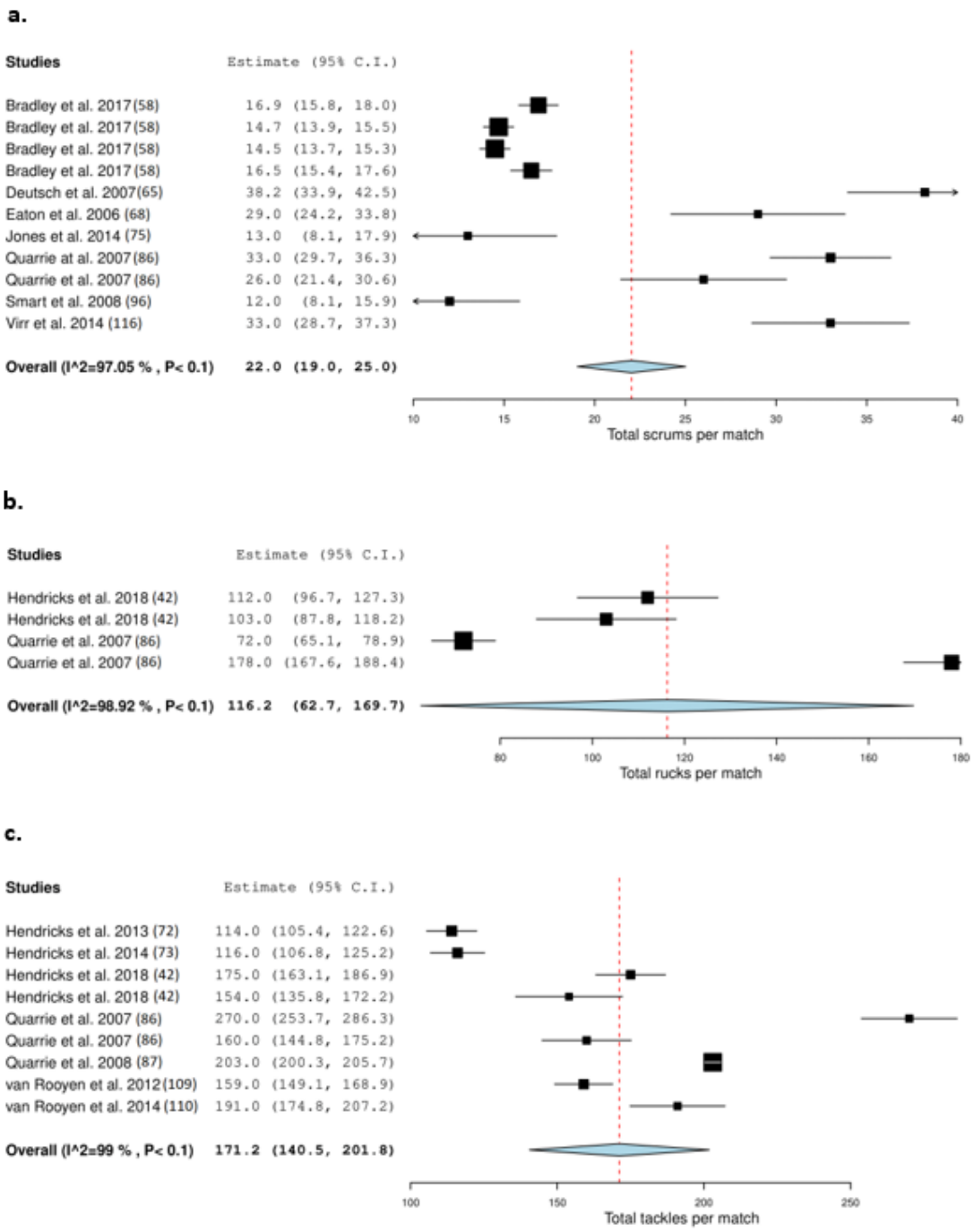

Figure. 2.5 *Meta-analysis of studies reporting absolute total scrums, rucks, and tackles per match (n) from video-based analysis in rugby union. The forest plot (mean and 95% confidence interval (95%CI)) presents the results of the meta-analysis of the pooled data estimates for the total a scrums, b rucks and c tackles per match. The squares and horizontal lines represent individual study mean and 95% CI and the diamond presents the pooled mean and 95% CI. The bigger the square the larger the sample size*

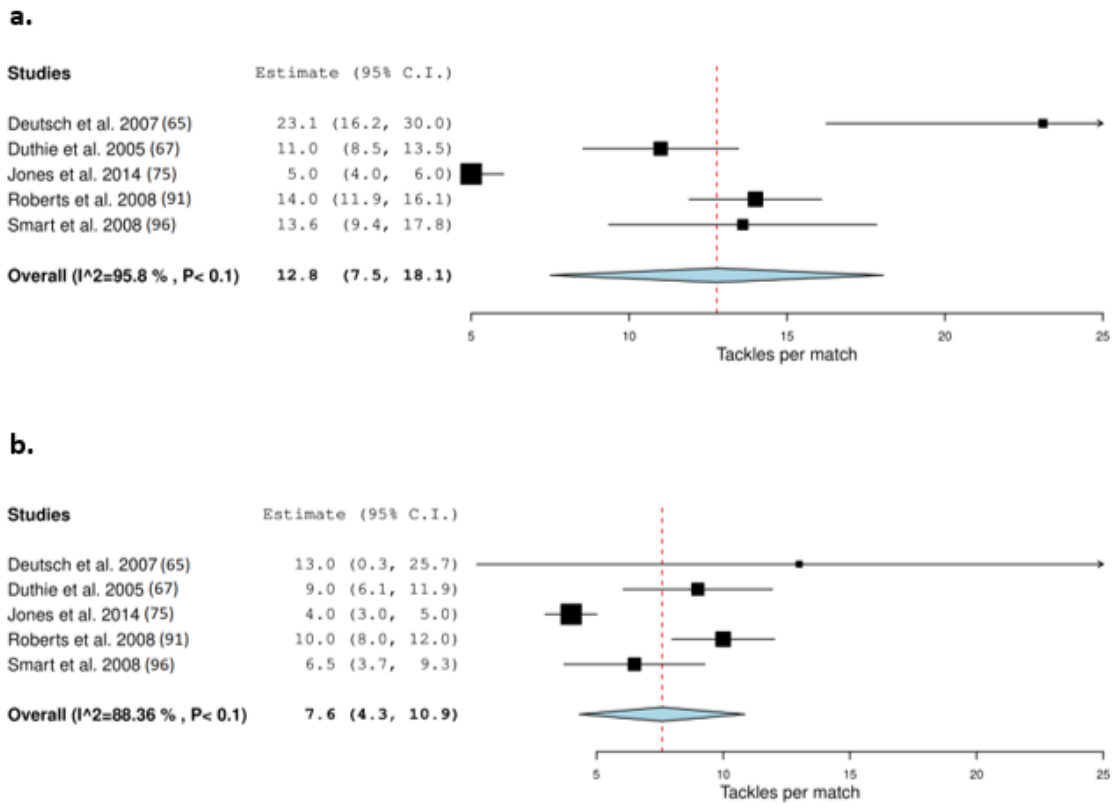

Figure. 2.6 *Meta-analysis of studies reporting absolute tackles per match (n) from video-based analysis in rugby union. The forest plot (mean and 95% confidence interval (95%CI)) presents the results of the meta-analysis of the pooled data estimates for the absolute tackle frequency for a forwards and b backs. The squares and horizontal lines represent individual study mean and 95% CI and the diamond presents the pooled mean and 95% CI. The bigger the square the larger the sample size*

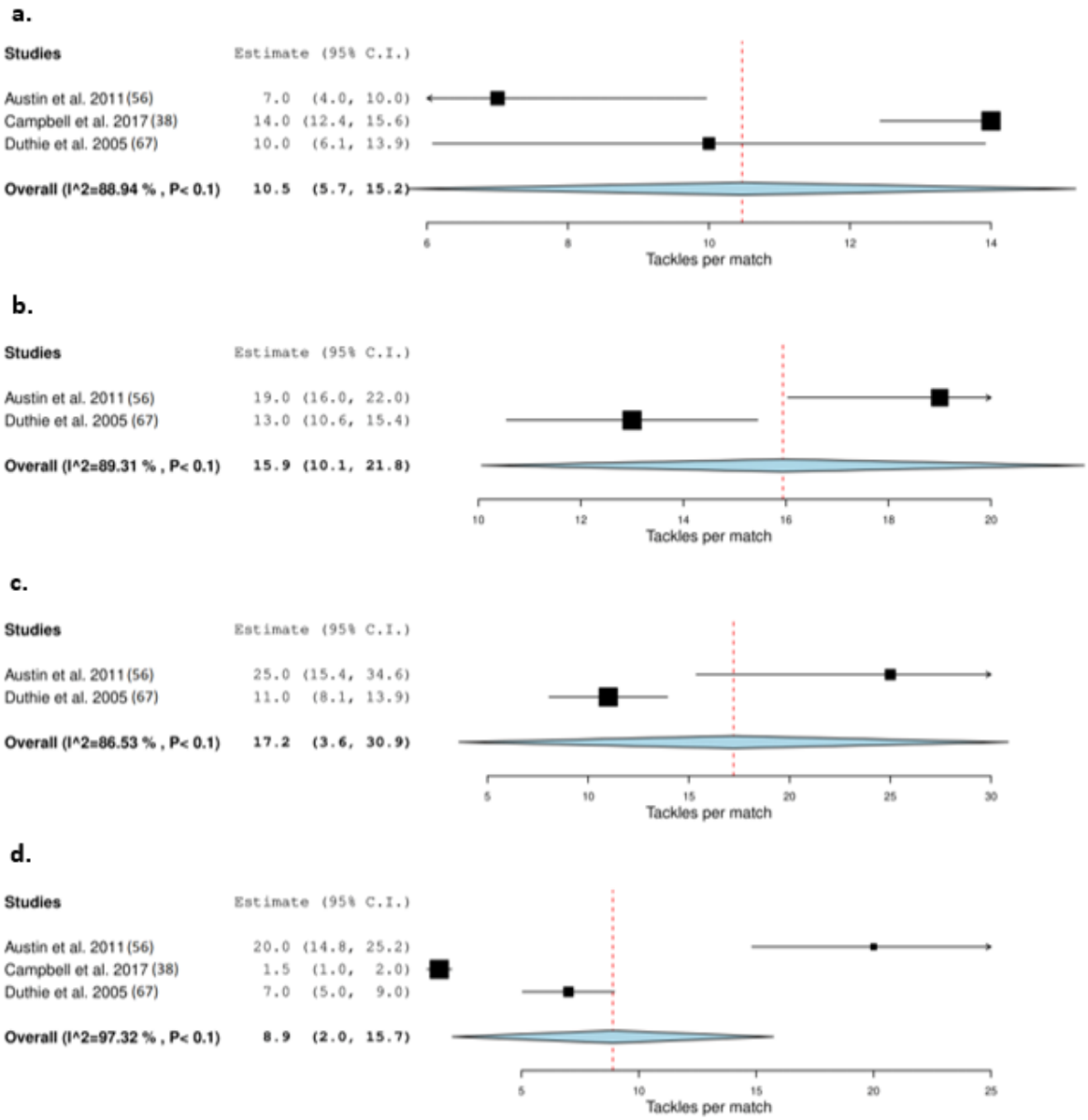

Figure. 2.7 *Meta-analysis of studies reporting absolute tackles per match (n) from video-based analysis in rugby union. The forest plot (mean and 95% confidence interval (95%CI)) presents the results of the meta-analysis of the pooled data estimates for the absolute tackle frequency for a front row forwards, b back row forwards, c inside backs and d outside backs. The squares and horizontal lines represent individual study mean and 95% CI and the diamond presents the pooled mean and 95% CI. The bigger the square the larger the sample size*

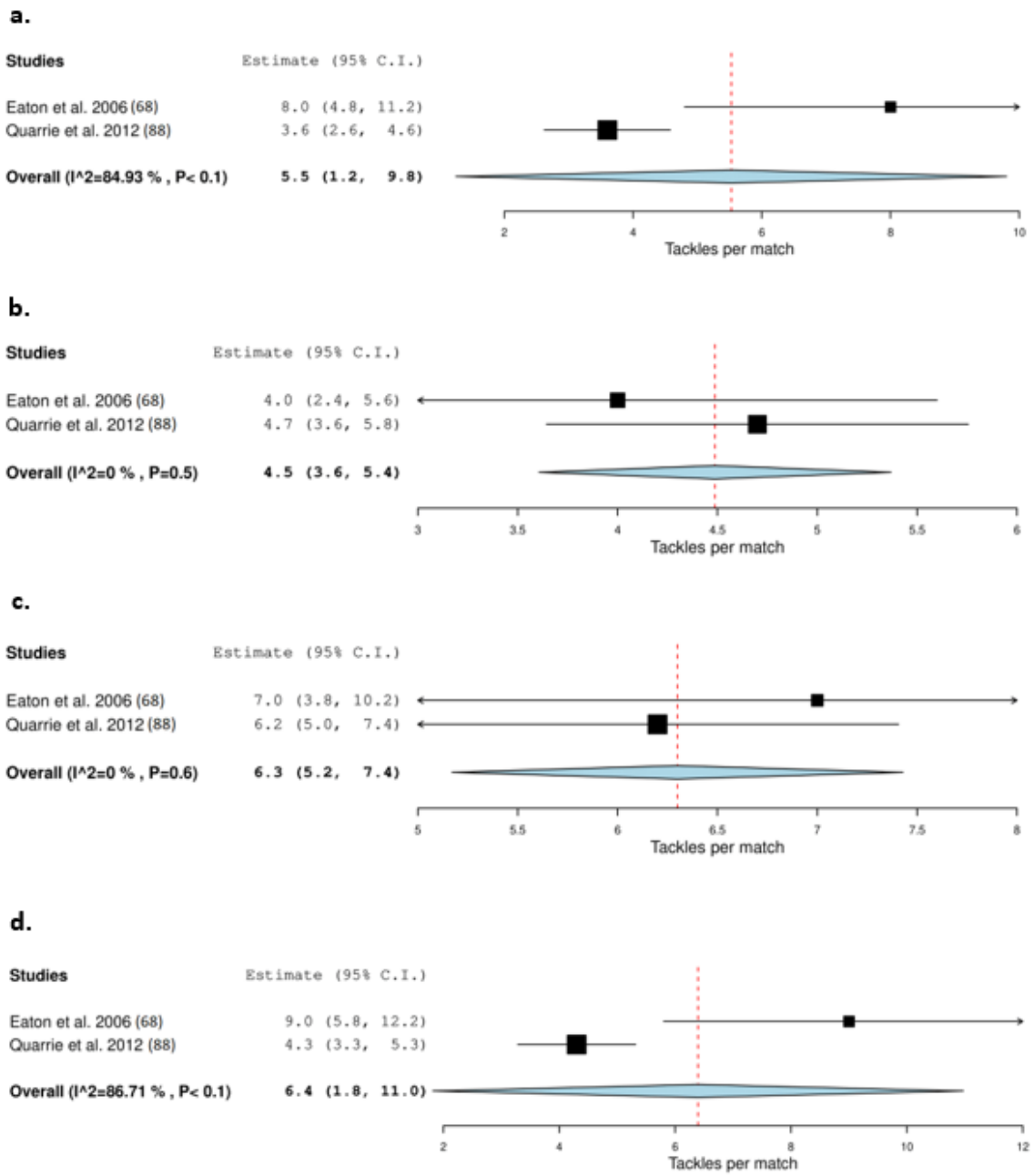

Figure. 2.8 *Meta-analysis of studies reporting absolute tackles per match (n) from video-based analysis in rugby union. The forest plot (mean and 95% confidence interval (95%CI)) presents the results of the meta-analysis of the pooled data estimates for the absolute tackle frequency for a props, b locks, c hooker and d scrumhalf. The squares and horizontal lines represent individual study mean and 95% CI and the diamond presents the pooled mean and 95% CI. The bigger the square the larger the sample size*

2.3.4.2 Rugby Union Training

Only one study reported collision frequency during training. This study reported that novice players perform an average of 28.2 ± 3.3 tackles during small-sided games, while experienced players perform 48.7 ± 3.3 tackles on average (112).

2.3.4.3 Rugby Sevens Match Play

Eight studies recorded the collision frequency by using video-based analysis (11%) (Table 2.4) (39,41,61,83,90,92–94). Ross et al. (2015) recorded the relative frequency of rucks and tackles at provincial and international level (92). Three studies recorded the frequency of collisions (61), contact actions (83), tackles, being tackled (ballcarrier) and scrums (in relation to high and low scoring matches) (90). Clarke et al. (2016) recorded 51 collisions for males and 44 collisions for females in a single match (61). On average, 14.1 (0 – 32.8) tackles occur per match (39,90), 4.8 (0 – 11.8) rucks per match (41,94) and 1.8 (1.7 – 2.0) scrums per match (41,90,93) (Fig. 2.9). Finally, backs and forwards experience more contacts in the second half of the match compared to the first half (83).

2.3.4.4 Rugby Sevens Training

No video-based training studies were found for sevens.

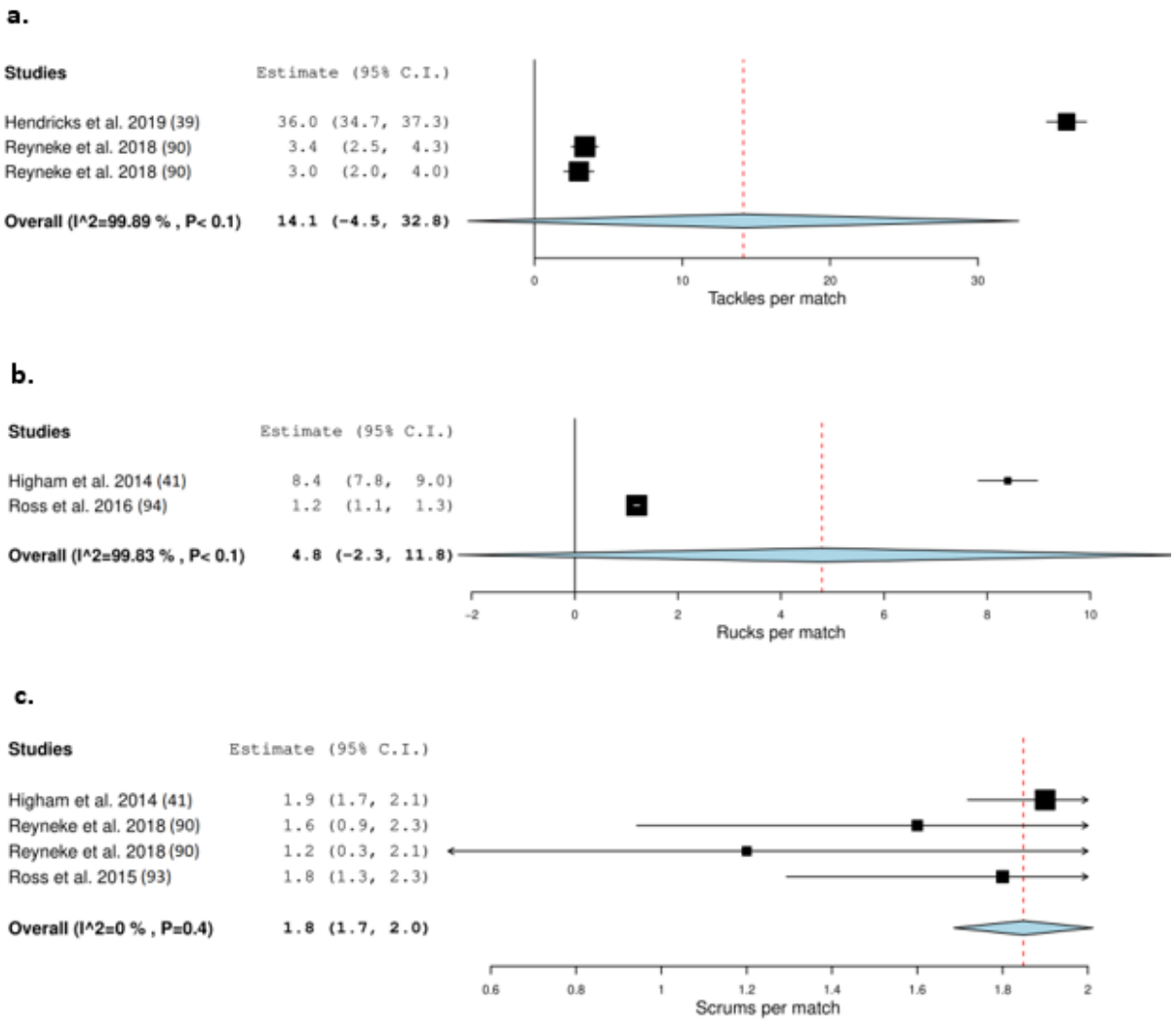

Figure. 2.9 *Meta-analysis of studies reporting absolute tackles, rucks, and scrums per match (n) from video-based analysis in rugby sevens. The forest plot (mean and 95% confidence interval (95%CI)) presents the results of the meta-analysis of the pooled data estimates for the absolute frequency of a tackles, b rucks and c scrums per match. The squares and horizontal lines represent individual study mean and 95% CI and the diamond presents the pooled mean and 95% CI. The bigger the square the larger the sample size*

Table 2.4. *Characteristics of collision frequency detected by video-based analysis in rugby union and rugby sevens.*

Study: Author (year)	Number of Matches/Training Sessions	Type of Collisions:	Frequency definition:	Frequency of collisions: Mean±SD		Relative frequency of collisions: Mean±SD (no. per min)	
Rugby union							
Austin et al. (2011) (56)	7 matches	Tackling	Number during match play	Front row forwards:20 ± 4 Back row forwards: 19 ± 4 Inside backs: 25 ± 13 Outside backs: 20 ± 7		NR	
		Scrummaging (ruck/maul/scrum)		Front row forwards:62 ± 13 Back row forwards: 68 ± 15 Inside backs: 17 ± 7 Outside backs: 14 ± 5			
Bradley et al. (2017) (58)	60 matches	Scrum	Scrum (count) total:	2013:16.9 ± 4.3 2014:14.7 ± 3.3 2015:14.5 ± 3.3 2016: 16.5 ± 4.5		NR	
Campbell et al. (2017) (38)	14 matches 29 training session	Tackles	Per match or training session	**Match:**	**Training:**	**Match:**	**Training:**
			Outside backs:	1.5 ± 1	1.1 ± 1.5	0.01 ± 0.01	0.01 ± 0.01
			Centres:	5.7 ± 2.6	2.9 ± 3.1	0.06 ± 0.02	0.03 ± 0.04
			Halves:	4.5 ± 2.4	1.8 ± 2.2	0.05 ± 0.02	0.02 ± 0.02
			Loose forwards:	7.2 ± 3.2	2.4 ± 2.6	0.08 ± 0.03	0.02 ± 0.04
			Locks forwards:	6 ± 2.9	2.4 ± 2.6	0.07 ± 0.04	0.02 ± 0.02
			Front row forwards:	5.6 ± 3	1.7 ± 1.8	0.07 ± 0.05	0.02 ± 0.02
		Rucks	Loose forwards:	12.9 ± 4.2	1.3 ± 3.8	0.1 ± 0.04	0.01 ± 0.04
			Locks forwards:	15 ± 6.4	1 ± 4.1	0.2 ± 0.1	0.01 ± 0.04
			Front row forwards:	10.9 ± 4.5	1.2 ± 3.6	0.2 ± 0.1	0.01 ± 0.03
		Mauls	Loose forwards:	3.1 ± 2.7	1.5 ± 3	0.03 ± 0.03	0.01 ± 0.03
			Locks forwards:	3.3 ± 3	1.9 ± 3.3	0.03 ± 0.03	0.02 ± 0.03
			Front row forwards:	2.9 ± 2.6	1.8 ± 3.4	0.04 ± 0.04	0.02 ± 0.04
		Scrums	Loose forwards:	23.4 ± 3.9	1.8 ± 3.4		
			Locks forwards:	21.4 ± 7.2	1.6 ± 3.2	0.3 ± 0.06	0.02 ± 0.06

			Front row forwards:	21.7 ± 5.5	1.6 ± 3.2	0.3 ± 0.1 0.3 ± 0.2	0.01 ± 0.03 0.01 ± 0.03
Deutsch et al. (1998) (64)	4 matches	Ruck/maul	Total	Props and Locks: 72 ± 7 Back row: 78 ± 8 Inside backs: 12 ± 2 Outside backs: 9 ± 4			NR
		Scrum		Props and Locks: 32 ± 3 Back row: 35 ± 1			
Deutsch et al. (2007) (65)	9 matches			**Forwards**:	**Backs**:		NR
		Ruck/maul Scrum Tackling	Total	66.9 ± 15.8 38.2 ± 8.7 23.1 ± 14	9.5 ± 5.7 23.4 ± 10.2		
Duthie et al. (2005) (67)	16 matches			**Forwards:**	**Backs:**		NR
		Static exertion	No per game	Front row: 78 ± 16 Back row: 82 ± 17 Total: 80 ± 17	Inside back: 27 ± 10 Outside back: 13 ± 5 Total: 21 ± 11		
		Tackles	No per game	Front row: 10 ± 8 Back row: 13 ± 5 Total: 11 ± 7	Inside back: 11 ± 6 Outside back: 7 ± 4 Total: 9 ± 6		
Eaton et al. (2006) (68)	6 matches	Rucks and mauls	Number	Prop: 38 ± 12 Hooker: 49 ± 10 Lock: 49 ± 19 Loose:48 ± 13 Scrum half: 15 ± 5 Inside back: 15 ± 9 Outside back: 13 ± 6			NR
		Tackling: Tackler		Prop: 8 ± 4 Hooker: 8 ± 4 Lock: 11 ± 3 Loose: 13 ± 6 Scrum half: 11 ± 4 Inside back: 9 ± 4 Outside back: 6 ± 3			

		Tackled		Prop: 5 ± 3 Hooker: 7 ± 4 Lock: 4 ± 2 Loose: 8 ± 5 Scrum half: 9 ± 4 Inside back: 5 ± 3 Outside back: 5 ± 3	
		Scrums		Prop: 29 ± 6 Hooker: 29 ± 6 Lock: 29 ± 6 Loose: 27 ± 7	
			Average Total	29 ± 6	
Fuller et al. (2007) (13)	50 matches	Contact events Scrums Tackles Rucks Mauls	Total Total Total Total Total	22842 1447 11048 7124 921	NR
Fuller et al. (2008) (69)	26 matches	Tackles	General play total	6219	NR
		One on one tackles	No of tackles in general play:	Tackler-1 (all): 3558 Arm: 1690 Collision: 384 Jersey: 93 Lift: 16 Shoulder: 826 Smoother: 526 Tap: 23	
		Double tackles	No of tackles in general play:	Tackler-1 (all): 2512 Arm: 1443 Collision: 10 Jersey: 86 Lift: 11 Shoulder: 746 Smoother: 209 Tap: 7 Tackler-2 (all): 2512	

				Arm: 1589 Collision: 14 Jersey: 22 Lift: 3 Shoulder: 358 Smoother: 527 Tap: 2		
		Arm double tackles:	No of tackles in general play:	Ball Carrier: Forward: 650 Back: 750		
		One-on-one collision tackles:	No of tackles in general play:	Ball Carrier: Forward: 146 Back: 217		
Hendricks et al. (2013) (72)	21 matches	Tackles Scrum Maul	Per match Total Total	114 ± 20 199 152	NR	
Hendricks et al. (2014) (73)	18 matches	Tackles	Per match Each competition week Per team	116 ± 20 149 131	NR	
Hendricks et al. (2018) (42)	12: Six Nations 15: Championship	Tackles	Total Championship Six Nations Per match in Six Nations Per match in Championship	4479 1853 2626 175 ± 21 154 ± 36	NR	
		Rucks	Total Championship Six Nations Per match in Six Nations Per match in Championship	2914 1234 1680 112 ± 27 103 ± 30		

Jones et al. (2014) (75)	4 matches	Tackles Contacts hit Impacts Scrum Contacts	Per match Per match Total Number Total	**Forwards:** 5 ± 3 15 ± 6 25 ± 9 13 ± 5 31 ± 14	**Backs:** 4 ± 3 6 ± 4 15 ± 7 0 16 ± 7		
Lacome et al. (2016) (77)	18 matches	Tackles	Players Completing Entire Match	NR		**Forwards:** First half: 0.1 ± 0.1 Second half: 0.1 ± 0.1	**Backs:** First half: 0.1 ± 0.1 Second half: 0.1 ± 0.1
Lindsay et al. (2015) (78)	NR	Impacts:	Total	NR		Group: 0.5 ± 0.2 Forwards: 0.6 ± 0.2 Backs: 0.4 ± 0.2 Front row: 0.5 ± 0.1 Locks: 0.5 ± 0.01 Loose forwards: 0.6 ± 0.4 Inside backs:0.4 ± 0.2 Outside backs: 0.3 ± 0.1	
		Tackles and tackle assists:	Total			Groups: 0.1 ± 0.1 Forwards: 0.2 ± 0.1 Backs: 0.1 ± 0.1 Front row: 0.1 ± 0.1 Locks: 0.2 ± 0.1 Loose forwards: 0.2 ± 0.1 Inside backs:0.1 ± 0.1 Outside backs: 0.07 ± 0.1	
		Rucks:	Total			Groups: 0.2 ± 0.2 Forwards: 0.3 ± 0.3 Backs: 0.1 ± 0.1 Front row: 0.3 ± 0.1 Locks: 0.3 ± 0.1 Loose forwards: 0.4 ± 0.4 Inside backs:0.2 ± 0.1 Outside backs: 0.1 ± 0.03	
		Ball carries	Total			Groups: 0.1 ± 0.1 Forwards: 0.1 ± 0.1 Backs: 0.1 ± 0.1 Front row: 0.1 ± 0.1	

						Locks: 0.1 ± 0.02 Loose forwards: 0.1 ± 0.1 Inside backs:0.1 ± 0.1 Outside backs: 0.1 ± 0.1
Lindsay et al. (2017) (79)	2 matches	Impacts	Total	Game 1: 21.3 ± 13.4 Game 2: 26.8 ± 13.5		NR
McIntosh et al. (2010) (80)	77 matches (15 Elite, 15 Grade, 24 <20)	Collisions	Total	Elite: 1422 Grade: 1368 <20: 2000		**Tackle per hour**: Elite: 142 Grade: 152 <20: 135
Quarrie et al. (2007) (86)	26 matches	 Scrums Rucks Mauls Tackles	Number of match activities	**1995:** 33 ± 7 72 ± 18 33 ± 8 160 ± 32	**2004:** 26 ± 7 178 ± 27 22 ± 9 270 ± 25	NR
Quarrie et al. (2008) (87)	434 matches	Tackle events	Total analysed Per game	140269 203 ± 29		NR
Quarrie et al. (2012) (88)	27 matches	Scrums	Per match	Prop: 25 ± 7.8 Hooker: 25 ± 7.6 Lock: 25 ± 7.9 Flankers: 25 ± 7.9 Number 8: 25 ± 7.5		NR
		Mauls	Per match	Prop: 1.4 ± 1.5 Hooker: 2 ± 2.04 Lock: 1.9 ± 1.9 Flankers: 1.8 ± 1 Number 8: 1.8 ± 1.4 Scrum Half: 0.2 ± 1 Fly Half: 0.2 ± 0.8 Midfield back: 0.3 ± 0.8 Wing: 0.2 ± 1 Full back: 0.3 ± 0.8	
		Successful tackles	Per match	Prop: 7.9 ± 3.6 Hooker: 9.7 ± 3.8 Lock: 11 ± 3.8 Flankers: 14 ± 4.1 Number 8: 12 ± 4		

				Scrum Half: 8.2 ± 3.3 Fly Half: 9.7 ± 3.5 Midfield back: 10 ± 4 Wing: 5.5 ± 2.7 Full back: 4.1 ± 2.3	
		Number of times tackled	Per match	Prop: 3.6 ± 2.6 Hooker: 6.2 ± 3.2 Lock: 4.7 ± 2.8 Flankers: 6.1 ± 3.4 Number 8: 9.7 ± 3.9 Scrum Half: 4.3 ± 2.7 Fly Half: 3.9 ± 2.6 Midfield back: 6.5 ± 3.1 Wing: 5.4 ± 2.9 Full back: 6.1 ± 3.1	
Reardon et al. (2017) (51)	13 matches	Collisions	Total	Prop: 33 ± 8 Hooker: 29 ± 8 Second row: 33 ± 7 Back row: 42 ± 8 Scrum half: 10 ± 6 Out half: 19 ± 3 Centre: 23 ± 7 Wing: 22 ± 3 Fullback: 20 ± 5	NR
Reardon et al. (2017) (89)	17 matches	Collisions	NR	NR	Tight five forwards: 0.7 ± 0.6 - 0.8 Back row forwards: 0.9 ± 0.8 - 1.01 Inside backs:0.3 ± 0.2 - 0.4 Outside backs: 0.4 ± 0.3 - 0.6
Roberts et al. (2008) (91)	NR	Rucks Mauls Scrum Tackle	Number	**Forwards**: 35 ± 8 25 ± 8 21 ± 12 14 ± 4	**Backs**: 11 ± 6 4 ± 4 10 ± 4
Roberts et al. (2014) (20)	30 matches (10 from each group: A, B, C)	Collisions Scrums Tackles Rucks Mauls	Total analysed Per match Per match Per match Per match	370 32.2 140.9 115.0 23.4	NR

Schoeman et al. (2015) (95)	30 matches	Tackles	Per position Total tackles in 30 games:	60 Loose-head prop: 568 Hooker: 475 Tight- head prop: 553 Loose- head lock: 666 Tight-head lock: 674 Blind-side flank: 742 Open-side flank: 868 Eighthman: 797 Scrum-half: 423 Fly-half: 505 Left wing: 277 Inside centre: 668 Outside centre: 515 Right wing: 319 Full-back: 301	NR
			Mean collision rate/80min:	Loose-head prop: 39.3 Hooker: 38.5 Tight- head prop: 42.1 Loose- head lock: 44.8 Tight-head lock: 41.2 Blind-side flank: 46.1 Open-side flank: 50.9 Eighthman: 43.1 Scrum-half: 16.3 Fly-half: 19.5 Left wing: 19.4 Inside centre: 32.3 Outside centre: 25.7 Right wing: 19.9 Full-back: 20.5	
			Mean tackle rate/80min:	Loose-head prop: 12.1 Hooker: 11.1 Tight- head prop: 13.2 Loose- head lock: 13.7 Tight-head lock: 14.1 Blind-side flank: 16.6 Open-side flank: 17.3 Eighthman: 14.7 Scrum-half: 8.9 Fly-half: 9.4 Left wing: 5.2	

				Inside centre: 12.9 Outside centre: 9.9 Right wing: 6.3 Full-back: 5.4			
Smart et al. (2008) (96)	5 matches	Tackles made Scrum Scrum Impact Collisions	Per match Number Total Per match	**Forwards:** 13.6 ± 7.5 12 ± 4.4 147.4 ± 89.8 43.6 ± 18.3	**Backs:** 6.5 ± 4.7 0 0 13.5 ± 7.4	**Forwards:** 0.6 ± 0.2	**Backs:** 0.2 ± 0.1
Smart at al. (2014) (97)	296 matches	Tackles	Successful tackles (%)	**Forwards**: 88 ± 14	**Backs**: 80 ± 20		NR
Takarada (2003) (101)	2 matches	Tackle	Mean tackles per match	14 ± 7.4			NR
Tucker et al. (2017) (107)	1516 matches	Rucks Mauls Tackles	Per match Per match Per match	162.9 10.4 158			NR
			Tackles/player/match	Fly half: 5 Scrum half: 3.8 Centre: 5.8 Full back: 2.1 Wing: 2.7 Hooker: 6.9 Number 8: 6.4 Prop: 5.5 Lock: 6.1 Flanker: 7.4			
Van Rooyen et al. (2008) (108)	7 matches	Impact contacts	Average per game	Total: 386 Forwards: 257 Backs: 125			NR
			Scrum: Ruck: Maul:	Forwards: 81 Forwards: 48 Backs: 8 Forwards: 14 Backs: 4.5			

Van Rooyen et al. (2012) (109)	69 matches	Tackles	Total per match 6 Nations Tri Nations RWC	21886 (average 159 ± 42) 165 ± 28 141 ± 24 156 ± 47		NR
Van Rooyen et al. (2014) (110)**(118)(118)(118)(118)(118)(118)(118)(118)(118)(118)**	15 matches	Tackle	Tackle situations per match	Average: 191 ± 32 Average winning team: 89 ± 30 Average losing team: 101 ± 24		NR
Vaz et al. (2010) (111)	**IRB competitions:** 64 matches	Tackles made:	Total	**Winners:** 88 ± 27.6	**Losers:** 89 ± 37.8	NR
Vaz et al. (2012) (112)	Training session (Small sided games)	Tackles	Tackles made:	**Novice:** 28.2 ± 3.3	**Experienced:** 48.7 ± 3.3	NR
Villarejo et al. (2013) (114)	48 matches	Tackles	Attempted tackles Tackles made Ineffective tackles	Front row: 10 Second row: 10.9 Back row: 14.3 Scrum halves: 12.5 Middle backs: 10.5 Back three: 5.9 Front row: 8 Second row: 8.6 Back row: 11.2 Scrum halves: 8.3 Middle backs: 7.2 Back three: 3.7 Front row: 0.7 Second row: 0.6 Back row: 1.1 Scrum halves: 1.7 Middle backs: 1.2 Back three: 0.9		NR
Villarejo et al. (2015) (115)	48 matches	Tackles	Attempted tackles	**Winning team:** Front row: 10.5 ± 14.04	**Losing Team:** Front row: 9.4 ± 12.4	NR

				Second row: 10.2 ± 8.6 Back row:14.5 ± 14.6 Scrum halves: 9.5 ± 11.1 Inside backs: 9.3 ± 12.9 Outside Backs: 5.5 ± 9.6	Second row: 11.6 ± 14.9 Back row: 14.2 ± 17.6 Scrum halves:15.3 ± 24.7 Inside backs: 11.4 ± 10.6 Outside Backs: 6.2 ± 7.4	
			Effective tackles:	Front row: 8.9 ± 12.9 Second row: 8.4 ± 7.3 Back row:12 ± 11.6 Scrum halves: 7.5 ± 9.3 Inside backs: 7.02 ± 10.9 Outside Backs: 4 ± 7.5	Front row: 6.8 ± 9.8 Second row: 8.7 ± 9.5 Back row: 10.6 ± 14.9 Scrum halves: 8.8 ± 15.4 Inside backs: 7.1 ± 7.2 Outside Backs: 3.3 ± 3.7	
			Ineffective tackles:	Front row: 0.5 ± 2 Second row: 0.5 ± 1.1 Back row: 1 ± 4.1 Scrum halves: 1.1 ± 3.1 Inside backs: 0.7 ± 2.03 Outside Backs: 0.5 ± 1.7	Front row: 0.9 ± 2.4 Second row: 0.8 ± 1.5 Back row: 1.1 ± 2.8 Scrum halves: 2.3 ± 6 Inside backs: 1.5 ± 2.8 Outside Backs: 1.4 ± 6.1	
Virr et al. (2014) (116)	10 matches	Ruck/maul/tackle Scrum	Total number	**Forwards:** 61 ± 12 33 ± 7	**Backs:** 25 ± 11	NR
Rugby sevens						
Clarke et al. (2016) (61)	2 matches	Collisions	Collisions	Men: 51 Women: 44		NR
Hendricks et al. (2019) (39)	135 matches	Tackles Ruck	per match Total Total	1.9 ± 1.3 8.4 ± 4.1 0.4 ± 0.7		NR
Higham et al. (2014) (41)	196 matches	Scrums Rucks Mauls	Per team per match Per team per match Per team per match			NR
Peeters et al. (2019) (83)	32 matches	Contact actions	Tackles/collisions/ rucks/ mauls	**Forwards**: First half: 5.3 ± 2.8 Second half: 6.3 ± 2.9	**Backs**: First half: 5.3 ± 3 Second half: 6.1 ± 2.7	NR

Reyneke et al. (2018) (90)	15 matches	Tackles:	Low (<21 score):	3.4 ± 1.8		NR
			High (≥21 score):	3 ± 2		
		Scrums	Low (<21 score):	1.6 ± 1.3		
			High (≥21 score):	1.2 ± 1.8		
		Ball Carry	Low (<21 score):	4.4 ± 2.9		
			High (≥21 score):	4.9 ± 2.5		
Ross et al. (2015) (92)	NR		**Total**		NR	
		Tackles:	Provincial:			0.2 ± 0.1
			International:			0.2 ± 0.2
		Rucks:	Provincial:			0.1 ± 0.1
			International:			0.2 ± 0.2
		Ball Carries:	Provincial:			0.3 ± 0.2
			International:			0.2 ± 0.2
Ross et al. (2015) (93)	54 matches			**Forwards**:	**Backs**:	NR
		Tackles	Per match	2.7 ± 2.6	2.41 ± 2.5	
		Scrums		1.8 ± 1.9		
		Ball Carries		3.2 ± 2.4	4.1 ± 3.2	
Ross et al. (2016) (94)	37 matches (between team analysis)	Tackles	Dominant tackles per match:	2.1 ± 2.3		NR
	50 matches (single team analysis)		Ineffective tackles:	8.1 ± 3.9		
		Rucks	Defensive ruck average per match:	1.2 ± 0.3		
			Ruck average:	1.2 ± 0.2		

NR= Not reported, RWC=Rugby World Cup. SD = Standard Deviation.

2.4 Discussion

To our knowledge, this is the first systematic review on quantifying collision frequency and intensity in rugby union and rugby sevens. This review demonstrates that video-based analysis and microtechnology are the main methods used to quantify collisions in rugby union and rugby sevens. Not surprisingly, the absolute collision frequency during rugby sevens matches was lower than rugby union due to the shorter duration of the game and fewer players on the field. When comparing relative frequencies though, rugby union players seem to perform less tackles and ball carries into contact than rugby sevens players, while rucks per minute were similar between the two rugby codes (78,92). Expressing collision frequencies relative to playing time provides coaches and players with the 'collision congestion' , a metric that can potentially be used in training to better prepare players for the collision demands of matches (119). With that said, only two studies expressed collisions or contact events per minute in sevens (85,92), which highlights an area for further work. In rugby union match-play, forwards experience more tackles than backs (12.8 (7.5 – 18.1) tackles and 7.6 (4.3 – 10.9) tackles, respectively). Another key finding of this review is that forwards experience more *very heavy* impacts (52.5 (29.8 – 75.2) vs. 41.7 (26.4 – 57.0) *very heavy* impacts) and *severe* impacts (10.8 (4.4 – 17.1) vs. 6.7 (5.1 – 8.4) *severe impacts*) than backs in rugby union. Coaches are recommended to train players specific to their positional grouping for appropriate adaptations. In both rugby cohorts, only six studies were completed on females (59,60,85,90,99,116) and two studies on both sexes (61,62). Overall, there was a lack of consistency on the definition of a collision. Also, grouping variables (i.e., how the positions were grouped) made it hard to make comparisons. It is recommended to integrate microtechnology and video-based analysis simultaneously to ensure maximal accuracy of metrics. Since there are only a few studies that have investigated the reliability and validity of MEMS, verifying the collision event/types needs to be addressed. There is still a limitation to this approach since video verification of collision events/types for MEMS has not been verified either but this is currently the most logical approach. Given the high injury incidence and burden of collision events, it is important that we adequately prepare athletes for collisions in training to meet the collision demands of matches.

To optimise training, researchers, trainers and sport practitioners typically study competition activities and demands, and attempt to replicate these demands in training (98,100,115,120). Training is subsequently monitored to ensure athletes meet said competition activities and demands (38). Monitoring training also ensures athletes are not exposed to any unnecessary injury risks, and are positively adapting to training (38). Only four studies quantified collision frequencies and/or intensities in training—three in rugby union (57,102,112) and one in rugby sevens (71), while 66 studies quantified frequencies and/or intensities of collisions in matches. Three studies related the

frequency and intensity of collisions during training to matches—two in rugby union (38,66) and one in rugby sevens (74). In both studies, collision frequencies and intensities were lower in training, suggesting that players may not be adequately preparing for matches (38,74). Indeed, the adaptations for a "collision-fit" player are likely to respond to general training principles including the concept of periodisation (121). Using general training concepts, such as periodisation, and collision demands data from match-play, coaches and practitioners can develop training programmes to enhance players' adaptability and capacity to repeatably engage in physical-technical contests without increasing their risk of injury; in other words, building a 'collision-fit' player. Recently, this has been suggested for skill training and Hendricks et al. (2018) described such a periodised plan for the rugby tackle (32). Understanding the adaptations for a "collision-fit" player will also allow for safer return to play protocols for collision sport athletes and reduce the risk of re-injury. To inform collision preparation practice, more work on collision training and its relationship to match demands, player development, performance and/or (re) injury risk is required. Collision training studies of this nature should also ideally be collected over more than one season and from multiple teams.

Collision frequency and intensities have been quantified in studies using video-based analysis (n = 37), microtechnology (n = 24) or both methods (n = 12). Each method has its advantages and disadvantages. For example, video-based analysis is laborious and reliant on human observation, while it may capture more contextual detail of the collision event (37). Conversely, microtechnology may be more efficient and objective, but its reliability and validity for quantifying collision demands is inconclusive at this stage (37,51,52). Also, customised algorithms detect collisions, making study comparisons difficult (122). With that said, studies are emerging to support collision metrics when used in conjunction with video-based analysis (50,52). Although some literature supports the use of microtechnology for collision monitoring, there is still a lack of validity regarding other metrics and therefore more investigation is needed (50). As such, a superior approach to quantifying collision demands from a research and practitioner perspective may be to integrate video and microtechnology (17,33). Using both video and microtechnology, coaches, practitioners and researchers are able to cross check the microtechnology data with video, determine its accuracy and distinguish between collision events (17,51,52). Additionally, the device being used should have established precision and accuracy for identifying collision events. If the collisions are not verified by video, the data produced by MEMS could be questionable.

If the goal is to ensure players are well-prepared for matches by providing the optimal collision frequency and intensity dose, the metrics (i.e., collisions, contacts, scrums, tackles, rucks and mauls) and grouping variables (i.e., specific positions, forwards and backs) between training and matches need to be consistent and more accurate. In other words, how collision demands are reported for

matches should be useful to the coach and practitioner, and transferable to a training setting. Therefore, metrics and grouping variables between the two settings need to be consistent to ensure this transfer. Strong engagement with the coach and practitioner when developing reporting metrics is therefore recommended (123). Recently, a consensus document for the video-based analysis of contact events was published to improve the consistency and quality of video-based analysis work in rugby union and sevens (17). A similar consensus-based approach may be required for microtechnology collision metrics (37,49). As mentioned, many studies report collisions differently, making study comparisons difficult between groups, methods used and between rugby cohorts. As a result, this limited the current synthesis. Collision intensity metrics in particular were inconsistent between studies. A possible reason for the inconsistency amongst studies is the use of different devices. Not all devices have completed validity and reliability tests which determine accuracy and precision of collisions. Therefore, some devices may be producing too many false positive collisions as seen when comparing MEMS and video footage (51). The lack of consistency between studies is a key factor limiting our understanding of collision loads (37). Additionally, the intensity of collisions is difficult to compare longitudinally, given that technology is constantly evolving. More recent technology, such as wearable sensors, is likely more accurate as algorithms are improved over time ensuring technology has a high specificity and sensitivity, and are more likely to detect a collision when it occurs (50), although limited studies can confirm this (52). We are also aware that our paper's cut off was ≥ 8 impacts. As mentioned previously, technology is constantly advancing which caused this to be a limitation of the methodology of this review.

The purpose of this review was to synthesise the frequency and intensity of collisions during training and matches in rugby union and rugby sevens. In both rugby cohorts, future studies should investigate training in comparison to match-play. Additionally, future studies should explore women's rugby. Many of these groups were understudied and are very important in our rugby community. A consensus-based approach for microtechnology is warranted since grouping variables and metrics were inconsistent throughout the studies. Beyond this, there are a number of other factors that can affect how players respond and adapt to different frequencies and intensities of contact. Collision events in rugby union and rugby sevens are dynamic and have a major technical-skill component (124,125). The opposing players' technical ability may also affect the perceived intensity of the collision event. The perceived physical and technical demands of collision events can also be captured using subjective RPE (126) and rating of perceived challenge (RPC) (121,126), respectively. These subjective ratings are useful when planning and monitoring training (126). Also, collisions are interspersed between periods of high intensity running (sprinting, accelerations, decelerations) and

low-intensity activities (walking, jogging). As such, advanced collision training should also include periods of high-intensity running to mimic complete match demands and fatigue conditions (120).

2.5 Conclusion

In conclusion, this review found a discrepancy in the number of studies quantifying collision demands in training compared to matches. While more work on quantifying the collision demands of training is required, studies should also compare training and matches if we are to improve our understanding of the relationship between training and matches. Another key finding is that the main method for quantifying collisions was video-based analysis. To improve the relationship between matches and training, integrating both video-based analysis and microtechnology is recommended, and the metrics and grouping variables between training and matches should be consistent. Per minute, rugby sevens players perform more tackles and ball carries into contact than rugby union players and forwards experienced more tackles than backs (12.8 (7.5 – 18.1) tackles and 7.6 (4.3 – 10.9) tackles, respectively). Another key finding in this review is that forwards experience more very heavy impacts (52.5 (29.8 – 75.2) vs. 41.7 (26.4 – 57.0) *very heavy* impacts) and severe impacts (10.8 (4.4–17.1) vs. 6.7 (5.1–8.4) *severe* impacts) than backs in rugby union. The frequency and intensity of collisions in training and matches may lead to adaptations for a "collision-fit" player and lend themselves to general training principles such as periodisation for optimum collision adaptation. Subjective measures such as RPE and RPC should be incorporated into the monitoring and management of the collision section of training to understand the internal load.

2.6 Additional tables

Table S2.1. *Methodological quality assessment of the final full text articles according to Downs et al. (1998)*(55).

Study: Author (year)	Question number												Total Score
	1	**2**	**3**	**4**	**6**	**7**	**10**	**11**	**12**	**16**	**18**	**20**	
Austin et al. (2011) (56)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Bradley et al. (2015) (57)	1	1	1	1	1	1	1	0	UT	1	1	1	10
Bradley et al. (2017) (58)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Campbell et al. (2017) (38)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Clarke et al. (2015) (59)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Clarke et al. (2015) (60)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Clarke et al. (2016) (61)	1	1	1	1	1	1	0	UT	UT	1	1	1	8
Clarke et al. (2017) (62)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Coughlan et al. (2011) (63)	1	1	1	1	1	0	0	0	UT	1	0	1	7
Cunniffe et al. (2009) (47)	1	1	1	1	1	0	0	0	UT	1	0	0	6
Deutsch et al. (1998) (64)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Deutsch et al. (2007) (65)	1	1	0	1	1	1	0	1	UT	1	1	1	9
Dubois et al. (2020) (66)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Duthie et al. (2005) (67)	1	1	0	1	1	1	0	1	UT	1	1	1	9
Eaton et al. (2006) (68)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Fuller et al. (2007) (13)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Fuller et al. (2008) (69)	1	1	0	1	1	1	1	1	UT	0	1	1	9
Gibson et al. (2015) (70)	1	1	1	1	1	1	1	UT	UT	1	1	1	10
Grainger et al. (2018) (71)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Hendricks et al. (2013) (72)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Hendricks et al. (2014) (73)	1	1	0	1	1	1	0	1	UT	1	1	1	9

Hendricks et al. (2018) (42)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Hendricks et al. (2019) (39)	1	1	0	1	1	1	0	1	UT	1	1	1	9
Higham et al. (2014) (41)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Higham et al. (2016) (74)	1	1	1	1	1	1	0	1	UT	1	1	1	9
Jones et al. (2014) (75)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Jones et al. (2015) (76)	1	1	0	1	1	1	0	1	UT	1	1	1	9
Lacome et al. (2016) (77)	0	1	0	1	1	1	1	1	UT	1	1	1	9
Lindsay et al. (2015) (78)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Lindsay et al. (2017) (79)	1	1	1	1	1	1	1	1	UT	1	1	1	11
MacLeod et al. (2018) (52)	1	1	1	1	1	1	1	1	UT	1	1	1	11
McIntosh et al. (2010) (80)	0	1	0	1	1	1	1	1	UT	1	1	1	9
McLaren et al. (2015)(81)	1	1	1	1	1	1	0	1	UT	1	0	1	9
McLellan et al. (2013) (54)	1	1	1	1	1	1	0	0	UT	1	1	1	9
Owen et al. (2015) (82)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Peeters et al. (2019) (83)	1	1	1	1	1	1	1	1	UT	1	0	1	10
Pollard et al. (2018) (84)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Portillo et al. (2016) (85)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Quarrie et al. (2007) (86)	1	1	0	1	1	1	0	1	UT	1	0	0	7
Quarrie et al. (2008) (87)	1	1	0	1	1	1	0	1	UT	1	1	1	9
Quarrie et al. (2012) (88)	1	1	0	1	1	1	0	1	UT	1	1	1	9
Reardon et al. (2017) (51)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Reardon et al. (2017) (89)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Reyneke et al. (2018) (90)	1	1	1	1	1	1	0	1	UT	1	0	1	9

Roberts et al. (2008) (91)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Roberts et al. (2014) (20)	1	1	0	1	1	1	0	1	UT	1	1	1	10
Ross et al. (2015) (92)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Ross et al. (2015) (93)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Ross et al. (2016) (94)	1	1	0	1	1	1	0	1	UT	1	1	1	9
Schoeman et al. (2015) (95)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Smart et al. (2008) (96)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Smart et al. (2014) (97)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Suarez-Arrones et al. (2012) (98)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Suarez-Arrones et al. (2013) (99)	1	1	1	1	1	1	1	1	UT	1	1	1	10
Suarez-Arrones et al. (2014) (100)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Takarada (2003) (101)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Takeda et al. (2014) (102)	1	1	1	1	1	1	0	1	UT	1	1	0	9
Tee et al. (2015) (103)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Tee et al. (2017) (104)	1	1	1	1	1	1	0	1	UT	1	0	1	9
Tee et al. (2020) (105)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Tierney et al. (2020) (50)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Tierney et al. (2021) (106)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Tucker et al. (2017) (107)	1	1	0	1	1	1	0	1	UT	1	1	1	9
Van Rooyen et al. (2008) (108)	1	1	1	1	1	1	0	1	UT	1	0	1	9
Van Rooyen et al. (2012) (109)	1	1	0	1	1	1	0	1	UT	1	1	1	9
Van Rooyen et al. (2014) (110)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Vaz et al. (2010) (111)	1	1	0	1	1	1	0	1	UT	1	1	1	9
Vaz et al. (2012) (112)	1	1	1	1	1	1	1	1	UT	1	1	1	11
Venter et al. (2011)(113)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Villarejo et al. (2013) (114)	1	1	0	1	1	0	0	1	UT	1	1	1	8

Villarejo et al. (2015) (115)	1	1	0	1	1	1	1	1	UT	1	1	1	10
Virr et al. (2014) (116)	1	1	1	1	1	1	0	1	UT	1	1	1	10
Yamamoto et al. (2020) (117)	1	1	1	1	1	1	0	1	UT	1	1	1	10

1. Is the hypothesis/aim/objectives of the study clearly described? 2. Are the main outcomes to be measured clearly described in the introduction or methods section? 3. Are the characteristics of the participants included in the study clearly described? 6. Are the main findings of the study clearly described? 7. Does the study provide estimates of the variability in the data for the main outcomes? 10. Have the actual probability values/effect sizes been reported (e.g.0.035 rather than <0.05) for the main outcome except where the probability value is less than 0.001? 11. Were the subjects asked to participate in the study representative of the entire population from which they were recruited? 12. Were the subjects who were prepared to participate representative of the entire population from which they were recruited? 16. If any of the results of the study were based on 'data dredging', was this made clear? 18. Were the statistical tests used to assess the main outcomes appropriate? 20. Were the main outcome measures used accurate (valid and reliable)? UT: Unable to determine

Table S2.2. *Characteristics of studies using microtechnology to record collisions during match-play or training sessions.*

Study: Author (year)	GPS provider:	Device (algorithm)	GPS device rate (Hz):	Accelerometer (100Hz):	Sampling frequency:	Number of files	Software:
Bradley et al. (2015) (57)	Catapult Innovations, Melbourne, Australia	Minimax S4	10	Yes	Yes	NR	NR
Campbell et al. (2017) (38)	GPSports Systems, Canberra, Australia	SPI HPU	15	NR	NR	NR	Team AMS, GPSports, Canberra, Australia
Clarke et al. (2015) (59)	GPSports Systems, Canberra, Australia	SPI HPU	5	NR	NR	64: National, 51 State	NR
Clarke et al. (2015) (60)	GPSports Systems, Canberra, Australia	SPI HPU	15	Yes	NR	64: National, 51 State	NR
Clarke et al. (2016) (61)	GPSports Systems, Canberra, Australia	SPI HPU	NR	Yes	NR	NR	NR
Clarke et al. (2017) (62)	GPSports Systems, Canberra, Australia	SPI HPU	5	NR	NR	Senior men:68 Senior women: 90 Elite men: 81 Elite women: 89	NR
Coughlan et al. (2011) (63)	GPSports Systems, Canberra, Australia	SPI-Pro	5	Yes	Yes	NR	Team AMS ; GPSports, Version 1.2, Canberra, Australia
Cunniffe et al. (2009) (47)	GPSports Systems, Canberra, Australian Capital Territory, Australia	SPI Elite	1	Yes	NR	NR	Team AMS ; GPSports, Version 1.2, Canberra, Australia
Dubois et al. (2020) (66)	GPSports Systems, Canberra, Australia	SPI HPU	5	Yes	NR	NR	NR
Gibson et al. (2015) (70)	Catapult Innovations, Melbourne, Australia	Minimax S4	10	Yes	Yes	136	Sprint 5.14 software
Grainger et al. (2018) (71)	StatSports Viper, Northern Ireland	NR	10	Yes	NR	462	STATSports Viper Rugby software
Higham et al. (2016) (74)	GPSports Systems, Canberra, Australia	SPI Pro X	15	Yes	NR	NR	Team AMS release 1 2011 revision 8, GPSports Systems
Jones et al. (2014) (75)	Catapult Innovations, Melbourne, Australia	Minimax S4, v.4.0	10	NR	NR	45	Catapult Sprint software (Catapult Innovations, Melbourne, Australia)
Jones et al. (2015) (76)	Catapult Innovations, Melbourne, Australia	Minimax S4, v.4.0	100	Yes	NR	112	Catapult Sprint software (Catapult Innovations, Melbourne, Australia)
Lindsay et al. (2017) (79)	Catapult, Victoria, Australia	Minimax S4	10	Yes	NR	NR	Catapult Sprint V5.1
MacLeod et al. (2018) (52)	STATSport Viper unit	NR	10	Yes	NR	NR	STATSports Viper Rugby software

McLaren et al. (2015) (81)	Catapult Innovations, Melbourne, Australia	Minimax S4	10	Yes	Yes	NR	Logan Plus 4.2 software (Catapult Innovations, Melbourne, Australia)
McLellan et al. (2013) (54)	GPSports Systems, Canberra, Australian Capital Territory, Australia	SPI-Pro	15	Yes	NR	NR	SPi-Ezy v2.1 software (GPSports Systems).
Owen et al. (2015) (82)	GPSports Systems, Canberra, Australia	SPI HPU	15	Yes	NR	189	Team AMS ; GPSports, Canberra, Australia
Pollard et al. (2018) (84)	STATSports, Belfast, UK	Viper Pod	10	NR	NR	4.5 (2.6) per player	Viper PSA Software, Version 2.6.1.176, STATSports, Belfast, UK
Portillo et al. (2016) (85)	GPSports, Canberra, Australia	NR	100	Yes	NR	NR	Team AMS software V R1.2011.6, GPS sports, Canberra, Australia
Reardon et al. (2017) (51)	Catapult, Innovations, Scoresby, VIC, Australia	OptimEyeS5	10	Yes	Yes	135	Sprint 5.1 software (Catapult Innovations, Scoresby, VIC, Australia)
Reardon et al. (2017) (89)	Catapult, Melbourne, Australia	OptimEyeS5	10	NR	NR	200	Sprint 5.1 software (Catapult Innovations, Scoresby, VIC, Australia)
Suarez-Arrones et al. (2012) (98)	GPsports, Australia	SPI Elite	1	Yes	NR	NR	Team AMS ; GPSports, Version 1.2, Canberra, Australia
Suarez-Arrones et al. (2013) (99)	GPSports Systems, Canberra, Australia	SPI Pro X	5	Yes	NR	NR	Team AMS software version 10 (GPSports, Australia)
Suarez-Arrones et al. (2014) (100)	GPSports Systems, Canberra, Australia	SPI Pro X	15	Yes	NR	NR	NR
Tee et al. (2015) (103)	GPSports, Australia	SPI Pro	5	Yes	NR	102	Team AMS software version 10 (GPSports, Australia)
Tee et al. (2017) (102)	GPSports, Canberra, Australia	SPI Pro	5	Yes	NR	46	Team AMS software (version 10)
Tee et al. (2020) (105)	GPSports, Canberra, Australia	SPI Pro	10	Yes	NR	103	Team AMS software version 10 (GPSports, Australia)
Tierney et al. (2020) (50)	StatSports Group Limited, Co. Down, Northern Ireland	MST unit (Weighted algorithm)	10	Yes (600Hz)	Yes	245	StatSports Rugby software
Tierney et al. (2021) (106)	StatSports, Down, UK	Apex Pro Series Pod	10	Yes (600Hz)	Yes	2869	StatSports Apex Rugby Software (Version 3.0.11171)
Vaz et al. (2012) (112)	GPSports Systems, Canberra, Australia	SPI Pro	5	NR	NR	NR	Team AMS, V2.1.0.5 P11 software
Venter et al. (2011) (113)	GPSports Systems, Canberra, Australia	SPI Pro	5	NR	NR	23	Team AMS ; GPSports, Canberra, Australia
Yamamoto et al. (2020) (117)	GPSports Systems, Canberra, Australia	SPI Pro X	5	Yes	NR	NR	Team AMS; GPSports Systems

NR= Not reported

Table S2.3. *Characteristics of studies using video-based analysis to record collisions during match-play or training sessions.*

Study: Author (year)	Camera system	Number of cameras	Location of camera relative to field	Notational analysis system
Austin et al. (2011) (56)	HITACHI DZ-GX5060SW, Hitachi LTD., Japan	3	On the halfway line approximately 30m above the playing field	A simple hand-notation game analysis system
Bradley et al. (2017) (58)	VirginMedia TiVo box	NR	NR	NR
Campbell et al. (2017) (38)	Legria HF R506, Canon, Tokyo, Japan	NR	3-5 m above the height of the playing field. The footage was taken from a vantage point 10-20 m from the field either side of the 22 m and halfway lines.	NR
Coughlan et al. (2011) (63)	NR	NR	NR	Sportscode Pro, Version 7.5.6, Sportstec, Warriewood, NSW, Australia
Deutsch et al. (1998) (64)	Panasonic MS-4, Matsushita Electronics, Japan	3	5± 6 m away from the side line at half-way, at an elevation of 3± 6 m.	NR
Deutsch et al. (2007) (65)	Panasonic MS-4, Matsushita Electronics, Japan	NR	5 and 15 m from the field, at an elevation of 5 – 10 m	Pro-Log, Time Frame International, New Zealand
Duthie et al. (2005) (67)	SONY DCR-TRV900E PAL, Sony Corporation of America	1	20 m above the ground midpoint of the rugby field	Part-Timer V1.1, Australian Sports Commission, Canberra
Eaton et al. (2006) (68)	NR	3	Image recognition sensors were fixed to the roof of the Northampton Saint's stadium.	Prozone
Fuller et al. (2007) (13)	DVD recordings from Rugby Football Union	NR	NR	NR
Fuller et al. (2008) (69)	DVD recordings from Rugby Football Union	NR	NR	NR
Hendricks et al. (2013) (72)	NR	NR	NR	Sports Code Elite Version 6.5.1, using an Apple iMac (Apple, USA)
Hendricks et al. (2014) (73)	NR	NR	NR	Sports Code elite version 6.5.1, using an Apple iMac (Apple, USA)
Hendricks et al. (2018) (42)	NR	NR	NR	Sports Code elite version 6.5.1, using an Apple iMac (Apple, USA)
Hendricks et al. (2019) (39)	NR	NR	NR	Sports Code elite version 6.5.1, using an Apple iMac (Apple, USA)
Jones et al. (2014) (75)	NR	NR	NR	Sportscode (Sportstec, NSW)
Lacome et al. (2016) (77)	Amisco, Pro, Sport Universal Process, Nice, France	NR	NR	NR
Lindsay et al. (2015) (78)	NR	NR	NR	Opta provided live performance data analysis
Lindsay et al. (2017) (79)	NR	NR	NR	Opta provided live performance data analysis
Macleod et al. (2018) (52)	NR	NR	NR	Sportscode, Version 8.4.0, Sportstec, NSW, Australia
McIntosh et al. (2010) (80)	NR	NR	NR	Snapperi (Webbsoft Technologies, Australia)
Peeters et al. (2019) (83)	NR	NR	NR	SportsCode, Hudl, USA

Quarrie et al. (2007) (86)	NR	NR	NR	Verusco Ltd., Palmerston North; www.verusco.com
Quarrie et al. (2008) (87)	NR	NR	NR	Verusco Technologies, Palmerston North, New Zealand
Quarrie et al. (2012) (88)	NR	NR	NR	Verusco Technologies Inc. (Palmerston North, New Zealand)
Reardon et al. (2017) (51)	NR	NR	NR	SportscodeTM (Sportstec by Hudl, Nebraska, USA)
Reyneke et al. (2018) (90)	NR	NR	NR	Sportscode V8.9, Sportstec, Australia
Roberts et al. (2008) (91)	Four Sony DCR-TRV900E, Japan; one Panasonic AG DP2000B, Japan	5	3–5 m from the nearest side-line	V9 time code generator, IMP Electronics, Cambridgeshire
Roberts et al. (2014) (20)	Sony DCR-TRV900E, Japan	1	Mounted on a tripod	SportsCode Pro 7.0.150, Sportstec, Australia
Ross et al. (2015) (92)	NR	NR	NR	Sportscode V8.9, Sportstec, Australia
Ross et al. (2015) (93)	NR	NR	NR	Sportscode V8.9, Sportstec, Australia
Ross et al. (2016) (94)	NR	NR	NR	Sportscode V8.9, Sportstec, Australia
Schoeman et al. (2015) (95)	Supplied by Cheetahs Super Rugby Franchise	NR	NR	Verusco TryMaker Pro (Verusco Technologies Ltd.; Palmerston North, New Zealand)
Smart et al. (2008) (96)	NR	NR	NR	AnalySports, Version AS10.0307, 2002, Palmerston North, NZ
Smart et al. (2014) (97)	NR	NR	NR	TryMaker Pro, Verusco Ltd, Palmerston North, New Zealand
Tierney et al. (2020) (50)	NR	NR	NR	Sportscode™ (Sportstec by Hudl, Nebraska, USA)
Van Rooyen et al. (2008) (108)	NR	NR	NR	SportsCode Elite version 6.5.2, Sportstec, Australia
Van Rooyen et al. (2012) (109)	NR	NR	NR	'Verusco Statistics Portal' (Verusco Sports 2012)
Van Rooyen et al. (2014) (110)	NR	NR	NR	SportsCode Elite version 6.5.1, Sportstec, Australia
Vaz et al. (2010) (111)	NR	NR	NR	Rugby Stats Fair Play Sports Analysis Systems V2, Australia) and Rugby Match Analysis and Statistics (IRB - Computacenter/S.A.S, 2003)
Vaz et al. (2012) (112)	Sony HDR–XR 155E-120G HandyCam; Japan		20 m from the side of the field at an elevation of 3 m	
Virr et al. (2014) (116)	Sony GR-DVL9800, Son Corporation, Tokoyo, Japan; Panasonic PV-GS150, Panasonic Corporation, Osaka, Japan; JVC GR-DVL520U, Victor Company of Japan, Ltd., Yokohama, Japan	4	Centre line (50m line) on 1.6 m tripods situated on top of a 2 m, scaffold, 5 m from the sideline	Dartfish TeamPro software, version 4.0.6.0, Dartfish, Fribourg, Switzerland

NR= Not reported

Chapter 3: Coaches in Rugby. What do We Know? A Scoping Review

3.1 Introduction

Rugby union, rugby league, and rugby sevens are popular invasion team sports played around the world, recreationally and professionally, from junior to senior, and by men and women (9). While the three codes have notable differences in terms of game rules, they share similar match characteristics – intermittent high-intensity running interspersed with technical-physical contests for ball possession and territory (10,11). The most frequently occurring of these technical-physical contests in all three codes is the tackle (11). Participating in these rugby codes has a range of physical, mental, and social health benefits (127). Like most sports though, it also carries a risk of injury, with the tackle event being the leading cause. For example, in professional rugby union, 22.4 (16.6 - 30.2) injuries per 1000 match player hours occur when being tackled and 6.8 (3.9 - 11.7) injuries per 1000 match player hours occur when tackling (128).

Broadly, the objective of sport science and medicine research across these rugby codes are directed towards preventing injury, improving performance, and developing young and senior players to improve rugby team performances. The majority of research with these objectives have the player as the subject of study. For instance, describing players physical and technical activities during matches and training (37,38). To date, numerous quality player-focused reviews have been published. These reviews range from narrative syntheses (29) to systematic reviews (36,129) and meta-analyses (129,130) , and serve to inform practice, policy, and identify gaps to guide future research. These player-focused reviews are also intended to assist coaches in understanding the demands of matches and training, and the risk of injury, to better prepare players mentally and physically for competition. With similar intentions, research focusing on the coach as the subject of study has also been conducted in the rugby codes. However, unlike player-focused studies, coach-focused studies in rugby have not been consolidated and synthesised in a meaningful to inform coaching practice, policy, and identify gaps to guide future research.

The coach is responsible for creating a positive environment that fosters learning and player well-being (35). On the field, coaches provide players with the appropriate training stimulus to ensure players are mentally and physically prepared for competition, and optimally challenge players to enhance their technical skill learning (36–38). Considering the high risk of injury, rugby has also targeted the coach as the key role player in preventing injury and concussion (35). For example, Clacy et al. (2015) found that 82.4% of identified themselves having a role in concussion prevention. BokSmart or RugbySmart injury prevention programmes are examples of programmes implemented to prevent injuries throughout the rugby communities (131,132). RugbySmart have also discovered that coaches know injury prevention is important but they do not always put it into practice (146). Successfully implementing a training programme or policy is therefore highly dependent on the coach

(11,136). The coach as a key stakeholder in the implementation and effective of a programmes is well-recognised (137,138). To improve implementation and effectiveness, a number of studies have also been conducted on coaches. However, unlike studies on players, this research has not been consolidated and synthesised in a meaningful way to inform practice, policy, and guide future research. Therefore, the purpose of this study is to provide a scoping review of the current literature on rugby union, rugby league and rugby sevens coaches.

3.2 Methods

A scoping review was used to address the objective of the study. A scoping review provides an assessment of the size, nature, and scope of the available literature by mapping out key aspects (139). This review used the Arksey and O'Malley's five-stage scoping review process (140) and followed the PRISMA guidelines for a scoping review. The process starts by identifying the research question and ends with consolidating, summarizing, and reporting results. This review was also based on Levac et al. 's framework for further clarity and advancement of Arksey and O'Malley's five-stage scoping review process (141).

Stage 1: Identifying the research question

The following research questions were identified for this review:

What is the knowledge and practices of coaches in all rugby codes?

What has been published in peer-review journals about coaches' knowledge on practices across all rugby codes?

How has rugby research on coaches been done so far?

What methods have been used to study rugby coaches?

What are the research areas on rugby coaches?

What are the key areas of research on rugby coaches?

Stage 2: Identifying relevant studies

The inclusion criteria for this review were i) coaches had to be the main participant of the study and ii) only rugby union, rugby league and/or rugby sevens coaches were included. Studies that included other sports were only included if the data of the rugby union, rugby league and/or rugby sevens coach(es) were clearly distinguishable. Articles had to be peer-reviewed original research studies published in English. Conference abstracts were excluded from this review.

Search Strategy

The search was conducted on five different electronic databases (EBSCOHost, PubMed, Scopus, SPORTDiscus and Web of Science) for all publications until January 2022. The combined key words were 'coach*' AND 'rugby union' OR 'rugby league' OR 'rugby sevens'. For example, the key works for the search completed in Pubmed was ((coach*) AND (rugby OR rugby league OR rugby union OR rugby sevens).

Stage 3: Study selection

After completing the initial electronic database search, duplicates were removed, and thereafter screened according to the PRISMA guidelines (53). The review was registered with OSF (registration number: 10.17605/OSF.IO/3H7YG). LP screened the publications for eligibility at the title and abstract level. LP screened all the full text publications (Figure 3.1). Publications that did not meet the inclusion criteria were removed. The final full-text publications (n=101) went through the data charting and extraction process.

Stage 4: Charting the data

The following data were charted for each study:

Authors (year)

Rugby code cohort

Type of coach

Level/s of coach

Topic of study

Purpose of study

Data collection methods

Sample size

Conclusions

Stage 5: Collating, Summarizing and Reporting

This scoping review presents the data in two ways. Firstly, numerically by a flowchart (Figure 3.1), and through frequency percentages (%) based on the data charting form. Secondly, thematically, by mapping out key concepts to answer the research questions. The inductive thematic analysis was

based on Braun and Clarke's six phase framework (142). A single author (LP) familiarized themselves with the data by manually reading and extracting data to form codes from each study. For example, if a study's aim was about coaches' input on injury prevention programmes the study would be coded as injury prevention. Thereafter, initial themes were developed from the codes and then analyzed to form the final themes (Figure 3.2). When analyzing the initial themes, the authors felt that *training practices* would be best suited under *coach knowledge* since the studies gave insight into the coaches' knowledge of training practices. The final themes included *coach knowledge, coach pedagogies* and *coach development. Coach knowledge* includes articles which gave insight into the reported knowledge of coaches on different aspects of coaching. *Coaching pedagogies* includes articles that investigate the different practices that coaches use to teach and develop their players. *Coach development* includes articles that studies how coaches progressed and evolved during their coaching careers. These themes were discussed amongst the authors to ensure they were relevant and useful in a practical setting. The thematic analysis section is reported in a narrative format.

Assessment of methodological quality

Although a quality assessment is not necessary for a scoping review, we have assessed the quality of the studies for the reader's benefit. The quality of the full text publications was assessed using the JBI Critical Appraisal Checklist for Qualitative research (143). The assessment was done by LP and SH (Additional files: Table S3.1). Studies were not eliminated based on quality.

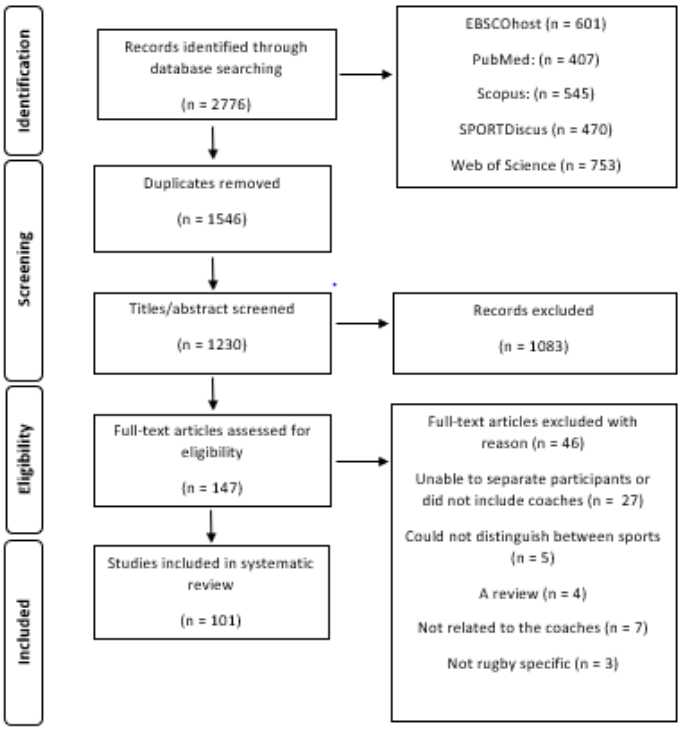

Figure 3.1. *Literature selection process for the scoping review.*

Initial themes	Coach knowledge	Coach pedagogies	Coach development	Training practices
Codes extracted	Injury prevention	Coaching styles	Stressors	Monitoring players
	Concussion knowledge	Reflective practices	Coping with pressure	Sport science
	Talent identification			Return to play
	Mini rugby union			
	Doping			
	First aid knowledge			
	Tackling technique			
	Referee abuse			
	Nutrition			
	Equipment usage			

Refined themes	Coach knowledge	Coach pedagogies	Coach development
Refined sub-themes	Injury prevention	Coaching styles	Fast tracking coaches
	Injury knowledge	Reflective practices	Coping with pressure
	Training knowledge		Childhood and adolescent experiences
	Doping knowledge		
	Various other knowledge from coaches		

Figure 3.2. *The process of Braun and Clarke's six phase framework.*

3.3 Results

3.3.1 Numerical analysis

A total of one hundred and one studies (n = 101) were included in the final analysis (35,133,149,239,150–158,134,159–168,135,169–178,136,179–188,144,189–198,145,199–208,146,209–218,147,219–228,148,229–238). In total, 4233 coaches participated in the one hundred and one articles. Most of the studies focused on rugby union (n = 78, 77%) (35,133,149–154,156–159,134,160–168,170,135,171,174,176,177,179,183,184,187–189,136,190–194,196–200,144,201–203,205–208,212–214,145,215–223,225,146,228–230,232,233,236,237,239,147,148) and rugby league (n = 14, 14%) (155,169,195,204,234,238,172,173,175,178,180–182,185). The remainder of the studies focused on a combination of rugby cohorts (n = 4, 4%) (209–211,227) and only one study focused on rugby sevens (n = 1, 1%)(224). Four studies did not specify the type of rugby (n = 4, 4%)(186,226,231,235). Only two studies specifically investigated female rugby (n = 2, 2%) (146,161). Table 3.1 shows the qualifications of the coaches in rugby union and rugby league. Table 3.2 shows the types of coaches for all three cohorts. Table 3.3 shows data collection methods for all three cohorts. Additional files include Table S3.1 to S3.3 which display the study characteristics, purpose of study and conclusion per theme.

Table 3.1. *Qualification of coaches, references and study sample size for rugby union and rugby league.*

Rugby union		
Qualification of coaches	**Reference**	**Number of studies referenced**
United Kingdom Coaching Certificate (UKCC) Level 1 to 4	(136,165,202,206,207,212,216,229,230,232)	10
BokSmart (a national rugby safety programme that enhance injury prevention and performance through evidence-based research)	(134,136,144,165)	4
Rugby league		
UKCC Level 1 to 4	(178,180,181,195,234)	5
Rugby league qualification	(173)	1

Table 3.2. *Types of coaches, references and study sample size for rugby union, rugby league and rugby sevens.*

Rugby union		
Types of coaches	**Reference**	**Number of studies referenced**
Rugby coaches	(35,134,176,177,179,184,187,189,191–193,196,136,198–201,203,206–208,212,213,144,214–216,219,221,225,229,230,232,237,145,146,148,151,159,160)	40
Head coach	(156,157,171,174,183,198,202,205,217,220,233,236,161–164,166–168,170)	20
Assistant rugby coach	(157,167,168,183,202,218,236,238)	8
Strength and conditioning coach	(152,170,171,191,194,198)	6
Schoolboy coaches	(133,135,149,150,153,159,165,197,207)	9
Rugby league		
Rugby league coaches	(172,173,234,175,178,180–182,185,195,204)	11

Strength and conditioning coaches	(169,180–182)	4
Head coaches	(155,169,181,238)	4
Assistant coaches	(155)	1
Development coaches	(169)	1
Rugby sevens		
Rugby sevens coach	(224)	1

Table 3.3. *Data collection methods, references and study sample size for rugby union, rugby league and rugby sevens.*

Rugby union		
Data collection methods	**Reference**	**Number of studies referenced**
Interviews	(146,147,168,171,177,190,199,202,208,212,213,215,149,216,217,220–222,225,228,229,236,237,150,239,154,156,163,164,166,167)	31
Questionnaires	(35,134,158–160,165,170,174,179,184,187,189,135,191,192,196–198,200,201,206,136,144,145,151–153,157)	30
Observations	(161,188,203,223)	4
Reflections	(218)	1
Focus groups	(176,205)	2
Combination of methods	(133,148,232,233,162,183,193,194,207,214,219,230)	12
Rugby league		
Interviews	(169,178,181,185,195,238)	6
Questionnaires	(172,173,175,180,182,204)	6
Combination of methods	(155,234)	2
Rugby sevens		
Interviews	(224)	1

3.3.2 Thematic analysis

Themes identified

The studies were divided into three themes:

- Coach knowledge (68%) (Table S3.2)
- Coach pedagogies (29%) (Table S3.3)
- and Coach development (4%) (Table S3.4).

3.3.2.1 Theme 1: Coach knowledge

Sixty-eight studies reported on Coach knowledge (35,133,149–158,134,159–168,135,169–178,136,179–188,144,189–198,145,199–206,146–148).

This theme was further divided into four sub-themes: *Coaches' knowledge injury prevention*, *coaches' injury knowledge, coaches' training knowledge* and *coaches' doping knowledge*.

3.3.2.1.1 Coaches' knowledge on injury prevention

Nine studies (n = 9) were conducted on coaches' injury knowledge (133–135,145,177,191–193,197). Coaches' knowledge on injury prevention consisted of nine studies (133–135,145,177,191–193,197). All injury prevention programmes/workshops that coaches took part in had predominately positive responses and were helpful to coaches. Injury prevention programmes such as *Activate* (145), shows how workshops facilitate coaches to implement injury prevention programmes. Three studies investigated the BokSmart programme (133–135) which is a national safety programme that aims to implement evidence-based research to prevent injury and enhance performance of rugby players (131). Brown et al. (2016) found that coaches from a higher socioeconomic status thought the BokSmart programme was unnecessary (26% of their comments were negative) while coaches from a low socioeconomic status had a positive perception of the BokSmart programme (only 3% of their comments were negative) (133). Brown et al. (2016), also found that most coaches thought the courses could be more practical (133). Brown et al. (2020) showed a meaningful improvement in the knowledge of safe scrum techniques and rules in 360 coaches following the attendance of an injury prevention course (BokSmart) (146). Sewry et al. (2017), investigated the change in coach's knowledge over the years after launching the *Safe Six* injury prevention programme. The authors found that the coaches knowledge increased 3.55 times in 2015 and 10.11 times increase in 2016 compared with 2014 (135). The implementation of the Mayday procedure by coaches was another safety protocol that was investigated by two studies. Poulos et al. (2015), evaluated the effectiveness of a strategic approach to improving the translation of the Mayday procedure by the coaches within community

sport. The prevention group's knowledge in the preseason increased from 30% in 2010 to 70% in 2011, and from 22% to 73% in the regular season (193). Most coaches in this study believed it was important and trained their players accordingly (192,193).

3.3.2.1.2 Coaches' injury knowledge

Sixteen studies investigated coaches' injury knowledge (n = 16)(35,148,179,186,189,196,201,204,151,153,157–160,172,173). Twenty-four percent of coaches believed that they play a role in preventing injuries and providing a safe environment for their players, while 70.6% believed that proper training contributed to prevention of concussions (35). Clacy et al. (2017), found that 71% of coaches tended to rely on medical staff on how to deal with a concussion (151). Niederer et al. (2018), found that 12 out of 20 coaches did not think it was their decision to decide whether a player should return to play proceeding a concussion (186). Eighty-two percent of coaches in Fraas et al. (2014)'s study agreed that the doctor is the most important decision maker when players are returning to play after a concussion (157). Identifying a concussion and educating their players on concussion risk was seen as essential amongst coaches (35,157). Overall, there was a positive trend of coaches improving their knowledge on injuries and, specifically, concussions over the years (159,160). However, continuous education for coaches on this topic is encouraged.

3.3.2.1.3 Coaches' training knowledge

Coaches agree that monitoring players is important for training (152,198). Comyns et al. (2018) concluded that 80% of coaches thought session-RPE was effective for monitoring performance and preventing injury (152). Seventy-one percent of coaches had a positive perception about proper tackle technique during different phases of play (165). Hendricks et al. (2017), found that coaches believed proper tackling technique was *very important* for safety reasons (mean: 4.6, 95%CI: 4.2 – 5.0 on the Likert scale) and for optimising performance (mean: 4.8, 95%CI: 4.4 – 5.0 on the Likert scale), however, further education is needed (136). Strength and conditioning coaches noted 11 aspects of fitness that is important to measure (170,171). Eighty percent of coaches value performance analysis extremely but 39% of coaches do not receive video footage. Only 20% of coaches had access to a performance analyst (187).

3.3.2.1.4 Coaches' doping knowledge

Only two studies were on coaches' doping knowledge (n = 2)(147,185). Most coaches believed they were confident enough to confront players about doping (147). If not, they would give someone else the responsibility to confront the player (147). Nicholls et al. (2015)'s study found that coaches believe doping education is needed for the players (185). Additionally, that many factors contribute to doping such as low self-esteem, availability, family, affordability, peers and other coaches (185).

3.3.2.2 Theme 2: Coach pedagogies

Twenty-nine studies investigated coach pedagogies (n = 29) (207,208,217–226,209,227–235,210–216). One study investigated the Beat the Game approach which shifted the coaches from being the sole decision maker to the players making decisions (207). Three studies investigated Game Sense (221,222,230), which implemented a shift from coach-centered learning to towards player-centered learning. Light et al. (2010) found that coaches thought the use of games improved players skills and reading of cue (221). Chapron et al. (2019), found that coaches were reluctant to move over to player-centered learning (214). Bennie et al. (2010), results shows that coaches felt that they do not only develop players on the field but off the field too (209). In two studies coaches agreed that the athlete-player relationship is essential and needs to be individualized (210,219). Bennie et al (2012)'s study concludes that most coaches have their own styles and all coaches believe the player had to have responsibility to develop (211). Collins et al. (2016) investigated coaches' intuitive decisions, finding coaches intuitive decisions came from experience (216). Three studies investigated reflective practices amongst coaches (212,218,234). Burt et al. (2014)'s study shows that coaches' main reason of not reflecting was lack of motivation (212). Another study found that reflective processes allowed for self-awareness and undoing of bad behavior amongst coaches (218). The 'Think Aloud' protocol was implemented by Whitehead et al. (2016), resulting in self and pedagogical awareness amongst coaches (234).

3.3.2.3 Theme 3: Coach development

Four studies were included in coach development (n = 4) (236–239). Coach development was further divided into three sub-themes: *Fast tracking coaches*, *coaches coping with pressure* and *coaches' childhood and adolescent experiences.*

3.3.2.3.1 Fast tracking coaches (transition from athlete to coach)

Two studies investigated into coaches who were fast tracked from athletes to coaches (n = 2) (236,237). Some were 'active' coaches where others were 'passive' in the process, but all were athletes in the past (236). Coaches thought their past experiences played a big role in their coaching career (237).

3.3.2.3.2 Coaches coping with pressure

One study investigated how coaches deal with pressure and the stressors in their job (n = 1)(239). This was different for each coach, but a conclusion was to implement programmes for coaches to learn how to deal with their stressors and pressure correctly (239).

3.3.2.3.3 Coaches' childhood and adolescent experiences

One study investigated childhood and adolescent experiences which guided coaches to where they are today (n = 1)(238).These experiences seemed to shape their intuition and gut feeling (238).

3.4 Discussion

Main findings

To our knowledge this is the first scoping review of the research on rugby union, rugby league and rugby sevens coaches. One hundred and one full text articles were eligible for this review. The final refined themes included *coach knowledge*, *coach pedagogies* and *coach development*. Our main finding within *coach knowledge* (n = 68) (35,133,149–158,134,159–168,135,169–178,136,179–188,144,189–198,145,199–206,146–148) was a positive trend in coach's knowledge of injuries, specifically concussions. Due to the nature of the game, education of injuries has been a focus for coaches in rugby over the years (131). According to the literature, the educational courses and additional input has increased injury knowledge amongst coaches. Although this is the case, coaches are still encouraged to continue educating themselves (35). While analysing the studies in the second theme, *coach pedagogies* (n=29) (207,208,217–226,209,227–235,210–216), five studies were implementing programmes or approaches to shift from coach-centred learning to player-centred learning (207,214,221,222,230). Some coaches were reluctant to make this shift while others acknowledged the difference it made to their player's development (214). *Coach development* includes the smallest number of studies (236–239), but highlights the gap in the literature. Overall, most of the research is done on coaches in rugby union followed by rugby league. Only one study investigated rugby sevens coaches. Given that coaches have one of the most influential roles in rugby, it is essential to have overview of what research has been done, the gaps in the literature and how researchers and practitioners should move forward.

Overview of numerical analysis

Throughout the numerical analysis, one can get an understanding of the methods used by qualitative studies, type of coach and qualifications of the coaches. This allows researchers to choose appropriate data collection methods for their study, find the gaps in the literature on coaches as well as the type of rugby being studied. In this review, interviews and questionnaires were the main method used for data collection. These methods allow researchers to collect in depth information from the participants (240). Interviews invite participants to describe the topic in detail whereas the questionnaire is more specific about the answer (240). United Kingdom Coaching Certificate (UKCC) Level 1 to 4 was the most common qualification for rugby union and rugby league coaches. Rugby union was commonly studied whereas rugby sevens only had one paper in this review.

Injury knowledge focuses on concussion

The main finding in this review is the positive trend of coaches' injury knowledge, specifically, coaches' concussion knowledge. In previous years, coaches had poor concussion knowledge, which led to players who were concussed being managed poorly (35, 173, 181). For example: Mathema et al. (2015) found that coaches could identify concussions correctly, but they would remove players from the field based on how the player is feeling (179), which could result in the player continuing to play the rest of the game, make poor decisions and possibly suffer from permanent brain damage (241). This example shows how coaches are key in the injury prevention process. Therefore, their knowledge of identifying concussions, understanding the gravity of a concussion and the return to play protocol is essential. Continuous education and input for coaches is needed which ensures that serious injuries are limited. Workshops and injury prevention programmes are other methods of injury prevention that were shown to assist coaches in this review (145). These programmes and workshops are implemented by the coach in their own setting. They can observe the positive changes in their players from these extra educational tools. Moving forward, the educational workshops, programmes or talks should occur on a regular basis, ensuring coaches are up to date with recent injury research/knowledge. An additional request from coaches throughout this review is to make the educational programmes or workshops more practical (133).

Coaches making a shift to coach-centred learning

Another substantial finding in this review is the shift from coach-centred learning to player-centred learning amongst the coaches. As mentioned previously, coach pedagogies are the different practices that coaches use to teach and develop their players. Coach-centred learning is the teaching style where coaches make all the decisions for the player and dictate how the game should be played whereas player-centred learning, focuses on the player learning and developing by themselves, including making their own decisions and learning from their mistakes or successes (221). Coach-centred learning was the main pedagogy that coaches used in this review. Through the implementation of player-centred learning interventions, coaches have found that player-centred learning can have positive outcomes for players and coaches (221). However, some coaches were reluctant to make this change and did not adjust their coaching style since they had been using their style of coaching for their whole career (214). Additionally, coaches mentioned how they did not only develop players on the field but off the field too (209). This highlights the importance of their coach's style and the impact it can have on the player. Player-centred learning is the better option but does have its limitations. This method of learning takes time for the coaches and players to see results. In this method of coaching, players make their mistakes and then reflect and learn from those errors to

come back and try again. Coaching assists in this process by helping the player realize the mistakes they are making. Although this will develop players who can make their own decisions in a game, it can take time to develop this thought process (214). Hopefully coaches continue to make their shift to player-centered learning.

Coaches' knowledge on monitoring players

There are many variables and aspects to monitor players in both the training and match setting. This can cause coaches to be lost in a sea of data and not focus on the essential variables. Eleven aspects of fitness were noted by Strength and Conditioning coaches in this review as important, which included acceleration, agility, anerobic capacity, body composition, cardiovascular endurance, flexibility, muscular endurance, muscular power, muscle strength, speed and other (170,171). Following on from this, Starling et al. (2017) investigated what rugby coaches want when monitoring fatigue and fitness (198). The authors found that coaches thought monitoring both the training load and the training responses of the athletes very important. Coaches placed an emphasis on monitoring physical and mental fatigue and recovery, which was spent monitoring players physical and mental fatigue for 5-10 minutes after every session (198). As mentioned previously 80% of coaches think session RPE was effective for monitoring performance and preventing injury (152). Coaches tend to use this variable to guide periodization, especially the taper period for players (152). Another important aspect of monitoring players is utilizing performance analysis. Painczyk et al. (2017) investigated into the utilization of performance analysis (187). The most concerning finding the researchers found were the lack of available video footage after a game which delays players having the chance to understand where they went wrong within the game. Additionally, most coaches (80%) did not have a budget for a performance analyst. Studies have also found that feedback reduces bias and allows for a more objective view on the player's performance. Unfortunately, the lack of funds and availability of resources results in the lack of feedback from coaches to players and a more subjective approach (187).

Gaps in the literature, future studies, and limitations

The purpose of this scoping review is to provide an overview of the current literature on rugby union, rugby league and rugby sevens coaches. Majority of the reviewed studies used interviews and questionnaires, whereas only four studies used observational methods. Although these studies have shown how coaches have knowledge on the subject, observational studies allow one to see change in the coaches practice (242).Future studies should focus on coach development, women's rugby

coaches and rugby sevens coaches. Only four studies were on coach development in this review, which highlights this gap in the literature (236–239). The consensus of these studies was that most coaches had being playing rugby their whole life and if you were a professional player previously, you were fast tracked in the coaching profession (236). Although this has some positive outcomes, it would be interesting to see how coaches, who were not always in the rugby scene, made their way to coaching positions. Coach development is an important aspect of understanding rugby coaches and how to assist them in their career path, therefore more research is needed. Additionally, future studies should focus on rugby sevens and women's rugby which were both poorly represented throughout this review. These rugby cohorts are fast growing, and further research of their coaches need to be done. This review is meant to be broad and give one an understanding of what we know about rugby coaches. In future, more specific reviews might be necessary if more detail is needed on a particular topic.

3.5 Conclusion

In conclusion, this scoping review found a positive trend in coach's knowledge of injuries, specifically concussions. Moving forward, continual practical educational input should be provided for our coaches to protect the welfare of our rugby players. Another finding was a shift from coach-centred learning to player-centred learning. Although, coaches are reluctant for this change it helps develop players to make their own decisions and read the game for themselves. Coaches thought monitoring both the training load and the training responses of the athletes very important. Coaches also think session RPE was effective for monitoring performance and preventing injury. Coaches tend to use this variable to guide periodization, especially the taper period for players. Another important aspect of monitoring players is utilizing performance analysis. Unfortunately, due the lack of funds and availability of resources, it results in the lack of feedback and a more subjective approach instead of the results one would get from performance analysis. Future studies should focus on coach development, women's rugby coaches and rugby sevens coaches. These topics were significantly underrepresented in this review.

3.6 Additional files:

Table S3.1*. Methodological quality assessment of the final full text articles according to JBI critical appraisal checklist for qualitative research.*

Study: Author (year)	Question number										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Avner et al. (2020) (207)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include
Bardon et al. (2021) (145)	NA	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Include
Basson et al. (2017) (144)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Bennett et al. (2018) (208)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Bennie et al. (2010) (209)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No (not specified)	Yes	Include
Bennie et al. (2012) (210)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Bennie et al. (2012) (211)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Blackett et al. (2018) (236)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	No (not specified)	Yes	Include
Blackett et al. (2020) (237)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Barrett et al. (2021) (146)	NA	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Include
Boardley et al. (2019) (147)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (not specified)	Yes	Include
Brown et al. (2016) (133)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Brown et al. (2020) (134)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Burt et al. (2014) (212)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	No (not specified)	Yes	Include
Carter et al. (2008) (148)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Cassidy et al. (2006) (213)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	No (not specified)	Yes	Include
Chapron et al. (2019) (214)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Include
Chiwaridzo et al. (2019) (149)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Chiwaridzo et al. (2019) (150)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Clacy et al. (2015) (35)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Clacy et al. (2017) (151)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include
Cole et al. (2018) (215)	NA	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Include
Collins et al. (2016) (216)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Comyns et al. (2018) (152)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Cooney et al. (2000) (153)	NA	Yes	Yes	Yes	Yes	No	No	Yes	No (Not specified)	Yes	Include
Cotterill et al. (2019) (217)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Cruickshank et al. (2013) (154)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Cupples et al. (2011) (155)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include

duPlooy et al. (2020) (156)	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Include
Fraas et al. (2014) (157)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Glaun et al. (1984) (158)	NA	Yes	Yes	Yes	Yes	No	No	Yes	No (Not specified)	Yes	Include
Gouws et al. (2020) (159)	NA	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Include
Griffin et al. (2017) (160)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Hall et al. (2015) (161)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Hall et al. (2016) (218)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No (Not specified)	Yes	Include
Hall et al. (2021) (219)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Include
Hapeta et al. (2019) (162)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Hassanin et al. (2014) (163)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (Not specified)	Yes	Include
Hassanin et al. (2018) (164)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Hendricks et al. (2013) (165)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Hendricks et al. (2017) (136)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Hill et al. (2015) (166)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Hodge et al. (2014) (167)	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include
Hodge et al. (2014) (220)	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include
Holmes et al. (2020) (238)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Jacobs et al. (2019) (168)	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (Not specified)	Yes	Include
Jones et al. (2014) (169)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Jones et al. (2016) (170)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Jones et al. (2017) (171)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Kemp et al. (2015) (172)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
King et al. (2010) (173)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Kraak et al. (2018) (174)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Kroon et al. (2016) (175)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Lewis et al. (2015) (176)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Light et al. (2010) (221)	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No (Not specified)	Yes	Include
Light et al. (2014) (222)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include
Llobet-Martí et al. (2017) (223)	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (Not specified)	Yes	Include
Malcolm et al. (2002) (177)	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (Not specified)	Yes	Include
Males et al. (2019) (224)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Martindale et al. (2013) (178)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Mathema et al. (2015) (179)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include

McCormack et al. (2020) (180)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
McCormack et al. (2020) (181)	NA	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Include
McCormack et al. (2021) (182)	NA	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Include
Middlemas et al. (2018) (183)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	No (Not specified)	Yes	Include
Morgan et al. (2020) (225)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Mouchet et al. (2013) (226)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No (Not specified)	Yes	Include
Mouchet et al. (2018) (227)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (Not specified)	Yes	Include
Muniz et al. (2018) (184)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	No (Not specified)	Yes	Include
Nicholls et al. (2015) (185)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Niederer et al. (2018) (186)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
O'Malley et al. (2017) (228)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Include
Painczyk et al. (2017) (187)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Painczyk et al. (2018) (188)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Pettersen et al. (2002) (189)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Piggott et al. (2012) (229)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No (Not specified)	Yes	Include
Pocock et al. (2020) (190)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Pote et al. (2021) (191)	NA	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Include
Poulos et al. (2011) (192)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Poulos et al. (2014) (193)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Reid et al. (2014) (230)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No (Not specified)	Yes	Include
Robinson et al. (2019) (194)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Romand et al. (2007) (231)	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (Not specified)	Yes	Include
Rothwell et al. (2019) (195)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Salmon et al. (2020) (196)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Sewry et al. (2017) (135)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Sharp et al. (2013) (232)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Shill et al. (2021) (197)	NA	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Include
Starling et al. (2017) (198)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Thelwell et al. (2010) (239)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Thomas et al. (2013) (199)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Thomas et al. (2013) (233)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Thomas et al. (2016) (200)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Van Vuuren et al. (2020) (201)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include

Vinson et al. (2017) (202)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Walters et al. (2012) (203)	NA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Include
White et al. (2013) (204)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Whitehead et al. (2016) (234)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Williams et al. (2017) (235)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Woodcock et al. (2011) (205)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include
Zinn et al. (2006) (206)	NA	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Include

1. Is there congruity between the stated philosophical perspective and the research methodology? 2. Is there congruity between the research methodology and the research question or objectives? 3. Is there congruity between the research methodology and the methods used to collect data? 4. Is there congruity between the research methodology and the representation and analysis of data? 5. Is there congruity between the research methodology and the interpretation of results? 6. Is there a statement locating the researcher culturally or theoretically? 7. Is the influence of the researcher on the research, and vice- versa, addressed? 8. Are participants, and their voices, adequately represented? 9. Is the research ethical according to current criteria or, for recent studies, and is there evidence of ethical approval by an appropriate body? 10. Do the conclusions drawn in the research report flow from the analysis, or interpretation, of the data? NA: Not Applicable

Table S3.2. *Coach knowledge related articles.*

Study: Author, (year)	Rugby code cohort:	Type of coach:	Level of coach/es:	Purpose of study:	Data collection methods (Questionnaire/intervention):	Sample size of coaches:	Conclusions:
Coaches' knowledge on injury prevention							
Barden et al. (2021) (145)	Rugby union	Rugby coaches (including medical staff and strength and conditioning coaches)	School level	The aim of this study was two-fold. The primary aim was to assess the effect of a pre-season coach workshop on *Activate* and assess the differences in post season HAPA scores between those who attended the workshop and those who did not.	Survey	76	All coaches agreed that injuries can shorten a player's career and cause them physical issues later in life. They also agreed that injuries are preventable. Coaches who attended the *Activate* workshop were more likely to adopt it in their practice. These results display how workshops are useful when trying to implement a programme. The *Activate* workshop did not change the perceptions of the coaches.
Brown et al. (2016) (133)	Rugby union	School or club coaches	NA	This study aims to investigate perceptions of coaches and referees about the implementation of BokSmart programme.	Interviews and focus groups	43	Coaches had both positive and negative perceptions of the BokSmart programme. The negative perceptions were predominately from the higher socioeconomic status coaches. This is possibly due to the coaches coming from high socioeconomic status already have the knowledge that you obtain from the BokSmart course. Low to mid socioeconomic status coaches struggled to implement the BokSmart techniques due to lack or resources. It is also highly probable that the high socioeconomic coaches have a false sense of security that they will not experience a catastrophic injury which could be the reason for the negative perceptions. Coaches also felt that they could benefit from the course being shorter and more practical.
Brown et al. (2020) (134)	Rugby union	Rugby union coaches	Most coaches had attended the BokSmart course and has some form of coaching qualification	This study aims to determine the effectiveness of the BokSmart course based on the coaches and referee's behaviour.	Questionnaire	390	The only meaningful change after the 2012 BokSmart course was knowledge of scrum and tackle techniques and rules. However, it was noted that the questionnaire could have a 'ceiling effect' as the scores before the course were high. Coaching experience had no association on the outcomes. It was noted that this is a concern due to the coaches relying heavily on past experiences for their learning resource.
Malcolm et al. (2002) (177)	Rugby union	Rugby union coaches	NA	This study aims to investigate injury management in elite rugby union.	Interviews	7	There was the lack of medical provision which has negative consequences. Players were returned to play too quickly and had to go to hospital for simple medical care, such as stitches, during a match. Coaches reported that they know they play a role in protecting players from injury. One coach said that the pressure from professionalism in rugby has led to a reduction in professionalism from his players. The coaches additionally reported that rugby becoming professional has led to no increase in injuries.
Pote et al. (2021) (191)	Rugby union	Rugby coaches,	NA	This study aims to investigate the injuries and injury	Questionnaires	25	Majority of the school recorded injuries but 25% did not record any injuries. The most injured players that were reported is the back row

		Strength and Conditioning coaches, or medical staff of rugby first team		prevention strategies of the first team rugby practitioners.			and the shoulders being the most common body part. Majority of the public and private schools implemented injury prevention programmes while non-fee-paying schools hardly implemented injury prevention programmes. Strengthening target areas was the most common method for injury prevention amongst all schools.
Poulos et al. (2011) (192)	Rugby union	ARU rugby union coaches	NA	This study aims to investigate the understanding of the Mayday procedure among rugby union coaches.	Questionnaire	67	The senior community rugby union coaches know about the Mayday procedure from ARU coaching education and believe it is effective in preventing injuries. 72% of the coaches found the Mayday procedure effective. Coaches highlighted benefits of the Mayday procedure such as: increasing confidence in players, increasing participation in the sport, relieving parents, and loved ones of worry, showing ARU's commitment to safety, providing a standard of safely amongst the sport and increasing awareness about safety in rugby. 92% of coaches train the mayday procedure regularly ad believe their players could execute it when necessary. Barriers during training included: not enough players, not taken seriously, technical problems, lack of time and confidence in teaching. ARU courses, experienced coaches, personal and practical experience helped with training but more translation into the community needs to occur. Coaches were mostly confident in training the Mayday procedure and intended to carry on training.
Poulos et al. (2014) (193)	Rugby union	Rugby union coaches	NA	This study aims to investigate the effectiveness of translating safety initiatives in community sport.	Interviews and questionnaires	70 for the questionnaire and 88 were interviewed	Most coaches were aware of the Mayday safety procedure and attended Mayday safety procedure training. There was a significant increase in knowledge post intervention. Coaches from certain intervention zones were required to train the Mayday safety procedure and found improvements of knowledge of the procedure, coaches recognised they needed to train players, frequent resources to train players, the coaches' belief of quality training for players and confidence in referee to adequately implement the procedure if needed. They believed the Mayday safety procedure was effective and increased the will to play in the front row which was always a challenge. The diffusion plan assisted in creating skills, beliefs and knowledge and encouraging environments in including safety interventions.
Sewry et al. (2017) (135)	Rugby union	Rugby union youth week coaches	NA	This study aims to evaluate the knowledge and awareness of coaches and players towards the BokSmart Safe Six programme.	Questionnaires	112	This study showed significant increase in the knowledge and awareness from the BokSmart *Safe Six* injury prevention programme. Coaches have also transferred their knowledge and awareness of injury prevention to their players. Coaches explained that they thought the *Safe Six* programme was for the warmup and improve performance. It was noted that there possibly a misunderstanding that coaches think this programme is for performance and not injury prevention. Social media, news outlets and SARU/Unions were the main sources of *Safe Six* information for coaches.

Shill et al. (2021) (197)	Rugby union	Youth rugby coaches	NA	This study aims to describe the current warm up for youth rugby, the coach beliefs and attitude on injury prevention, the intention to implement a NMT warm up for youth rugby and the outcome expectancy following the workshop.	Survey	48	85% of coaches used a warm-up which was mostly aerobic and included some balance. All coaches rated concussions and spinal injuries as the most serious injury. Prior to the workshop, most coaches strongly agreed to a rugby specific warm-up before a game. Most coaches believed that a player would get injured during a season and that most injuries were preventable. All coaches understood the risk of injury in youth rugby. Most coaches had a high intention to implement the programme in their training.
Coaches' injury knowledge							
Carter et al. (2008) (148)	Rugby union	Rugby union coaches	Level 0, 1 or 2 Australian rugby union coaching qualification or no coaching qualification	This study aims to investigate the knowledge of management and mechanisms of injuries and technical needs of coaches in junior rugby union.	Interview and questionnaire	35	Only a third of the coaches identified the leg as the most common injured area by the ball carrier, the head and neck for the ruck/scrum and half of coaches identified the shoulder the most likely injury location for the tackle. More than half of the coaches identified the tackle as the injury event that causes the most injury. Around half of the coaches identified RICE as the treatment for a bruise or strain. Coaches additionally identified that a previous injury is a factor contributing to a re-injury. Coaches stated that they need increased knowledge about technical skill for the scrum. Although these technical needs were associated with coaches who had no ARU qualification. The more coaching sessions the coaches took and the ARU qualification, the higher the injury knowledge score. Coaches in this study do have a limited knowledge of injury mechanisms and management in rugby union. Coaches would benefit from education on injury risk management as the current ARU may not provide sufficient knowledge on soft tissue injury management.
Clacy et al. (2015) (35)	Rugby union	Rugby union coaches	NA	This study aims to investigate how individuals in community rugby union perceive their responsibilities to prevent concussions.	Questionnaire	16	Most coaches in this study were involved in a concussion at some point and believed that coaches play a role in concussion prevention. Coaches identified training properly, teaching and correcting technique and educating players, parents and themselves was their role to play in concussion prevention. Coaches noted that being able to identify a concussion and educating players and parents about symptoms were essential. Some coaches also noted that coaches have the responsibility to provide a safe environment for the players, ensure they are fit to play rugby and follow safe return to play protocols.
Clacy et al. (2017) (151)	Rugby union	Rugby union coaches	NA	This study aims to investigate the knowledge of concussion management among different levels of the rugby system.	Questionnaire	17	Most coaches were able to identify concussion symptoms, only one coach was not able to do so. Most coaches thought it was their responsibility to remove the injured player from the field, identify a concussion, and to seek out medical assistance. This study found that there was too much relance on the medical professionals. It was recommended that medical professionals should be at every rugby game and training sessions and all players should have the same baseline test.

Cooney et al. (2000) (153)	School rugby	School rugby coaches	Majority of the coaches participated in IRFU coaching schemes and some had no qualifications	This study aims to investigate the knowledge of management and prevention of serious neck injuries among school rugby coaches.	Questionnaire	36	To prevent serious neck injuries, school rugby coaches reported preventative measures such as ensuring players are flexible, strong and fit, and vigilant coaching. Neck strengthening exercises were included in most of the coaches training programmes. 97.2% of coaches in this study matched players for their age. Concerning factors were that the majority of the coaches only started pre-season training 2-4 weeks before in season and only 50% of the coaches had first aid qualifications. Most coaches did know not know to move a player when injured and to seek medical assistance. Additionally, first aid signs and symptoms were not identified well. Education of schoolboy rugby coaches about serious injuries is recommended.
Fraas et al. (2014) (157)	Rugby union	Head and assistant rugby union coaches	NA	This study aims to investigate the concussion knowledge and management among rugby union coaches.	Questionnaire	6	Overall, the coaches have an adequate knowledge of the management, knowledge of concussion practices. All coaches agreed that being unconscious was not the only result of a concussion. Coaches were able to identify various correct symptoms of a concussion (78-100% accurate). They were open to baseline testing for identification of concussions if it allowed faster return to play and better medical decisions. As for the best course of treatment, coaches believe rest, followed by non-contact training was the best method. Majority of the coaches believe the doctor was best suited to determine return to play dates. However, most coaches believed that if a player had no symptoms, they are ready to return to play. It is recommended that coaches continue to update their knowledge of concussions.
Glaun et al. (1984) (158)	Rugby union	First team school rugby union coaches	NA	This study aims to investigate the first aid facilities available and medical cover at school rugby matches and coaches' knowledge of managing serious head and neck injuries.	Questionnaire	29	It was very concerning that, overall, the coaches have little knowledge on how to deal with serious injuries. 38% of the schools put the coaches in charge of first aid. Only 62% of the coaches had first aid training. Majority of coaches did not know that if a player is unconscious, they should treat the player as if they have a serious neck injury and if they are conscious you must ask if their neck hurts before moving them. Coaches need to undergo first aid training.
Gouws et al. (2020) (159)	Rugby union	Rugby coaches	School level	The aim if this study is to investigate the if the coaching knowledge of injuries and prevention of injuries translates into youth rugby.	Questionnaire	16	The coaches first aid knowledge increased over the years but is still not sufficient. Knee injuries were the most common injury in school rugby. Injuries occurred when players were training too little or too much. Coaches need to prepare their player more adequately and improve their knowledge on preventing injuries.
Griffin et al. (2017) (160)	Rugby union	Rugby union coaches	NA	This study aims to investigate the knowledge of concussions among the rugby union coaches and referees.	Questionnaire	337	Overall, there was a good level of knowledge regarding concussions among coaches. Coaches have a strong knowledge of recognising signs and symptoms. The average symptom recognition score is higher than previous studies. Coaches seem to be benefiting from concussion education. However, there were a few misunderstandings. Concerning areas were return to play knowledge and the misunderstanding about the effectiveness of protective headgear against concussions. It is concerning that some coaches saw other coaches letting a potentially concussed player continue being on the field.

Kemp et al. (2015) (172)	Rugby league	Rugby league coaches	NA	This study aims to investigate the attitudes, experiences, and challenges the rugby coaches and trainers have when using the concussion guidelines over the competitive season.	Questionnaires	17 rugby league coaches and 13 rugby league trainers	Coaches and trainers in rugby league use the concussion guidelines to make the decisions to remove players from the field if they have a suspected concussion and inform the players and parents about the suitable time for the player to return to play. Both coaches and trainers find it hard to make these decisions and find they have pressure from players and parents to return players faster than they should to the field. The coaches noted that there is a lack of support from the coaching staff on these decisions. The attitudes vary among the coaches and trainers. It was recommended that the guidelines should be very clear and easy to use. The importance of the guidelines needs to be explained to coaches and trainers. Education about concussions is recommended for players and parents.
King et al. (2010) (173)	Rugby league	Rugby league coaches	A rugby league qualification	This study aims to investigate the first aid and concussion knowledge of the rugby league team.	Questionnaires	50	The first aid knowledge results were concerning amongst coaches. No coaches passed the first aid knowledge score and only 48% had a first aid certificate. These results can have a big impact on the players safety. Coaches knew concussions were serious and that it impacted the players outside of rugby. The most concerning factor was that 78% of coaches believed that players could return to player after 7 days post-concussion and did not require medical clearance before returning. Although majority of the coaches had the knowledge to identify a concussion and knew it had long term side effects, there is a need for concussion education among coaches in rugby league.
Mathema et al. (2015) (179)	Rugby union	Rugby union coaches	NA	This study aims to investigate the experiences and level of concussions knowledge among rugby union team.	Questionnaires	44	Overall, the coaches in this study had the worst level of concussion knowledge. Most coaches did know to remove a player when they are showing signs of a concussion. A concerning factor is that coaches rely a lot on how the player is feeling to warrant being taken off the field and not what happened on the field. Some coaches also believe equipment will protect against a concussion although this is proven not to be the case. The negative impact one less player has on a team influences the coach's decisions to remove a player from the field. Therefore, education for coaches on concussions is needed preferably from the medical staff.
Niederer et al. (2018) (186)	Rugby	Head, assistant, or athletic rugby coaches	NA	This study aims to investigate the knowledge and implementation of return to play guidelines after a concussion.	Questionnaire	61	The implementation of concussion guidelines and concussion knowledge varies across the team. The coaches did not know common concussion diagnosis tools such as GCS and SCAT. The coaches tended to pass the decision making onto someone else in the team regarding concussions. Coaches had little knowledge on concussion symptoms and long-term effects. Although coaches knew about return to play protocol, they did not apply this knowledge. Education, empowerment, and awareness about concussions for coaches need to be put in place as the medical team are not always present.
Pettersen et al. (2002) (189)	Rugby union	Canadian rugby union coaches	NA	This study aims to investigate the attitudes of headgear to prevent concussions in players and coaches in rugby union	Questionnaire	9	Most coaches were not convinced that headgear could help against the risk, the severity, or the incidence of concussions. They thought that it could lead to player getting more injuries as they have a 'false sense of security'. There were a few coaches thought headgear was effective.

							Education and research need to be done on the use of headgear in rugby.
Salmon et al. (2020) (196)	Rugby union	Rugby union coaches	NA	This study aims to investigate the concussion knowledge, attitudes and reporting intention of high school coaches and players.	Questionnaires	733	All coaches in New Zealand are required to attend the RugbySmart course every year. The concussion score of coaches were higher than players. Coaches can identify concussion symptoms and long-term effects. The coaches' attitude towards concussion were very positive. A concerning factor was that only 56% of coaches thought to take the player to the hospital when unconscious. During the season, the coaches' attitude towards concussions dropped during the season. The reasoning behind this is player take risk during the final stages of the competition. Coaches' intention to report concussion and ensure players are fully recovered when returning to play was high. Coaches experience is associated with a positive concussion attitude.
Van Vuuren et al. (2020) (201)	Rugby union	Western Province rugby union coaches	NA	This study aims to investigate the concussion knowledge and attitude of rugby union stakeholders.	Questionnaire	37	BokSmart courses and workshops seem to have a positive influence on the coaches' attitude and knowledge about concussions. Coaches had a high score with concussion risk taking and according to the knowledge of concussions for coaches, the score was sufficient.
White et al. (2013) (204)	Rugby league	Rugby league coaches and trainers	NA	This study aims to investigate the knowledge of concussion safety among coaches and trainers.	Questionnaire	267 were rugby league coaches and 228 were rugby league sports trainers	Overall, this study found that rugby league coaches and sport trainers had a good knowledge about concussions. The one misunderstanding was that players who have sustained a concussion can be returned to player when they are not showing anymore symptoms. Coaches need to understand that players must return to play gradually once cleared by the medical staff. Concussion management guideline still need to be embedded in the rugby community.
Coaches' training knowledge							
Basson et al. (2017) (144)	Rugby union	Western Province mini rugby union coaches	BokSmart accredited, IRB level 1, IRB level 2, other qualifications, or no qualifications in coaching rugby	This study aims to investigate mini rugby union coaches.	Questionnaire	91	This study reported a lack of knowledge, confidence, and coach education amongst mini rugby union coaches. Although majority of the coaches felt well equipped and were coaching rugby players optimally, 23% of coaches believed they were not equipped for the role and were not coaching rugby players adequately. Possibly because many of the rugby coaches did not have any rugby qualifications. It is recommended to design a mini rugby union coaching course to educate and guide mini rugby coaches.
Barrett et al. (2021) (146)	Rugby union	Women rugby coaches	Level 2 RFU or IRFU	The aim of this study was to investigate the experiences of women rugby coaches in UK and Ireland.	Interviews	21	Coach education courses in UK and Ireland develop excellent knowledge and skills. These courses were interactive and practical which created a positive experience. It was still felt amongst coaches that it is a male dominating sport in these courses. However, this was advantageous when they could interact and display their knowledge to the male coaches and in turn learn from them. Coaches noted that there should be more women tutors in the coaching courses.

Chiwaridzo et al. (2019) (149)	Rugby union	High school rugby union coaches	NA	This study aims to investigate the perceptions that coaches believe motivate school rugby union participation and strategies for team selection.	Interviews	22	Coaches have key insight into the motivation of schoolboys to play rugby. The overall theme for school rugby participation is that it is their choice to play. There were various intrinsic and extrinsic factors contributing to why schoolboys participate in rugby. Intrinsic factors included personal preference, passion, enjoyment, and the nature of the sport (the physical nature, accommodations, and spectator presence) and extrinsic factors included influence from other peers, professional ambitions, and financial rewards. Coaches additionally noted that parents and team selection played a big role in their participation to play rugby. In conclusion all motivation is an individualised choice, and it is influenced by environmental and contextual factors. For team selection coaches looked at a range of qualities including training performances, physical qualities, rugby skills, attitudes, and fitness.
Chiwaridzo et al. (2019) (150)	Rugby union	High school rugby union coaches	NA	This study aims to investigate the coaches' perceptions on qualities of a good rugby player and what qualities are considered when selecting for talent identification programs.	Interviews	22	Coaches identified qualities of rugby players that are considered for talent identification programmes under four themes including: physiological characteristics, anthropometric attributes, rugby skills and psychological qualities. Under physiological characteristics, qualities such as muscular strength, power, endurance, anaerobic capacity, speed, and recovery time were considered important for a good adolescent rugby player. Anthropometric attributes included the ideal height and weight. Rugby skills included the player performing passes, handling the ball, catches and tackles. Psychological qualities include game sense, decision making, visual and auditory skills were important. Lastly, coaches noted that the player must be coachable, have courage, discipline, passion and be hardworking.
Comyns et al. (2018) (152)	Rugby union	Strength and conditioning coaches	NA	This study aims to investigate if strength and conditioning coaches find the session-RPE method effective and valid.	Questionnaire	20	Majority of the coaches collected session-RPE 15 minutes after the session and was collected verbally. Although it must be noted that 41% of the coaches took the session-RPE reading immediately after the session which is not advised. Another concerning factor was 30% of the coaches did not collect session-RPE after every session making it hard to conclude accurate training load. Half of the coaches used session-RPE for periodisation of the players training program. 80% of coaches believe that they found session-RPE valid and effective for quantifying training sessions. Coaches did mention they found it effective to monitor both injury prevention and optimising performance.
Cruickshank et al. (2013) (154)	Rugby union	Rugby union specialist coach	NA	The study aims to investigate the culture change in professional sport.	Interviews	3	The culture change within the team was assisted but coaches and management. The coaches have started to recentre the team culture by optimising the performance of staff and players. The team shifted away from drinking heavily after away matches to optimising high performance. The coaches tried to ensure there was a balance in player's ability. An emphasis was put on holistic training by focusing on players who were not selected for the team by providing a reason behind it, ensuring competition time, provide an individualised

							programme and recognition of their abilities. Another focus was to have an 'open door policy' and providing an opportunity for feedback.
Cupples et al. (2011) (155)	Rugby league	Head and assistant rugby league coaches and trainers	NA	The study aims to investigate the factors of performance for rugby league players.	Interviews and questionnaire	13	Coaches identified various performance indicators of performance for rugby league players. Coaches agreed that communication and mental toughness amongst all positions were important cognitive indicators. Halfback, five eighth and hooker indicators were being able to concentrate, make decisions under pressure, to organise and to cope with the constant physical load. Reading the game was a significant indicator for outside backs and adjustables. 'Reading the play' and decision making are indicators for hookers, fullbacks, halfbacks and five eighth. Centres and wingers need to be able to make decisions at speed for both attacking and defensive situations. Second rowers' need to be able to make accurate decisions. For elite level specifically players need to have a good attitude, be disciplined and coachable. Different game skill indictors were different amongst the positions, specifically, front rowers: ball carry, lock: defensive techniques, fullback: support play and hooker: dummy half pass. Many of the positions shared crucial skill sets. Physiological factors include ball speed for wingers, strength for front rowers, strong aerobic capacity for hookers, second rowers and locks, and agility and mobility for centres and second rowers. Coaches further highlighted the importance of off-field behaviour – living a good lifestyle, working hard at school/work and the player's character. Coaches found that cognitive factors were the most important.
duPlooy et al. (2020) (156)	Rugby union	Head coaches	International level	The aim of this study was to understand the leadership challenges of South African rugby coaches.	Interviews	6	The coaches felt that the slow decision making from SARU was a problem. This creates delays, confusion, and frustration. They also felt that there was a lack of professionalism in SARU. Another environmental factor that coaches pointing out was the economic conditions in South Africa which draws players and coaches overseas. All coaches agreed that having good and effective relationships with the board of the unions and SARU is important. However, there seems to be a lack of communication between coaches and the board. Another challenge is managing and understanding players, especially when they are from different cultures and backgrounds. Coaches also feel a large amount of pressure and are sometimes unsure about their future.
Hall et al. (2015) (161)	Rugby union	Rugby union head coach	Second highest certificate of coach education	This study aims to investigate the microstructure of a female head coach's coaching practice.	Rugby Union Coach Observation Instrument (RUCOI)	1	Most of the player's training was spent focusing on playing form. These methods align with the Game Sense approach. However, the coach does spend time on training form which allows for more short-term improvements in technical performance. Both playing form and training form have their benefits which confirms why she would blend the training activities. The coach held importance to discussing matters with her colleagues during training to ensure clarity and sharing of information. The coach spent little time engaging with her players during the matches. On match day there was always a warmup with no

							focus on playing form. Questioning and praising players varied throughout the season and activities.
Hapeta et al. (2019) (162)	Rugby union	Head rugby union coach	NA	This study aims to investigate how the Maori knowledge and values influence the rugby team.	Interviews and group discussions	6	The inclusion of pūrākau (Māori stories) and the 'Maunga of Success' model into the team's lifestyle (on and off the field) allowed players to embrace the culture, have a sense of belonging and develop good leadership. The coach found that this connected the team to high performance. This model includes 5 tiers: physical, technical and tactical, brotherhood, leadership and 'the ultimate competitor'. This created an attitude change in the team. Leadership developed by earning respect from the players and always try your best which follows the All Black mantra- 'Better people make better rugby players'. The Māori values of being excellent, resourceful, holistic wellbeing and resilient have enhanced the wellbeing and performance of the team. There were no negative comment or findings.
Hassanin et al. (2014) (163)	Rugby union	Head rugby union coach	NA	This study aims to investigate the socio-culture influence of the rugby coaches' beliefs about coaching.	Interviews	3	Coaches have developed their beliefs through their past experiences of coaching and playing rugby. These beliefs have been influenced by the local culture. Respect, sacrifice, controlled aggression, persistence, and hard work are qualities that the coaches believe are needed in rugby players. These qualities were valued more in rugby players than the desire to win. They believed that coaching was about developing moral and ethical values and developing character. This extended past rugby from the player to the person. Teamwork was strong indicator for team selection – including commitment and putting the tam above themselves. The coaches cultural influence differed depending on the country they were in. The culture strongly influenced the coaching practices by the emphasis being placed on values and character of the players and how the coaches taught their players.
Hassanin et al. (2018) (164)	Rugby union	Head rugby union coach	Level 3 New Zealand Rugby union coaching accreditation	This study aims to investigate how the cultural context influenced the rugby coaches' beliefs about coaching.	Interviews	3	The coaches focused mainly on developing good people through their coaching practices and used the athlete-centred approach. They emphasised the importance of learning traditional values and morals than skill development. The rugby clubs in New Zealand play a big role in player development. Coaches ensure players are devoted to the club and give back to the club before moving on with their careers. Players who held good values, put the club and the team over themselves were essential for creating a good team culture. Team rituals ensured the good team culture was maintained – including war cries, uniform, showing respect to the referee and dress codes for matches. The coaches believed in holistic and humanistic coaching. Education and socialising are an important part of their coaching pedagogies for development of the person. They believed that the coach-player relationship was essential on and off the field. The Māroi culture influenced rugby in general, the way the coaches taught and what they valued. The haka and the concept of mana played a big role in their coaching pedagogies and how the player competed.

Hendricks et al. (2013) (165)	Rugby union	Western Province Rugby union school coach	Majority have level 1 or 2 coaching qualification. All coaches had done the BokSmart courses	This study aims to investigate the attitudes and behaviours of school rugby coaches towards coaching tackle technique.	Questionnaire	7	Overall, there was a strong, positive attitude amongst the coaches regarding injury prevention. The majority of coaches stated that proper tackle technique was important to prevent injury and improve performance. Other technical skills that were indicated as important to prevent injury were proper ball carrying, scrumming, tackling and rucking technique. Additionally, 'falling to the ground' was noted as an important technique. Coaches mainly gain knowledge and awareness from fellow coaches and rugby matches (TV and live). Padded equipment and verbal guidance were the most important methods used by coaches to prevent injury and optimise performance of the tackle. Although, this study had positive outcomes, coaches need to be educated on how to reduce risk of injury among technical skills.
Hendricks et al. (2017) (136)	Rugby union	Western Province rugby union coaches	Level 2 or 3 or no qualification. All had completed the BokSmart safety course.	This study aims to investigate the attitude, knowledge, and behaviours of rugby coaches towards the tackle.	Questionnaire	8	The coaches in this study had a positive attitude and vast knowledge of the important of coaching proper technique of the tackle, high injury risks and the inclusion of scientific knowledge. Coaches had a good attitude towards implementation of injury prevention programmes to reduce injury risk and improve performance. Although coaches believed that tackle technique was important, only 16% of their training sessions consisted of tackle training and only used equipment 50% of the time which emphasises that coaches' behaviour and attitudes are not aligned. Education of coaches were predominately via comminating with other coaches or watching rugby matches. Coaches need to be educated practically and theoretically on proper tackle technique to ensure coaches are confident coaching.
Hill et al. (2015) (166)	Rugby union	Head rugby union coaches	NA	This study aims to investigate the coaches' perspective of psychological characteristics and behaviours for the talent development process.	Interviews	15	Coaches identified various positive and negative characters of players that are successful and unsuccessful. A few positive psychological characteristics identified by the coaches were commitment, resilience, ability for the player to make sacrifices, motivation, ability to focus and a good work ethic. Players who did not show these characteristics were dropped from the programme as players need to drive their own development. Additionally, the coaches identified dual-effect characteristic which included characteristics that were positive but if the player is obsessive, it could have maladaptive effects. For example: obsessive passion and perfectionism. The coaches did believe that they had interventions and support for players who struggled with these characteristics. A few negative psychological characteristics included players using avoidance based coping strategies, affirmation seeking players, lack of commitment, inconsistency, and inability to sacrifice. Coaches noted that mental health issues were becoming more prominent in rugby. Where the coaches referred players to doctors and psychologists, there was still a lack of awareness among coaches.
Hodge et al. (2014) (220)	Rugby union	Head and assistant rugby union coaches	NA	This case study aims to investigate the motivational development of the All Blacks' rugby team.	Interviews	2	Head coach of the All Blacks made changes in the team environment, moving towards a leadership group, giving players more accountability and ownership and allowing for dual management of the team (the player and coaches). The coaches used more dynamic and flexible

							coaching pedagogies and encourage the players and staff hold legacy and culture with pride. The team followed the saying "Better People Make Better All Blacks" and celebrated success of current and past players. Additionally, the coaching staff were all on the same level – no hierarchy. Overall, the All Black coaches encourage a motivational environment but allowing player to have choices, accountability, expectation of excellence, make decisions, take initiative, work as a team, and provide empowering feedback.
Jacobs et al. (2019) (168)	Collegiate rugby	Head and assistant USA rugby collegiate coaches	NA	This study aims to investigate the coaches' perspectives of referee abuse.	Interviews	15	Personal characteristics, relationships, social influences, expectations, and culture were factors that influence other coaches to engage in referee abuse. Ego was one of the main factors of personal characteristics that coaches identified. Some coaches devalued referees, especially if their main goal was winning. When coaches had a relationship with the referee, they were likely to not be abusive towards them and realise that referees were valuable. Coaches emphasise that they are role models to the players which reduces their possibility of abusing referees. They also believe that coaches need to teach their players to respect their coach and be an example. If not, their players believe it is okay to abuse the referees. Coaches believe that referees need to be fair and provide a safe environment for players to play rugby. When that is not the case there will be an increase in abusive behaviours especially when players are not being protected. The rugby culture is respectful; however, other sports do not have the same level of respect which influences referee abuse when a player or coach moves to rugby.
Jones et al. (2014) (169)	Rugby league	Strength and conditioning coaches, development coaches and head coach	NA	This study aims to investigate the coaches' perceptions of the transition from sub-elite to elite rugby league player.	Interviews	9	Coaches found that there needs to be a balance of personal and environmental demands and critical incidences when a player is transitioning from sub-elite to elite player to prevent discourse of the player. The transition is stressful, so players need to be personally developed and ready for elite competition to make the change. The players attitude, physical ability, ability to learn, and discipline are personal qualities that assist during the transition period. Coaches agreed strongly that work ethic was an important theme. Players' identity, activities off field, physicality, and injury status play a big role in the transition process. Resources for the psychological level of players is coping mechanisms, confidence and support and the psychosocial level includes the nature of the club's culture, off field activities and the expected role the player must meet.
Jones et al. (2016) (170)	Rugby union	Head, senior, academy strength and conditioning coaches	Multiple Strength and conditioning qualifications.	This study aims to investigate the training and monitoring of the rugby strength and conditioning coaches.	Questionnaire	43	Coaches reported that they test 11 aspects of fitness. Body composition was the most common followed by speed, muscular power, acceleration, and strength. Tests were completed during pre-season and in-season. Strength training was completed on a regular basis (majority 3 days a week) because coaches believe it is important for performance. 3-5 sets of 5 reps based on repetition max were prescribed during in and off-season training. Free sprinting and

							plyometrics were the most common exercises for speed training. Most coaches used periodisation strategies for their strength and conditioning programmes. Coaches preferred to practice strength then endurance training to prevent any concurrent training effect. Refer to article for specific details.
Jones et al. (2017) (171)	Rugby union	Head, senior, academy strength and conditioning coaches	Multiple Strength and conditioning qualifications.	This study aims to investigate the difference in monitoring and training of strength and conditioning coaches in the southern and northern hemisphere.	Interviews	40	Eleven aspects of physical testing occurred in pre and in-season period in both the northern and southern hemispheres. Southern hemisphere coaches tested more for agility then northern hemisphere coaches. Although the remainder of the testing was similar amongst the different hemispheres there were differences in protocols. All coaches included strength training and Olympic weightlifting exercises. The squat was the most important exercise occurring to coaches. 3 days of strength training per week in season and 4 days a week in off season period was the most common frequency for strength training. Free sprinting was the most common speed test for northern and southern hemispheres. Northern hemisphere coaches taught more sprint mechanics where southern hemisphere coaches used more plyometrics. Coaches integrated both endurance and anaerobic training in their programmes. Refer to article for specific details.
Kraak et al. (2018) (174)	Rugby union	Head rugby union coaches	World Rugby Level 2 qualification, South African Rugby Union qualification or another qualification	This study aims to investigate the head rugby coaches' use of performance analysis.	Questionnaire	46	All the coaches used performance analysis and thought it was a very useful tool. The majority of coaches had full access to the video footage, predominately the provincial and school coaches. University and school coaches only get video footage two days after the match. Most coaches, especially the university coaches, did their analysis themselves as there is no access to a performance analyst and they like to assess the findings. When coaches have the results, they mainly use it to provide feedback to players, decide team selection, to plan and to adjust their game strategy. Only provincial coaches film their training sessions daily. Benefits or performance analysis include assessing players' spatial awareness and technical ability. Coaches did find that performance analysis was time consuming, and they struggled to have the right equipment and time to work on it. Coaches felt confident and flexible in their key performance indicators when analysing the footage. Rugby clubs, universities and schools need performance analysists to be accessible to relieve the coaches of this task.
Kroon et al. (2016) (175)	Rugby league	Rugby league coaches	NA	This study aims to investigate the attitude, awareness and knowledge of mouthguard use of coaches.	Questionnaire	32	Most of the coaches promoted the use of mouthguards amongst players. Their recommendation was to use the custom-made mouthguards. 90% of coaches had delt with a face injury previously. Most of the coaches believed that a dentist could sort out a knocked-out tooth. 41% thought you had to reinsert the tooth themselves within 15 minutes. Majority of coaches thought that one transported the tooth in a milk or water medium to the dentists. In conclusion, coaches are aware of the benefits of a mouthguard but need to translate it to their players. Coaches need to be educated about traumatic dental injuries.

Lewis et al. (2015) (176)	Rugby union	Rugby union coaches and development officers who had coaches	NA	This study aims to investigate the presence of relative age effect in rugby union and the affect that player selection has on the relative age effect.	Focus groups	26	This study indicated that the Welsh age group Rugby Union prefers the players born in the early section of the year. Physical size is the most important characteristic of a player followed by skill ability. Personal characteristics were reported as important such as a good work ethic, open mindedness and being coachable. All regional coaches only looked at the current performance and winning than the development of players over time. The process and factors for team selection may increase the risk of relative age effect occurring in the club. However, at district level, the coaches looked at future potential in player more than the higher levels. It was noted by coaches that it is difficult to select on future potential. All coaches had different opinions on what to look for in a player. Personal preference and past experiences seem to have an impact on team selection. Majority of the selection was done through game observation.
Martindale et al. (2013) (178)	Rugby league	Rugby league coaches	Level 1, 2, 3, 4	This study aims to investigate the coaches' perceptions, knowledge, and opinions on the relevance of sport science in sport.	Interviews	21	Overall, coaches vary in perception that sport science is relevant and useful, but majority find it relevant and applicable at any level of rugby. The coaches past experiences, education and open mindedness seem to vary their perception. Coaches reported that sport scientists need to understand the needs in the sport before they research or apply their knowledge and not use too much scientific language. Therefore, coaches and sport scientists need to develop relationships to make a difference in sport and to guide each other. NGBs and sport institutions can help with the integration and access of sport scientists.
McCormack et al. (2020) (180)	Rugby league	Rugby league coaches and strength and conditioning coaches	UKCC level 3 or level 4. All strength and conditioning coaches have undergraduate degree, MSc, MPhil or PhD in strength and conditioning.	This study aims to investigate the physical qualities that are important for future performance and career longevity in rugby league.	Questionnaires	24	Coaches found that strength, acceleration, and power were the most important physical characteristics. Strength and power qualities were ranked the highest for forwards, and speed, power, and acceleration for backs. Coaches ranked hookers and halves' most important physical quality as acceleration. Coaches ranked endurance as important for u19 players. Power was ranked the most important for u16 player longevity and strength for u19 player longevity. Pre-season training focused on physical qualities in both age groups and had the biggest training load amongst the seasons. Tactical training volume was important in-season for both u19 and u16 players. However, gym, conditioning, speed, and physical training was significantly higher in u19 player during pre-season training. Weekly training load, agility, skill, and physical training was higher in u19 than u16 in-season training. Although coaches deemed these physical qualities as important, many of these qualities were not reflected in their coaching practices.
McCormack et al. (2020) (181)	Rugby league	Rugby coach, head of youth rugby and Strength and Conditioning coaches	MPhil, UKCC level 3 or 4, UKSCA or NSCA qualifications	This study aims to investigate the perceptions of rugby and S&C coaches on fitness testing.	Interviews	24	One of the outcomes of this paper is that coaches thought monitoring is important, but it is not everything. Many other factors need to be considered, especially for team selection. Fitness data is needed to design fitness programmes, setting targets and ensure players are fit enough for match play. Most of the coaches monitored their players through observation or coach discussions. The S&C's use fitness data as

							a 'readiness to train' marker. Coaches and S&C's have also been using GPS devices and have found it very useful. Fitness testing was also seen as a way to positively impact the environment they train in and allow for assistance in decision making processes. The perceptions of fitness testing differ between difference coaching roles.
McCormack et al. (2021) (182)	Rugby league	Rugby coaches and Strength and Conditioning coaches	NA	This study aims to evaluate the level of agreement between player rankings based on objective physical performance data and subjective rankings made by rugby and S&C coaches.	Survey	22	The main finding in this study is that coaches cannot accurately rate all aspects of the players physical performance. The most important aspects when subjectively evaluating performance was physical and rugby performance and attitude. For the most optimal approach to evaluating plyer performance would be combining both subjective and objective tests.
Middlemas et al. (2017) (183)	Rugby union	Head and assistant rugby union coaches and scrum coach	NA	This case study aims to investigate debriefing and previewing performance in a rugby union team.	Meetings, observations, interviews and collecting of artefacts	4	Performance and results were the main purpose of the previewing and debriefing performance session and the success of these sessions varied on the purpose and the coach. When some coaches lead the sessions, they had a purpose and clarity to reduce confusion on the field. Other coaches had less of a focus and engagement from the players. The coaches encouraged players to analyse and reflect on their own performance to create a self-drive amongst the players – adopting a player-centred approach. Players had access to their footage throughout the week. When there was limited time to debrief, develop and prepare for competition it had a negative impact on their next game. A balance needs to be found between competition, reflection, and planning to ensure psychological recovery.
Muniz et al. (2018) (184)	Rugby union	Rugby union coaches	NA	This study aims to investigate the knowledge of training practices and experiences among Cadiz rugby coaches.	Questionnaire	50	Coaches found that teaching methods, activities, laws of the game and mini rugby were the best content taught in their initial coaching course. They found techniques and tactics important for their coaching practices. The coaches learnt to be more democratic in their coaching practices but thought the course should be longer. In conclusion the authors believed that the coaches did not have adequate initial training and have very little experience.
Painczyk et al. (2017) (187)	Rugby union	Rugby union coaches	World Rugby level 2 or working towards level 3.	This study aims to investigate the utilisation of performance analysis among rugby coaches.	Questionnaire	51	The results in this study reveal that coaches have very little access to video footage after game, performance analysis and computerised notational systems. If coaches did receive footage it took two days after a match to get to them. 82% of coaches were only providing feedback based on recalled events during the game which is only 59% accurate. Coaches additionally, did not have access to a performance analyst despite knowing the importance. Both these situations could be due to lack of funds. The feedback to the players is flawed due coaches not using a systematic approach to observation. Feedback was given to small groups of players lasting 10-40 minutes using video footage. Factors affecting the ability for coaches to provide substantial feedback are lack of time, availability of equipment and lack of a budget for a

							performance analyst. Most coaches used performance analysis for short- and medium-term planning such as: team selection and changing the strategy of the next match. Most coaches also do not use performance indicators and if coaches do use them, they vary from match to match. All coaches agreed that performance analysis is valuable. The main benefits were evaluating a player's performance, effectiveness of match tactics, fitness of players, evaluating new strategies, and identifying weaknesses of players.
Painczyk et al. (2018) (188)	Rugby union	Club rugby union coaches	NA	This study aims to investigate the intra and inter reliability testing of the computerised notational system among rugby coaches to use for performance analysis.	Observation	5	Overall, this study showed a good comparison amongst Western Province Rugby Union coach coders and the experienced coder. The intra and inter reliability testing of the computerised notational system is reliable.
Pocock et al. (2020) (190)	Rugby union	Specialist place kicker coach	NA	This study aims to investigate the practices and constraints of rugby union place kickers and their coaches.	Interviews	6	Coaches highlighted that it was hard to incorporate place kickers into game simulations. Constraints noted by coaches in this study for place kickers include task, environmental, individual, and situational constraints. Task constraints include angle and distance to the goalposts. Environmental constraints include various weather conditions and surfaces. Individual constraints include expectation of success and fatigue during matches. Situational constraints include previous performance in the same match. These constraints can help coaches develop situations to represent these demands to make match-play pressure easier for the place kicker. Place kicker practice normally takes place after a training session due to lack of time during the session and the coaches believe the player is practicing under fatigue. One of the coaches used headphones playing the noise of a crowd to induce stress on the place kicker.
Robinson et al. (2019) (194)	Rugby union	Head strength and conditioning specialists or individual in charge of strength and conditioning	NSCA or other qualifications	This study aims to investigate the strength and conditioning practices in South African high schools.	Interviews or questionnaires	43	Speed is the most common physical test done in private and no fee schools and muscular strength in public schools. All coaches reported that they included flexibility training in their programme where dynamic stretching was the most common exercise in public and private schools and static stretching was the most common in no fee schools. Speed and agility training was mostly completed weekly where sprinting was the most common exercise for speed development and any exercise with a change of direction was used for agility training. Plyometric exercises were used by most coaches. Jumping exercises were used by private and no fee school and public schools used box drills. Majority of coaches used resistance training three times a week predominately in pre-season training and continued into in-season training. No fee schools used agility, resistance training and plyometrics less than private and public schools because of lack of funds or lack of knowledge. This reflects into the exercise variation among the school. The different exercises relate to the socioeconomic status of the

							school, level of rugby and the education of their coaches. Education and upskilling of no fee school rugby coaches is needed.
Rothwell et al. (2019) (195)	Rugby league	Rugby league coaches	UKCC Level 2, 3 or 4	This study aims to investigate the rugby league development of players in relation to cultural, historical and social constraints.	Interviews	24	The development of rugby league players is complexed. Coaches prefer informal learning and found themselves learning from other coaches. Coaches believe that education has a 'one size fits all' approach but mainly for teaching techniques. Coaches believe that there is a big emphasis on physical size and masculinity in rugby league. There is not enough emphasis on skills and techniques. When techniques are taught it is predominately coach led learning. There should be a shift towards coach facilitated earning so player can figure out their own problem. Coaches reported that parents play a big role in the player's rugby career. A talent development coach explained that one needs to work on playing styles as opposed to skills in the game. Coaches reported that players tend to replicate other playing styles when developing as a player. Coaches found it challenging when players transitioned to another club because of different coaching pedagogies. Coaches had to change their ways to support the player.
Starling et al. (2017) (198)	Rugby union	Head rugby union coaches, rugby union coaches and Strength and conditioning coaches	NA	This study aims to investigate the methods used to monitor player's training load.	Questionnaires	55	Coaches think that monitoring training load is important, specifically, to reduce injuries. Coaches seem to think that one needs equipment and resources to monitor training load successfully. It would be ideal for coaches to spend a short period of time (5/10minutes) after training to assess fatigue and recovery. This study highlights that coaches are unaware what the best variable they should be monitoring. They use more subjective measures than objective measures.
Thomas et al. (2013) (199)	Rugby union	Rugby union coaches	NA	This study aims to investigate the perceptions that the rugby coaches have on childhood participation in rugby and the key components needed for participation.	Interviews	9	All coaches thought childhood participation in competitive rugby is appropriate with less structure (as early as u7). Coaches believe that it should always be about having fun and enjoyment and not trophies. They feel that there should be many unstructured small-sided games for the children to have fun and increase participation. This would allow children to develop the basic skills of rugby and have psychosocial advantages. Technical skills should be introduced slowly to children. Regarding contact, some coaches thought it could impact the decision-making skills of the children. They all thought it should be introduced in small-sided games starting with tackling. They highlighted that it should not be the sole focus and technical skills are more important but is essential to be introduced. Scrums and lineouts (late specialisation skills) were seen as unnecessary at such a young age. Coaches felt that the game of rugby should be quick, and the children should have more ball in play time. Coaches encourage children to play various positions and various other sports to ensure positive development. Coaches felt that adults, coaches, and referees played a big role in the development of children in rugby and should be a positive influence.

Thomas et al. (2016) (200)	Rugby union	Rugby union coaches	RFU qualifications up to level 1	This study aims to investigate the perceptions and beliefs of U9 rugby union coaches towards the rules and structure of the game.	Questionnaire	202	Traditionalists (favoured introducing complex skills and positions) believed that the structure of the U9 game should replicate the adult game and include the complex skill sets. The moderates (favour the complex skill sets but not with too much structure) believed there should be a replicate of the adult game but should not include scrums, lineouts, and positions. Radicals (favour less structure and no complex skill sets and positions) believe there should be no complex skill set pieces. Besides traditionalists, the coaches believe that small-sided games are key for the development and enjoyment of U9 rugby. All coaches thought a small number of players in a team was needed, passing, tackling and ball skills was an important component for U9 rugby and the enjoyment of children of the most important. Overall, most of the coaches agree to a mores structured game.
Vinson et al. (2017) (202)	Rugby union	Head and assistant rugby union coaches	Level 3 and 4 formal coaching qualification	This study aims to investigate the usage of an online video coaching platform among coaches for training, match performance and player engagement.	Interviews	5 head coaches and 7 assistant coaches	The online coaching platform (Coach Logic) provided more player engagement which many coaches enjoyed. Coaches believe if players are involved, they will be more committed. Some coaches used the system to analysis content before the match or training session. Coaches also saw an improvement in players' intrinsic motivation. Coaches worked on various skills with Coach Logic. Some coaches thought it helped with improving communication, positively influenced behaviours and culture of the team, teamwork, team cohesion, positive environment and player development and empowerment.
Walters et al. (2012) (203)	Rugby union	Rugby union coaches	NA	This study aims to investigate the verbal behaviour of coaches at children's competition.	Observation using adaptation of the Parent Observation Instrument for Sports Events (POISE)	18	Coaches make many comments during children's rugby competitions. Rugby coaches comment more than other coaches in different sports but have the lowest percentage of positive comments. Many negative comments were directed at the players and the referees. There needs to be a change to a more positive influence.
Woodcock et al. (2011) (205)	Rugby union	Head coach, forward coach, and backs coach	NA	This study aims to investigate the qualities that coaches consider influential among developing youth players.	Focus groups	7	Three main themes derived from the coaches were progressive development, professional environment, and performance environment that are need for developing young rugby players. Psychological qualities that the coaches believe are important for young rugby players is Game Sense, to be self-aware, honest, and be coachable. Players need to be able to adapt to the game and solve problems. Coaches agree that they need to support the development of players growth as a player and a person. Coaches need to provide a positive environment for the players to develop optimally and agree that their training sessions is the place for players to develop. For example: coaches question players instead of disciplining them for making mistakes. Coaches noted that there needs to be a balance between encouraging players and criticism. Coaches encourage players to support each other.
Zinn et al. (2006) (206)	Rugby union	Club rugby union coaches	NA	This study aims to investigate the nutrition level and knowledge, of rugby coaches.	Questionnaires	168	73% of coaches believed they had the knowledge to provide nutritional advice to their players. Most of the coaches provided their players with nutrition advice which was mostly about fluid issues. Coaches who did not give advice lacked confidence, did not have enough time, or stated

							that another professional was giving the players advice. Coaches who had given out advice had a higher nutrition knowledge score and qualifications than those who did not give advice. Coaches had the most knowledge on nutrient types. Although fluid was the most common category to give advice to players, the answers were poor. Coaches seems to have a misconception on the role of protein for optimal performance and weight gain. Supplement knowledge was the poorest scored category. Most coaches had not received formal nutrition training. Roughly half of the coaches used outside professionals for nutritional advice (mostly doctors, physiotherapist and dietitians). Coaches mainly learnt their information from lectures or seminars or other personnel. Overall, coaches are not prepared to give correct nutritional advice to their players.
Coaches' doping knowledge							
Boardley et al. (2019) (147)	Rugby union	Technical and strength and conditioning coaches	NA	This study aims to investigate the doping confrontation beliefs among coaches.	Interviews	16	Coaches in this study were confident that they could effectively confront players about doping, with the main purpose of finding out why the player was doping, highlight the risks associated or being morally opposed to doping. Coaches doping confrontation efficacy beliefs in confronting players about doping were stronger when there is evidence. Possibly having the resources to confront players about doping may be important for the coaches' doping confrontation efficacy beliefs. Some coaches stated that they want to enhance their knowledge however, due to time constraints they are unable to educate themselves further and did not hold anti-doping as a top priority. Past experiences and good networks seem to influence coaches' doping confrontation efficacy beliefs. Some coaches expressed that showing empathy when confronting a player about doping and having a strong coach-athlete relationship is important. Coaches who were not confident in confronting player gave the responsibility to someone else in the club.
Nicholls et al. (2015) (185)	Rugby league	Rugby league coaches	NA	This study aims to investigate the coaches' perceptions of the susceptibility and attitudes of adolescents towards doping.	Interviews	11	Coaches believe that availability and affordability influence players to dope. Additionally, parents, peers and other coaches also impact this behaviour. Coaches found low self-esteem was the most related issue to doping. They found adolescent players are more susceptible than adults and are more likely to be negatively influenced. Other factors that coaches believe could influence doping is stress, ethnicity, age, country of residence, and participation level. Coaches need to be educated and aware of this to help appropriately. Concerning factors are that there is little to no education of doping for non-elite rugby players and lack of testing. Coaches felt that although players knew it was wrong, they would dope if they knew they were not being tested. In conclusion, this study's results support the Sport Drug Control Model.

Table S3.3. *Coach pedagogy related articles.*

Study: Author, (year)	Rugby code cohort:	Type of coach:	Level of coach/es:	Purpose:	Data collection methods (Questionnaire/intervention):	Sample size of coaches:	Conclusions:
Avner et al. (2020) (207)	Rugby union	Rugby union academy coaches	UKCC-L4	This study aims to investigate the coaches' approach to Beat the Game – a problem-based learning approach to coaching, the effects that Beat the Game had on players and how this has changed the coaching ability of the rugby union coaches.	Interviews and observation	3	When following the Beat the Game principles the coaches believed to have shifted from being the sole decision maker to allowing the players to explore and make their own decisions. The problem-based learning approach promotes player development and the movement away from the traditional coaching pedagogies.
Bennett et al. (2018) (208)	School rugby	Secondary school rugby coaches	NA	This study aims to investigate the secondary school rugby coaches' pedagogies.	Interviews	5	Understanding coaching pedagogies is complexed and the power relationship between coach and player is important. All coaches in this study have different coaching styles and beliefs about power and control. Overall, it was observed that there is a reluctance amongst coaches to shift towards learner centred coaching.
Bennie et al. (2010) (209)	Rugby league and rugby union	Head and assistant rugby union and rugby league coaches	NA	This study aims to investigate professional coaches' perceptions on effective coaching.	Interviews	1 head coach and 1 assistant coach in both rugby league and rugby union	Coaches believe they have an important responsibility to develop players on and off the field. In professional sports, such as rugby, coaches have their own coaching philosophes, beliefs, and attitudes and while the holistic coaching approach is encouraged, it is not always realistic. Coaches in this study emphasised the importance of humanistic goals and developing not only the player but the person.
Bennie et al. (2012) (210)	Rugby league and rugby union	Head and assistant rugby union and rugby league coaches	NA	This study aims to investigate the perceptions of professional coaches and athletes of the coach-athlete relationship and the effective coaching styles.	Interviews	1 head coach and 1 assistant coach in both rugby league and rugby union	All coaches in this study stated that a form of athlete-coach relationship is essential to interact with the team effectively. The two coaching styles found in this study were family oriented or professional relationship. Although having a trusting and respectful relationship allows for effective coaching styles the most suitable interpersonal relationship is still unknown. It can be said that the preferences of the individual is paramount to an effective relationship.
Bennie et al. (2012) (211)	Rugby league and rugby union	Head and assistant rugby union and rugby league coaches	NA	This study aims to investigate the effective coaching leadership among professional coaches and athletes.	Interviews and observations	1 head coach and 1 assistant coach in both rugby league and rugby union	Various effective coaching styles were observed in this study. Coaching styles ranged from being empowering to controlling. Rugby league coaches had a coach-centred learning approach where rugby union coaches had more of a player-centred learning approach. While there was a difference in coaching approaches, all coaches believed that players need to have some amount of responsibility to increase player accountability. Each coach had their own approach to leadership that was effective to their staff and players.

Burt et al. (2014) (212)	Rugby union	Rugby union coaches	UKCC Level 1 or 2	This study aims to investigate the barriers to reflective practices perceived by coaches.	Interviews	10	All coaches used reflective practices sporadically, either using methods such as reflection-in-action or reflection-on-action. Some coaches believed they did not need to reflect as it was not part of their job, that they did not see a benefit, or the training sessions were all similar. Barriers preventing coaches from reflecting were the lack of RFU or clubs checking up on them, they were volunteer coaches or lack of formal reflection sessions. However, the main reason why coaches did not reflect was that they did not have the motivation to do so. Coaches also pointed out that reflection was only a small part of their UKCC Level 1 and 2 courses. It is suggested that the RFU make the sessions more enjoyable and practical to encourage coaches to reflect.
Cassidy et al. (2006) (213)	Rugby union	Rugby union coaches	NA	This study aims to investigate the coaches' perceptions of the CoDe program (coaching education program).	Interviews	8	CoDe program (theory-based coach education program) introduced coaches to different learning styles. Many of the coaches had never thought of players as learners before and that each player could have difference learning preferences. Previously the coaches would have one learning style. They now incorporate different visual and hearing techniques. Coaches acknowledged that this was a different way of coach education for them. They agree the skill aspect to rugby is important, but this side of coaching holds its importance. Coaches also stated that meaningful engagement with other coaches was important and something that they had not done previously. Finally, coaches acknowledge the importance of reflecting to become more confident and a better coach.
Chapron et al. (2019) (214)	Rugby union	Head and support rugby union coaches	Three of the coaches had Level 3 or 4 coaching qualification	This study aims to investigate the influence of action research within a coaching group.	Reflections, coaching team discussions and observations	5	Action research allowed one to discuss situations and create opportunities for coaches to gain knowledge, motivation, and reflective abilities. Overall, the main finding in this study showed that one can change the coaches' pedagogical methods. It must be noted that this is time consuming for the coach and a large amount of motivation, patience, and clarity is need in the early stages. After the early stage of action research, the coaches in this study started to collaborate and think independently which improved their coaching methods. Coaches started to use problem-based learning and more of a player-centred approach and allowed players to make their own decisions. These actions had a positive influence on the team and coaches found that players had improved.
Cole et al. (2018) (215)	Rugby union	Rugby union coaches	NA	This study aims to investigate the team culture of the Manawatu Turbos and how the culture has influenced the leadership style and values used by coaches.	Interviews	3	There are many reasons for the Manawatu Turbos team success, but team culture and talent are key factors. The awareness of the drinking culture as a counteract to the team success, has shifted the team's mindset. Reinforcement of the team's culture was the reason the Manawatu Turbos are successful. The values of the team include hard work, honesty, integrity, loyalty, and innovation. Informal rituals were associated with the team's success. The Manawatu Turbos have a collective informal leadership which they propose was a reason for their improvement of players and is a very effective style of leadership. It allows for empowerment of the team and application of the team's

							culture and values. The coaches noted when they changed to an autocratic leadership the team's success rate dropped emphasising the importance of flat, collective leadership.
Collins et al. (2016) (216)	Rugby union	Rugby union coaches	NA	This study aims to investigate the intuitive decisions of high-level coaches.	Interviews	18	Coaches agreed that intuitive decisions were part of their coaching practices in certain situations, including during a game, team selection, and signing players. Decision making of the coaches came from experience and the nature of the situation. A few coaches noted the importance of reflective practices contributing to their intuitive decisions. Most of the intuitive decisions brought upon novel and insightful ideas and directions but most of the time coaches planned out everything, were conservative and consistent. Factors that influenced the institute decisions were situational, past experience, context, and skill.
Cotterill et al. (2019) (217)	Rugby union	Rugby union coaches	NA	This study aims to investigate the coaches' perceptions of the captain at professional level of rugby union.	Interviews	8	Two values that coaches find important in a captain is the ability to develop relationships among athletes and lead by example. Coaches believe that task, motivational and external leadership are the core aspects of a captain. Multiple coaches noted the development from having one captain to having multiple leaders within the team and sharing the responsibility. Coaches found that it created a more focused team and more support for the captain. One of the challenges captains face is transitioning from player to captain. The captain takes on the responsibility to be a role model, be the drive of motivation and advocate hard work both on and off the field. The coaches highlighted that the captain is the voice of his team and needs to interact with the coaching staff. Another important factor was a well-established coach-captain relationship.
Hall et al. (2016) (218)	Rugby union	Rugby union coach	UKCC Level 3 and MSc in sport coaching	The study aims to investigate the experiences of a rugby union coach's reflective practice.	Reflections	1	The coach found reflecting emotional especially at the beginning. Low self-awareness can lead to a negative response to reflective practices. The reflective process took the coach through initial paralysis and embarrassment to a vulnerable yet positive state. The reflective process allowed for critically deconstructing and reconstructing of the coaches' coaching practices. Furthermore, allowed the coach to realised unwanted coaching behaviours, that he now has changed, when previously he was unaware.
Hall et al. (2021) (219)	Rugby union	Head coach	International level	This study aims to provide a case study on the complexity of the job of a head coach	Observations and interviews	1	Being head coach consists of many roles and not just coaching. It is very important to create the right atmosphere for the players and coaches. She needs to ensure everyone works together. Being head coach is a stressful job. She also can understand what the players have been through since she was an international player previously. She can relate to them better which is advantageous. This case study highlights the leadership and management a head coach must have. It also shows how important relationships, and a network is for a coach.
Hodge et al. (2014) (220)	Rugby union	Assistant rugby union coach	NA	This case study aims to investigate the strategies to avoid chocking from public	Interviews	1	The coaches knew their players needed to be able to deal with the pressure of playing rugby at the top level. The coaches started by giving the players more responsibility and making them accountable. They

				expectations and pressure for the All Blacks' rugby team.			moved into a dual management role where players and coaches managed the team. The coaches additionally shifted the focus away from the score and towards training to be the best team out there. They focused on better coping mechanisms such as the Haka before matches. The head coach believed that if you walked towards pressure you were able to gain some control over it. He practiced this by putting the players into stressful situations and making decisions under pressure. They also worked on improving the leadership, confidence, and resilience of the players but overall ensuring that the players enjoyed playing rugby.
Light et al. (2010) (221)	Rugby union	Rugby coaches	Provincial or nation level (level 3 ARU coach)	This study aims to investigate the extent at which Game Sense has impacted elite rugby.	Interviews	4	The coaches used games in training to test the players skills, develop decision making skills, independence, and game perception and to develop fitness. Most of the coaches balanced structured and unstructured activities depending on the level of the player. One coach aligned with the Game Sense approach and believe players needed to learn through informal games. All coaches recognised the importance of learning through games. Although the coaches used game-based learning, Game Sense pedagogies is limited.
Light et al. (2014) (222)	Rugby union	Head rugby union coaches	NA	This study aims to investigate the characteristics of rugby union coaches' coaching habitus and their perceptions and use of Game Sense.	Interviews	4	Coaches believe being a good coach means players need to respect you and one needs to lead and manage people well. Other important characteristics included have more knowledge than your players, having a good work ethic, being committed and enthusiastic. Some of the coaches were more hands on with their players where others had a more hands off approach. The coaches believed a good rugby player needed to have talent, be resilient, passionate, hard working and tough. Speed, strength, and game sense were also viewed as important characteristics. Past experiences have helped coaches understanding player's development. Some coaches were unable to adapt the player-centred approach.
Llobet-Martí et al. (2017) (223)	Rugby union	Rugby union coaches	NA	This study aims to investigate how coaches transfer the responsibility to players	Observation	1	This study analysed the segments of interactivity (SI) between the coach and the players. There are six segments of interactivity including SI Activity Organisation, SI Guided Practice, SI Autonomous Practice, SI Discussion, SI Recapitulation and SI Transition. There was a decline in the SI Activity Organisation as the sessions progressed which highlights the transfer of responsibility to the players. Coaches can support players by asking questions and slowly introducing more player-centred learning. Coaches use both verbalisation and demonstration to ensure the player understands the task. Both the player and coach proceed to ask questions to clarify the player knows what to do. During practice, the players tend to perform the task while the coach observes them. An example of transferring the responsibility is when the coach puts a player in charge of a task. Coaches also spark discussions to engage and evaluate certain tasks through reflection. Throughout this process the coaches are transferring responsibility to the players.

Males et al. (2019) (224)	Rugby sevens	Rugby sevens coach	NA	This study aims to investigate the efficiency of the Basic Performance Demand Model.	Interviews	1 rugby coach	The Basic Performance Demand model is not intending to be a coaching tool. It can be used but one does need development time with the coaches and players. Additionally, the model needs to be adapted to the needs and goals of the athletes, especially for training sessions, to ensure the players reach their achievement. The model consists of four fundamentals: mastery motivation, decision making, execution, and teamship. The Basic Performance Demand model is efficient and relevant amongst elite coaches. The coaches reported the following: the materials need to be customized to the coach and players' needs, should be used mainly in training setting and should be modified to the relevant of the players. Although, it is seen to be effective, more trials need to occur in sport.
Morgan et al. (2020) (225)	Rugby union	Rugby union academy coaches	NA	This study aims to investigate coaches' perceptions of decision making in a rugby union team	Interviews	5	All coaches found decision making an essential part of rugby. Players need to react to many things as the game progresses. Technical ability, fatigue, and weather conditions were factors coaches believed impacted decision making during a game. Some coaches believe players should have the freedom to make their own choice where other coaches were more rigid with their game plan. Pre-planned moves were used by all coaches before a match. Coaches agreed that discussions about the players decision should be with the players. Many of the coaches had different ideas and perceptions about how to go about the discussion and reviews of players decisions and if it was a successful or unsuccessful outcome. To improve decision making coaches agreed that one needs to move away from drill-based and more towards game-based situations. There was more of an importance based on developing rather than winning.
Mouchet et al. (2013) (226)	Rugby	Rugby coaches	NA	This study aims to investigate coaches' communication during match-play.	Interviews	6	In this study it was noted that coaches are influenced by the French rugby culture. Coaches have different styles based on their past experiences, visions of the team, expectations and characteristics of themselves and the players. There is a complex and dynamic nature to the coaches' actions. Majority of the coaches gave positive feedback to their players during matches. When the game was very tight and important there was some negative feedback towards the players. Some of the coaches tried to calm their players down to ensure concentration during the match with no aggression towards the opposition.
Mouchet et al. (2018) (227)	Rugby sevens and rugby union	Rugby sevens and union coaches	NA	This study aims to investigate coaches' perceptions of their management skills in rugby union match-play.	Interviews	7	The authors noted a 'coaching genre' that is shared by coaches. The 'coaching genre' seems to come from the French rugby culture. Coaches agree that analysis of the "rapport de force" between the teams and observation of the game is important when managing a match. There were many differences amongst coaches in the same team during observation which could be lack of discussions within the team. Coaches do ensure there are routines of functioning happen within the team. These routines are specifically for player substitutions. Coaches also mentioned the process of evaluation amongst the teams,

							comparing the game to what they expected, and ensuring the coach is reading the field properly. Coaches had different jargon to explain their strategies for observation. Coaches also noted that they need to be competent when managing substitutes. Decisions to substitute are based on how the player is playing in comparison to his normal ability. Coaches believe past experiences are important when dealing with match situations.
O'Malley et al. (2017) (228)	Rugby union	Club and international rugby union coach	NA	This study aims to investigate the knowledge of the relationship among the coach-athlete-coach triad.	Interviews	2	This study investigated the lived experiences of a coach-athlete-coach relationship. In this situation, there were two different coaching styes – one had a strict style of coaching and the other had a friend-like style of coaching. All coaches need to work together and communicate for the player to achieve. The coaches had a perception of each other before they even met which highlights the need for early communication among coaches. This study displays the triad is a complex environment. One cannot control any relationship, but communication is a key factor.
Piggott et al. (2012) (229)	Rugby union	Rugby union coaches	Formal UK coach education course	This study aims to investigate the formal coach education in the United Kingdom using the neo-Foucauldian perspective	Interviews	2	Coaches expressed that the courses were rigid and restrictive. They only show them minimal styles of coaching. These restrictions made coaches feel frustrated and doubtful of their skills. The aim of this style of coach education is to graduate the coaches with knowledge of coaching methods and practices but coaches only respond well to open courses which allows discussion. Coaches did express that there was limited time for any discussions of the course work. Course educators should allow for more time for discussions and other options for how the coaches can learn.
Reid et al. (2014) (230)	Rugby union	Rugby union coaches	Level 1 or level 2	This study aims to investigate the introduction of Game Sense in rugby union coaching practices.	Interviews and questionnaires	22	Game Sense shifts away from coach-centred approach to athlete-centred approach suggesting that players learn from game situations and reflect on these experiences. Due to multiple problems of introducing Game Sense to coaches there was a lack of understanding. The coach educators were inconsistent about their messages and interpretation of what Game Sense was. Lack of definitive terms and consistency made the message hard to give to the coaches. Coaches felt like they needed time to work though Game Sense pedagogy ideas and they expressed they did not have the time and support from the educators. They also wanted practical time because they could not visualise Game Sense in their practice. The RFU needs to provide a clear message of Game Sense to the coaches in a practical and reflective way otherwise coaches are going to go back to their old ways.
Romand et al. (2007) (231)	Rugby	French rugby coaches	NA	This study aims to investigate the perceptions and practices of coaches towards the moral character displayed by players.	Interviews	16	The coaching role is complexed. Coaches aim to teach respect (to rugby and others), teamship, and competitiveness to their players and assist in their moral development. All coaches discipline poor sportsmanship during matches and training. Coaches expressed the importance of players respecting the game. Players who do not follow respect, especially to their teammates, and values of the coaches can be

							expelled from the club. However, more than half of the coaches believed that when you start playing at a higher level one should bend the rules slightly to win. Additionally, some coaches noted that aggressiveness can have some positive effects for the team and sometime allowed towards the opposition. Most of the coaches believe that the player must respect and adapt to the referee. The coaches believe that they set the tone for the players, especially on match day and players can be a 'reflection of the coach'. There were mixed perceptions if moral development and competition is compatible. All coaches try to make their actions seem correct and avoid being held accountable for their behaviours.
Sharp et al. (2013) (232)	Rugby union	Volunteer rugby union coaches	UKCC 1, 2 or 3	This study aims to evaluate the mental skills programme for youth players and coaches.	Focus groups and interviews	4	All the coaches thought mental skills training would be an asset to training and valuable for players. The coaches' positive perceptions could be the reason for the players positive views. Coaches expressed that they wanted their players to be able to deal with competition, understand the game and be able to handle pressure. Coaches believe that from their players participating in the mental skills training they gain various skills and techniques. They saw changes in teamwork and communication skills. Coaches were seeing players implementing these techniques on the field. Qualities such as being honest, open with players and coaches and self-awareness were displayed in their rugby performance after training. Coaches are fully supportive of this training and think coach education should continue.
Thomas et al. (2013) (233)	Rugby union	Head rugby coach	NA	The aim of this study is to investigate the issues that arose from implementing the Tactical Games Approach (TGA) in junior rugby union	Observation and journal entries	1	The head coach found that when he was setting the programmes it tested his knowledge and understanding of rugby. He found he was planning his coaching sessions for the competitive matches and not so his players could learn. He found it hard to change his habits and listen to the players answers. Once he stopped interring with the players, he started to see the benefits and how his players were developing. The player's motivation and enjoyment did increase with this approach.
Whitehead et al. (2016) (234)	Rugby league	Rugby league coaches	UKCC level 2	This study aims to investigate a 'Think Aloud' intervention to implement reflection-in-action among coaches to improve their coaching practices.	Observation and interviews	6	Throughout the 'Thinking Aloud' protocol the coaches transitioned from reflecting using descriptive verbalisations to feelings-driven verbalisations. Coaches additionally were evaluating their actions frequently which highlights the transition to high level reflection practices. This protocol allowed coaches to question and be aware of their actions and simulate their thought process. Self and pedagogical awareness were positive observations that was noted in this study. Coaches' communication skills improved throughout the workshop and they became more confident. Coaches suggested that the intervention should be longer to see more improvements and that reflection practices should be more included in the coach education programmes.
Williams et al. (2017) (235)	Rugby	Rugby coaches	Level 1 coaching qualification	This study aims to investigate the educational context of coach learning.	Interviews, focus groups and blogging	20	Some of the coaches thought the formal coaching was unsatisfactory. Coaches believed the longer sessions of coaching learning and development programme allowed one to understand the information better. Coaches additionally, responded well to learning in their own

							practical environment and having time to work through the new information. Coaches had different teaching methods including social media, discussions, workshops, theory classes and practical classes which coaches responded positively to. Overall, the coaching learning and development programme was successful in teaching coaches in a positive constructive way.

Table S3.5. *Coach development related articles.*

Study: Author, (year)	**Rugby code cohort:**	**Type of coach:**	**Level of coach/es:**	**Purpose:**	**Data collection methods (Questionnaire/intervention):**	**Sample size of coaches:**	**Conclusions:**
Fast tracking coaches (transition from athlete to coach)							
Blackett et al. (2018) (236)	Rugby union	Head/assistant coaches, high performance coaches and director of rugby	NA	This study aims to investigate the experiences and transitions of fast-tracked coaches.	Interviews	7	All coaches in this study followed a fast-tracked pathway into coaching after their athletic career. 'Active' coaches pursued their own development of coaching knowledge and experience during their professional career. 'Passive' coaches only decided to become a coach after their retirement from professional rugby. All coaches in this study did not need to go through a formal recruitment process for their coaching position because of their past career. The study suggests that these retirement practices are encouraged by senior management to form a like-minded work environment.
Blackett et al. (2020) (237)	Rugby union	Rugby union coaches	National Governing Bodies' level 3 coach accreditation	This study aims to investigate player's identity transformation who had a fast-tracked career pathway into a high-performing coaching role post professional career.	Interviews	10	Coaches each had their own personal coaching physiologies and ensured their values were reflected in their coaching style. Coaches also stated that their past experiences as an athlete played a big role in the coaching philosophy they have now. Coaches in this study mostly considered their identity fixed rather than a dynamic process. Only a small number of participants treated their identity as dynamic or fluid and practiced in reflective practices.
Coaches coping with pressure							
Thelwell et al. (2010) (239)	Rugby union	Assistant specialist rugby union coach	NA	This study aims to investigate the associations between stressors and coping mechanisms among coaches.	Interviews	1	The coach reported poor performance as a stressor and that he used emotion-focused strategies (showing his frustration physically and verbally) to deal with it or avoidance strategies (getting out of the environment. Player availability and team selection was another stressor and emotion-focused strategies are used to cope (humour and self-talk). The last stressor was having conflicting views of training with other coaches within the team. To cope with this stressor emotion-focused strategies were used (self-talk), the use of a mentor, using problem-focused strategies such as talking to the other coach and

							approach-focused strategies were used (pointing out his goals). Interventions are needed to help coaches deal with their stressors.
Coaches' childhood and adolescent experiences							
Holmes et al. (2020) (238)	Rugby league	Head rugby league coaches	NA	This study aims to investigate the childhood and adolescent learning experiences that influenced participation of the coaches in rugby league.	Interviews	6	Coaches developed their thought process, behaviour, and values for their career from their childhood and adolescent learning experiences. Early in their lives, participants were apart of rugby communities which guided them into their current careers. Majority of the time when coaching coaches use their intuition or their gut feeling it is their sub-conscious cognitive process which is developed from the habitus of participation in rugby from childhood. Coaches identified values that they believed were important which were prominent in the community they grew up in. For example: coaches believe players should have a good work ethic, be honest, competitive, and put the team first. These values reflected their rugby communities in their child and adolescent years. Parents, fathers, teachers, and brothers played big roles in their mindset of hard work, leadership, toughness, competitiveness, and passion. The coaches want to understand their players so they can work well together using a more holistic or humanistic coaching approach.

Chapter 4: The Relationship between Tackle Technique and External Load of a Simulated Tackle

4.1 Introduction

Winning the tackle is a contributing factor for team success in rugby football (23). It is a physical-technical contest amongst opposing players to compete for territory and ball possession (28,243). The tackle is also the most frequent contact event in all rugby cohorts such as, rugby union, rugby league and rugby sevens (11). For example, in rugby union, each player is involved in 10 - 15 tackles per match (29). Although winning the tackle is important for team and player success, it also has the highest injury incidence, and burden (injury incidence rate multiplied by mean severity) (18,19,21,44). For instance, in rugby union, 19 injuries per 1000 player hours occur when tackling (i.e., tackler) and 29 injuries per 1000 player hours occur when being tacked (i.e., ball carrier) (22). Since the tackle is the major contributor to a player's injury risk and success, monitoring of the technical-physical load of the tackle contact should become a common coaching practice. (30–32).

Monitoring players' technical-physical load in training and matches is important to ensure players are adequately prepared for competition demands, reducing injury risk and enhancing performance. Recently, World Rugby has realized the importance of training contact to prepare for competition and have published contact guidelines where players should be engaging in full contact training for 15 minutes, controlled contact for 40 minutes and live set piece for 30 minutes of training a week (34). The purpose of these guidelines is to reduce injury risk but will simultaneously improve their technical skill performance (244). For such contact guidelines to be fulfilled, proper collision load monitoring is required. Monitoring physical and skill training is essential for coaches to assess the amount of physical work their players are experiencing and ensure they are reaching these recommended physical and technical demands (30). As a result, coaches can ensure players are well conditioned for match play (38). One way to measure these demands is using minutes and frequency of contacts (32). Coaches and other sport practitioners, commonly use devices such as GPS units and microtechnology devices to monitor these contact and non-contact demands (245). Microtechnology devices include MEMs which provide researchers with accelerometer-derived load measures such as *PlayerLoad*™ (245). *PlayerLoad*™ or a collision load equivalent, has been used to quantify non-contact demands of rugby union and rugby league. Research studies have investigated *PlayerLoad*™ and collisions, however, these studies have been few and far between. It must be noted that these studies have shown that *PlayerLoad*™ has the ability to monitor contact load (48). Another aspect of external load is kinematics and kinetics data (i.e., force, energy, velocity, and momentum). However, monitoring these variables is not as easy in a training or match setting because extensive equipment is needed (i.e., force plates, markers and cameras), which is why microtechnology devices are popular. Markerless motion capture is a newly popular method that is an inexpensive method to use to measure kinematics (246). Sport scientists can determine these variables without markers from high quality video footage, however,

this is time consuming and skill dependent (246). While markerless motion is emerging amongst sports, it is only validated for walking gait in sagittal plane (247). This is due to issues such as sampling rate and more complex multiplane movements. It must be noted that the reliability and validity in the rugby codes has not been established. Video coding is also subjective which leads to possible human error. These variables can be very important for technical skills such as the tackle, to ensure players technique is accurate and they are being as efficient as possible.

Proper tackle technique is associated with injury prevention and team success (16,28,248). In rugby union, studies have investigated injuries, mental and neuromuscular fatigue, level of play, physical measures, and performance in relation to tackle technique (25). Furthermore, studies have investigated into the head kinematics in during the tackle (249,250), kinematics during one-on-one tackles (251–254), and mass, velocity, momentum and kinetic energy of the tackler and ball carrier before the tackle contact (10,255). None of these studies to our knowledge have investigated kinematics or *PlayerLoad*™ of the tackle in relation to tackle technique. Therefore, the aim of this study is to investigate *PlayerLoad*™ and kinematics of a simulated tackle in relation to tackle technique proficiency.

4.2 Methods

4.2.1 Study Overview

This study used a cross-sectional study design. Twenty (n = 20) amateur male rugby union players participated in this study (age: 21.7 ± 4.7 years, body mass: 89.1 ± 17.2 kg, height: 176.9 ± 6.4cm). Each participant performed twelve tackles on the collision sport simulator over two testing sessions (six tackles per session). Each player performed three tackles on their dominant shoulder and three tackles on their non-dominant shoulder per a session. After each session, players filled out a form of subjective measures to determine their internal load. In total, 240 tackles across all participants were video recorded and their tackle technique were analysed. The tackles were split into three categories based on their tackle technique. Furthermore, *PlayerLoad™* and kinematics data were analysed between tackle technique categories. Each participant provided informed consent before testing. All tackle data on the contact simulator is stored in a registered database (HREC REF R027/2019). Ethical approval for the study was granted by the University of Cape Town Human Research Ethics Committee (HREC REF 061/2021).

4.2.2 Collision sport simulator

Each participant performed twelve tackles on the collision sport simulator (24). A previous study using the collision sport simulator showed that the simulator is comparable to real-life one-on-one, front-on tackle drills and tackle contact based on tackle technique (24). In brief, the collision sport simulator comprises of two A-frames spanned by three horizontal beams attached to a pneumatic system to drive a detachable 'tackle dummy'. The 'tackle dummy' has a mass of 37.8 kg and comprises of three separate metal shells (upper body, torso and lower limb) enclosed by three layers of foam and rubber. The design allows for flexion and extension. A lever is secured to the central horizontal beam via a movable trolley (trolley 'A'). This trolley is situated adjacent to a second 'floating' trolley (trolley 'B') that has a hook for the attachment of a detachable 'tackle dummy'. Trolley 'B' and the dummy are propelled forward by the lever arm and trolley 'B' of the pneumatic system along the central horizontal beam. The desired velocity is determined via the force of pressure exerted by the compressor that drives the pneumatic system. For testing, the 'tackle dummy' moves at approximately 2.12 ± 0.09 metres per second towards the tackler before a tackle is performed, which is comparable to a tackle in real matches (255).

4.2.3 Tackle technique proficiency criteria

Each tackle was recorded with a video camera (EOS 200D, Canon, South Africa) positioned three meters away and parallel to the midpoint of the collision sport simulator. The tackle proficiency was analysed by two researchers using the standardized tackling technique criteria that were adapted from Burger et al. (2019)'s study. A two-way random-effects model intraclass correlation coefficient (ICC) and the typical error of measurement (TEM) were used to determine intra-rater and inter-rater reliability. For intra-rater reliability, ICC = 0.01 and TEM = 0.9 and for inter-rater reliability, ICC = 0.4 and TEM = 0.5. The technique criteria consists of a list of observable actions that represents the model form of movement and are used to coach techniques for tackling into contact (256). The player is either awarded one point if the action is performed correctly or zero points for an incorrect action. A total score is calculated for the complete tackle and for each of the three tackle phases – (1) pre-contact phase (0.5s preceding contact), (2) contact phase (player makes contact with the other player), and (3) post-contact phase (after contact has been made). The maximum technical proficiency score on the contact simulator is 11 arbitrary units (AU) (28,257). The total technical proficiency score and percentage are provided for each category. Total percentage is the sum of the tackling proficiency criteria divided by the total criteria number (11 AU) multiplied by 100.

4.2.4 Microtechnology derived measurements

The *PlayerLoad™* for each tackle was captured using the Catapult OptimEye S5 (Firmware version: 7.42.) (OptimEye S5, Catapult Innovations, Melbourne, Australia). Participants wore the device as they would in a match i.e., on their upper back, between the scapulae and secured by a vest. Catapult OptimEye S5, is a 10 Hz GPS unit and includes an inbuilt accelerometer (3D 16g), gyroscope (3D 2000 degrees per second) and magnetometer, all of 100 Hz. The *PlayerLoad™* data were retrieved from OpenField software 1.22.0 (OpenField Cloud – Catapult Wearables, 2019). The Catapult devices intra-reliability was proven to be excellent with most of the within CV (covariance) being less than 2.0% (7).

4.2.5 Subjective measures

Each participant filled in a subjective measures' form before and after each testing sessions. The form included Likert scales for RPE scale (CR-10) and RPC scale. The form also included Visual Analogue scales to measure mental fatigue, and their perception of their neuromuscular fatigue. Neuromuscular fatigue can be defined as an exercise-induced reduction in the force/power-generating capacity of a muscle or muscle group (258). This was used to determine the intensity of the tackles, which was no different between the tackle technique categories (Additional Table S4.1).

4.2.6 Video derived kinematics data

Three GoPro Hero 7 cameras (1080p, 120fps) (Hero 7, GoPro, Inc, United States of America) were positioned along the side of the tackle simulator. For time synchronisation, a bright LED was flashed which all three cameras could see. For calibration of extrinsic camera parameters, a checkerboard was moved across the field of view for all three cameras once in position.

These videos were analysed using Deeplabcut (246) to provide markerless motion capture of player and tackle dummy position estimates. Following this, the estimates were 3D reconstructed using Sparse Bundle Adjustment and finally a low pass filter was applied to the resulting 3D joint positions. In order to detect the tackle events, the tackle dummy's 'x' acceleration was monitored for a 'spike'. The 'x' axis was anteroposterior and was selected due to the optimal position of the tackle equipment. After the videos were analysed using Deeplabcut, the h5 files were filtered using a median filter (https://docs.scipy.org/doc/scipy/reference/generated/scipy.signal.medfilt.html). For each body part, the x and y coordinates were passed into a list of size N frames. Where N is the total number of frames for the tackle. The volume argument of the above function was the x and y lists. In both instances, the kernel size was set to 3 (default setting). Side note, if any of the points were greater than 500 pixels - it would be considered an outlier (setting the likelihood to zero). After the

3D reconstruction was completed, the same filter was used on the x, y and z coordinates (using the same arguments). The final filter used was a digital filter (https://docs.scipy.org/doc/scipy/reference/generated/scipy.signal.filtfilt.html) where argument b and a were determined using a butterworth filter (https://docs.scipy.org/doc/scipy/reference/generated/scipy.signal.butter.html). The order of the filter N was set to 3 and the critical frequency Wn was 0.05. The above filtered points were splined in order to find the velocity and acceleration.

4.2.6.1 Definitions

Table 4.1 shows all the video-derived kinematics variables and definitions. The left shoulder and hip were the two joints selected for the analysis. The shoulder is the first point of contact for the player and the hip is the used for driving the tackle.

Table 4.1: *Video-derived kinematics variables and definitions*

Variable	**Definitions**
Initial velocity (Vi) shoulder [m.s^{-1}]	Shoulder of the tackler's initial velocity (just before impact). This is the velocity in the x-direction (anteroposterior).
Final velocity (Vf) shoulder [m.s^{-1}]	Shoulder of the tackler's final velocity (impact with the ground). This is the velocity in the x-direction (anteroposterior).
Initial velocity (Vi) hip [m.s^{-1}]	Hip of the tackler's initial velocity (just before impact). This is the velocity in the x-direction (anteroposterior).
Final velocity (Vf) hip [m.s^{-1}]	Hip of the tackler's final velocity (impact with the ground). This is the velocity in the x-direction (anteroposterior).
Energy of hip at impact [J]	The kinetic energy of the tackler's hip at impact using only the x coordinates: KE = 0,5*mass of player*(initial velocity of the hip in the x-direction)^2
Force of shoulder at impact [N]	The force at which the tackler's shoulder impacts the tackle dummy (in the x-direction). F = mass of tackler*(acceleration of tackler's left shoulder in the x-direction)
Power of shoulder at impact [Nm.s^{-1}]	The power at which the tackler's shoulder impacts the tackle dummy. P = force of left shoulder at impact)*(initial velocity of left shoulder at impact)
Momentum of hip at impact [kgm.s^{-1}]	Total momentum when the tackle dummy and tackler collide. p = momentum of hip + momentum of lower quartile of tackle dummy (all in the x-direction)

Total Momentum at impact [kgm.s^{-1}]	Total momentum of the dummy and tackler when tackle dummy and tackler collide. p = momentum of hip + momentum of lower quartile of tackle dummy (all in the x-direction) Only the hip was used in this case since the hip joint is used to drive the player in the tackle when contact is made.
Velocity after impact [m.s^{-1}]	Using the data set provided and looking at the velocity of the tackle dummy and hip (averaging the two) in the x-direction immediately after impact until the tackle dummy and player made contact with the ground.
Distance travelled [m]	The distance travelled by the tackler in the x-direction (how much distance the tackler covered from making contact with the tackle dummy to when the player and tackle dummy make contact with the ground – pushing the tackle dummy in the direction it came from) using position.
Contact time [s]	The total time in which the tackler was in contact with the tackle dummy to when the player and tackle dummy make contact with the ground (using the frame rate and how many frames are present from start to end of a tackle).
Acceleration of shoulder at impact [m.s^2]	The acceleration of the shoulder of the tackler in the x-direction at impact.

4.2.8 Data Analysis

Following the download of the Comma separated value (CSV) files for each player from OpenField, each tackle was individually analysed. Using the player's technical proficiency scores, the individual tackles were divided into three technical scoring categories: low scoring tackles (≤ 7 AU), medium scoring tackles (8 AU) and high scoring tackles (≥ 9 AU). The tackle sets were also divided into three technical scoring categories: Low scoring tackle set (≤ 44 AU), medium scoring tackle set (45 - 51 AU) and high scoring tackles (≥ 52 AU). The data were split into tertiles to ensure the categories were more evenly distributed. Since there were so many variables used in this study, relative importance was identified using a Random Forest Plot model to determine the most important variables for tackle technique. The greater the decrease in Gini index, the greater the relative importance the variable has to tackle technique. The variables with the highest relative importance were subjectively determined from the Random Forest Plot graph by looking for a break in the graph (Gini index ≥ 14.0). A confusion matrix and Out-of-bag (OOB) estimate of error were conducted using the *caret* package to assess the

model which was carried out in R. Differences between technical scoring categories were considered meaningful if there was no overlapping of 95%CI confidence intervals (259,260). We accept the limitations of this method of examining overlap (i.e., rejects the null hypothesis less often than the standard method when the null hypothesis is true, and fails to reject the null hypothesis more frequently than does the standard method when the null hypothesis is false), but are satisfied with level of accuracy for this study. Cohen's effect size statistic (ES) was used to determine the magnitude of the differences between technical categories. Effect sizes of < 0.20, 0.21 – 0.59, 0.60 – 1.19, 1.20 – 1.99 and > 2.0 were considered trivial, small, moderate, large, and very large, respectively. Data are reported as mean, 95% confidence intervals (95%CI). All statistics and graphs were produced in R statistical program (R Core Team, 2013).

4.3 Results

4.3.1.1 Random Forest Plots for technical scoring categories

Figure 4.1 shows the relative importance of tackle technique in the random forest plot model for the contact phase of the tackle. The variables that showed to be the most important for classification between the three categories of tackle technique were *PlayerLoad* at *Contact* (Gini index = 25.4), *initial velocity of shoulder* (Gini index = 17.2), *energy of the hip at contact* (Gini index = 16.2), and *power of the shoulder at contact* (Gini index = 14.0).

4.3.1.2 Model performance

Model for the random forest analysis had an OOB estimate of error rate of 57.39%. The confusion matrix showed the class error was 59% for the high scoring tackles, 83% for medium scoring tackles and 38% for low scoring tackles.

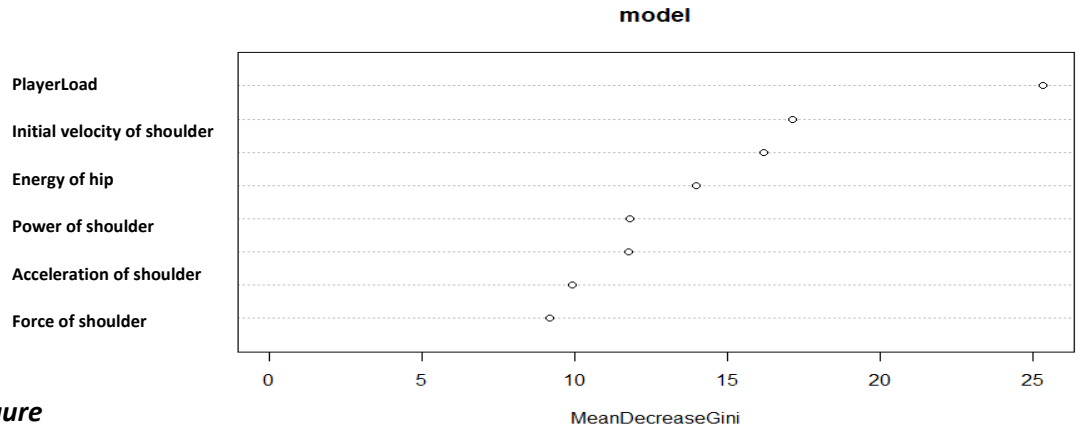

***Figure 4.1**. Random Forest Plot model for the contact phase of the tackle.*

4.3.2 Technical proficiency scores

Table 4.2 shows the total technical proficiency scores for each technical criteria and the overall score for by technical scoring category. Figure 4.2 shows the three different technical categories. Pre-contact, contact and post-contact total technical scores were significantly different between categories (Table 4.2).

Table 4.2. *Mean and 95% confidence intervals (95%CI) of tackle proficiency scores for each category. Data were reported in arbitrary units (AU). Three technical scoring categories: Low scoring tackles (≤ 7 AU), medium scoring tackles (8 AU) and high scoring tackles (≥ 9 AU).*

				Low versus Medium		**Low versus High**		**High versus Medium**	
Tackle Proficiency Criteria (AU)	Low scoring tackles (95%CI)	Medium scoring tackles (95%CI)	High scoring tackles (95%CI)	Effect size	Interpretation	Effect size	Interpretation	Effect size	Interpretation
Low body position (dipping i.e., upright-to-low)	0.8 (0.7 – 0.9)	0.9 (0.8 – 0.9)	1.01	0.3	Small	1	**Moderate***	0.5	Moderate
Straight back, centre of gravity ahead of base of support	0.9 (0.9 - 1.0)	1.0 (0.9 – 1.0)	1.0	0.5	Small	0.7	Moderate	0	Trivial
'Boxer stance' (elbows bent, hands forward and open)	0.8 (0.7 - 0.9)	0.9 (0.8 – 0.9)	1.01	0.3	Small	0.7	**Moderate***	0.1	Trivial
Head up and forward with eyes open	1.0	1.0	1.0	NA		NA		NA	
Shortening steps	0.0	0.2 (0.1 – 0.3)	0.4 (0.2 – 0.5)	0.8	**Moderate***	0.6	**Moderate***	0.4	Small
Pre-contact total	3.6 (3.5 – 3.7)	4.0 (3.8 – 4.1)	4.3 (4.2 – 4.4)	0.8	**Moderate***	1.4	**Large***	2.2	**Very Large***
Explode with leading leg into contact	0.5 (0.4 - 0.6)	0.5 (0.4 – 0.6)	0.8 (0.7 – 0.9)	0	Trivial	0.7	**Moderate***	0.7	Moderate
Contact target with shoulder within region below shoulders and above hips	0.4 (0.3 - 0.5)	0.9 (0.9 – 1.0)	1.0 (0.9 – 1.0)	1.2	**Large***	1.6	**Large***	0.4	Small
Place head on correct side of ball-carrier	1.0	1.0	1.0	NA		NA		NA	
Contact total	1.9 (1.8 - 2.0)	2.5 (2.3 – 2.6)	2.8 (2.7 – 2.9)	1	**Moderate***	1.7	**Large***	0.6	**Moderate***
Drive through contact with legs and shoulder	0.3 (0.2 – 0.4)	0.4 (0.2 – 0.5)	0.4 (0.3 – 0.5)	0.2	Small	0.2	Small	0	Trivial

Arm usage (wrap i.e., hit-and-stick)	0.8 (0.7 – 0.9)	0.8 (0.7 – 0.9)	1.0	0	Trivial	0.7	**Moderate***	0.7	**Moderate***
Jackle	0.0	0.4 (0.3 – 0.552)	0.7 (0.65 – 0.8)	1.3	**Large***	2.6	**Very Large***	0.7	Moderate
Post contact total	1.1 (0.9 – 1.2)	1.6 (1.4 – 1.7)	2.2 (2.0 – 2.3)	0.8	**Moderate***	1.8	**Large***	1.1	**Large***
Total Score	**6.5 (6.4 – 6.7)**	**8.0**	**9.3 (9.2 – 9.4)**	**3.2**	**Very Large***	**5.0**	**Very Large***	**3.5**	**Very Large***
Percentage	**59%**	**73%**	**84%**						

***Significantly different**

.

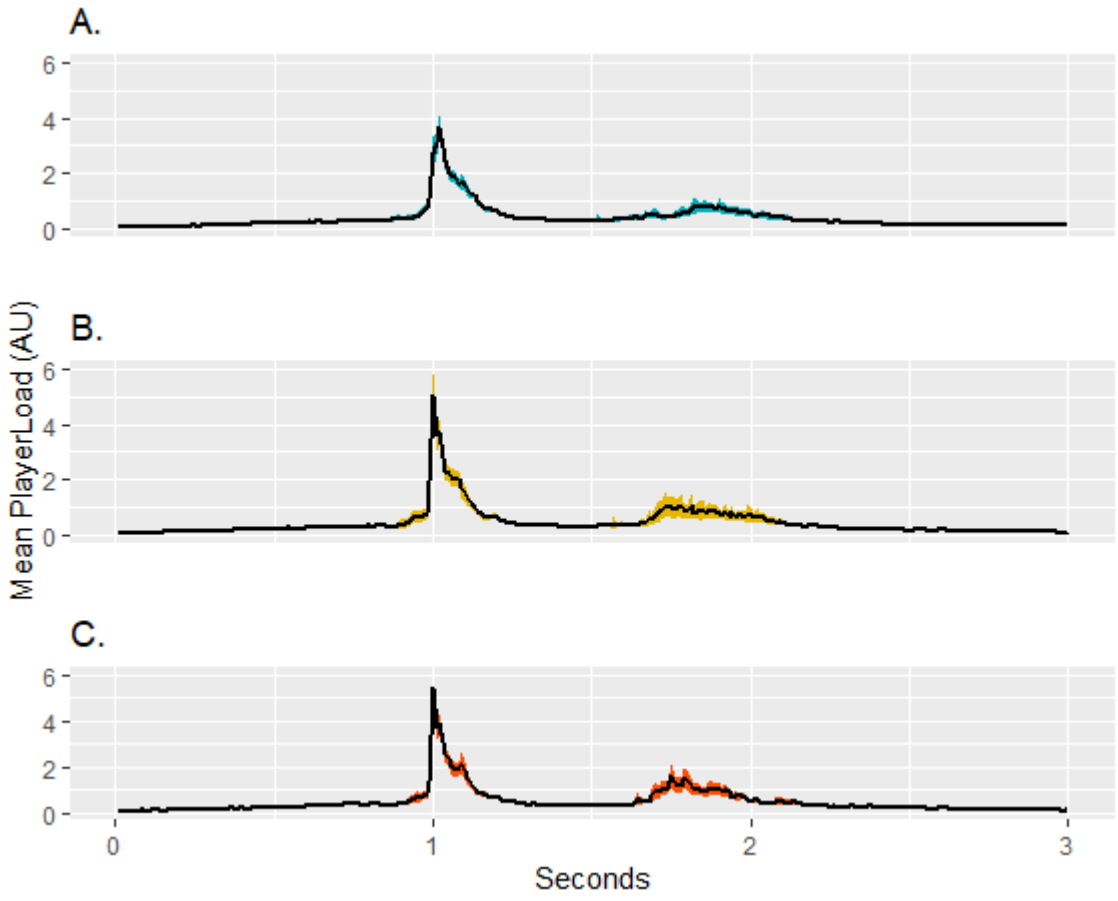

Figure 4.2. *Mean PlayerLoad™ and 95% confidence intervals of the 3 categories of tackles.* ***a.*** *Low scoring tackles (tackles scoring ≤ 7).* ***b.*** *Medium scoring tackles (tackles scoring 8).* ***c.*** *High scoring tackles (tackles scoring ≥ 9).*

4.3.3 Video derived kinematic measurements

Mean and 95% confidence intervals are provided for video derived kinematic measurement and microtechnology derived measurements in Table 4.3 and 4.4 respectively. *Power of the shoulder at contact* in the high scoring tackles was significantly higher than in the low scoring tackles (low scoring tackles: 7.9 (95%CI 5.3 - 10.5) kW versus high scoring tackles: 27.8 (95%CI 11.36 - 44.3) kW, ES: small). *Force of shoulder at contact* was higher in low scoring tackles than medium scoring tackles (low scoring tackles: 3.6 (95%CI 2.61 - 4.5) kN versus medium scoring tackles: 1.5 (95%CI 0.4 - 2.60) kN, ES: small). The mean *Force of the shoulder* in high scoring tackles was in the left direction (direction at which the Tackler is tackling) while in the low and medium scoring tackles the mean was in the right direction. *Acceleration of shoulder at contact* was higher in low scoring tackles than medium scoring tackles (low scoring tackles: 50.3 (95%CI 39.2 - 61.5) m/s^2 versus medium scoring tackles: 16.6 (95%CI 3.9 - 29.3) m/s^2, ES: small). There was no significant difference between any of the other video-derived kinematic measurement and categories.

4.3.4 Microtechnology derived measurements

PlayerLoad^{TM} at contact is significantly higher at contact in high scoring tackles than in lower scoring tackles (low scoring tackles: 6.0 (95%Cl 5.6 - 6.4) AU versus high scoring tackles: 7.1 (95%Cl 6.6 - 7.7) AU, ES = trivial) (Table 4.4).

Table 4.3. *Mean and 95% confidence intervals (95%CI) of video derived kinematic measurements for each category. Three technical scoring categories: Low scoring tackles (≤ 7 AU), medium scoring tackles (8 AU) and high scoring tackles (≥ 9 AU).*

				Low versus Medium		**Low versus High**		**High versus medium**	
Physical load measurements	Low scoring tackles *(95%CI)*	Medium scoring tackles *(95%CI)*	High scoring tackles *(95%CI)*	Effect size	Interpretation	Effect size	Interpretation	Effect size	Interpretation
Vi of shoulder at contact (m/s)	-0.9 (-1.4 to -0.4)	-1.3 (-2.1 to -0.5)	-1.6 (-2.5 to 0.8)	0.1	Trivial	0.2	Small	0.1	Trivial
Vi of hip at contact (m/s)	-0.8 (-2.0 to -1.6)	-2.0 (-2.5 to -1.5)	-1.4 (-2.0 to -0.7)	0.6	Moderate	0.4	Small	0.3	Small
Energy of hip at contact (kJ)	0.1 (0.1 to 0.2)	0.3 (0.1 to 0.5)	0.4 (0.1 to 0.6)	0.3	Small	0.7	Moderate	0.2	Small
Force of shoulder at contact (kN)	3.6 (2.6 to 4.5)	1.5 (0.4 to 2.6)	-2.1 (-0.8 to 5.1)	0.3	**Small***	0.8	Moderate	0.4	Small
Power of shoulder at contact (kW)	7.9 (5.3 to 10.5)	7.7 (4.0 to 11.5)	27.8 (11.4 to 44.3)	0.005	Trivial	0.5	**Small***	0.4	Small
Momentum of hip at contact (kg.m/s)	-74.9 (-84.5 to -65.3)	-82.9 (-103.5 to -62.2)	-58.1 (-85.3 to -30.9)	0.1	Trivial	0.2	Small	0.3	Small
Total momentum at contact (kg.m/s)	-25.4 (-44.7 to -6.1)	-28.8 (-54.9 to -2.7)	-15.6 (-75.2 to 44.0)	0.02	Trivial	0.1	Trivial	0.1	Trivial
Acceleration of shoulder at contact (m/s^2)	50.3 (39.2 to 61.5)	16.6 (3.9 to 29.3)	23.5 (-9.9 to 56.9)	0.4	**Small***	0.3	Small	0.1	Trivial

The initial direction for the tackler is towards the left (negative x) ***Significantly different**

Table 4.4. *Mean and 95% confidence intervals (95%CI) of microtechnology derived measurements for each category. Data were reported in arbitrary units (AU). Three technical scoring categories: Low scoring tackles (≤ 7 AU), medium scoring tackles (8 AU) and high scoring tackles (≥ 9 AU).*

				Low versus Medium		**Low versus High**		**High versus Medium**	
Physical load measurements (AU)	Low scoring tackles *(95%CI)*	Medium scoring tackles *(95%CI)*	High scoring tackles *(95%CI)*	Effect size	Interpretation	Effect size	Interpretation	Effect size	Interpretation
PlayerLoad™ **at contact**	6.0 (5.6 to 6.4)	6.3 (5.8 to 6.8)	7.1 (6.6 to 7.7)	0.1	Trivial	0.1	**Trivial***	0.3	Small
Total contact *PlayerLoad™*	44.1 (41.1 to 47.2)	40.7 (37.8 to 43.7)	45.1 (41.7 to 48.6)	0.2	Small	0.1	Trivial	0.3	Small

***Significantly different**

4.4 Discussion

Main findings

This study aimed to explore tackle technique and external load of a simulated tackle. Firstly, a Random Forest Plot was completed, which shows that *PlayerLoad™* was the most important variable in relation to the technical scoring categories, followed by *initial velocity of the shoulder, energy of the hip at contact* and *power of the shoulder at contact*. The main finding in this study is that *Power of the shoulder* and *PlayerLoad™ at contact* was higher in the high scoring tackles than the low scoring tackles. *Force and Acceleration of the shoulder at contact* was also higher in the low scoring tackles than medium scoring tackles. These findings provide a deeper understanding of tackle technique and may potentially assist coaches and researchers. Understanding the relationship and importance of different aspects of the tackle will allow for coaches to focus on the important aspects in contact training.

High proficiency tackles produce more power of the shoulder at contact

Power of the shoulder at contact is shown to be higher in the high scoring tackles. It is well-established that players with a high tackle proficiency have a lower risk of injury and higher likelihood to win the tackle (25). The results from this study suggest that high proficiency tackles also produce more power at the shoulder at contact. Furthermore, *force and acceleration of the shoulder at contact* was lower in the high scoring tackles. Although, players produce higher force in the lower scoring tackles, it can be suggested that they are not executing the force in the correct way or place from the video footage. Therefore, they do not produce a powerful tackle. Further investigation is needed to see if this is the case. Since players with high tackle technique produce higher power, players who are preparing and going into contact may be in their optimum position in pre-contact and contact phases, and therefore are producing higher power. However, further investigation is needed. Momentum going into the tackle has also previously been hypothesized as an indicator of tackle dominance (10). If a player is going into contact with lower momentum, they are less likely to dominate the tackle (10). In this study no differences were found between tackle technique and momentum of the hip. However, further investigation into the shoulder is advised.

PlayerLoad™ and contact demands

Another metric that was highlighted in this study is *PlayerLoad™. PlayerLoad™* has shown up prominently in the results of this study. Previous studies have shown a near perfect correlation between collision load or *PlayerLoad™* and observed tackle count (6,48,50,52). Collision load and *PlayerLoad™* are different names used by different devices. MacLeod et al. (2018) concluded that microtechnology can be used for monitoring contact but should be used with caution (52). However,

none of these studies have investigated tackle technique and *PlayerLoad™*. High *PlayerLoad™ at contact* was found in high proficiency tackles. In other words, players producing high scoring tackles are experiencing more load at contact. This can suggest that when players are in their optimum tackling position, they are able to encounter more load. Additionally, the highest relative importance shown in the Random Forest Plot model was *PlayerLoad™ at contact.* Since there were so many variables in this study, the Random Forest Plot model highlights the most important variables. Further analysis can be done to get a more detailed result amongst the technical proficiency groups.

Markerless motion capture as a future monitoring tool

Although microtechnology devices and video analysis are the main methods used to monitor players (36), getting kinematics and kinetics data (such as, force, power or energy) can be challenging in a field setting. The markerless motion capture method is cost effective, non-evasive method and can be used in training setting (246). This method is new and emerging. There are only validity studies completed in other sports (261,262) and for walking gait in sagittal plane (247) but not in rugby and therefore, must be used with caution. Deeplabcut is the program used to produce data for markerless motion capture and is novel to the field of sport science and medicine (246). Deeplabcut has been used in other scenarios to research into biomechanics. For example, Nath et al. (2019) used this markerless motion capture method on cheetahs to understand their biomechanics (246). Deeplabcut has also been used in live rugby match scenarios (263). Since this method is cost effective and gives one a large amount of data it may be a 'game changer' to understanding the tackle further and what other key elements we need to look out for. However, this method is not without limitations, the researcher or practitioner must have the skills to use and understand Deeplabcut (246).

Limitations and future studies

The aim of this study is to investigate *PlayerLoad™* and kinematics of a simulated tackle in relation to tackle technique. This study is based in a lab-based setting on the collision sport simulator which is used to investigate further into the rugby tackle in a controlled and safe environment. Although the simulator has been proven to replicate a one-on-one tackle the next step would be investigating external load and tackling technique on the field. Furthermore, this study only investigated front on tackles and future studies should investigate different types of tackles. A limitation of this study is not investigating the dominant and non-dominant shoulders and should be investigated in future studies. Additionally, the acceleration variable must be used with caution because it violates the Nyquist sampling theorem. This is based off the Go pro sampling rate (264). Future studies should also investigate how external load metrics vary amongst positions and level of play. Additionally, future studies can investigate into the subcategories of tackle proficiency and *PlayerLoad™*. Since

microtechnology still requires more validation, it has been recommended that coaches and sport practitioners use microtechnology and video analysis simultaneously to ensure superior accuracy (36,37).

4.5 Conclusion

This is the first study to explore external load of a tackle and its relationship to tackling technique. The main finding in this study was that high proficiency tackles produce higher *power of the shoulder at contact*. This result suggests that a player in the optimum position into contact will produce more power at contact. *Force and acceleration of the shoulder at contact* was higher in the low scoring tackles. Although, players produce higher force in the lower scoring tackles, it can be suggested that they are not executing the force in the correct way or place. The reason behind the inverse relationship between power and force of the shoulder at contact may be the players in the correct tackle technique producing more power but less force. Therefore, being more efficient. Whereas the players with poor tackle technique may be executing their force inefficiently at contact. Further investigation is necessary. The relative importance of the technical score categories shows that *PlayerLoad™ at contact* is an important variable for technical scoring categories. Furthermore, *PlayerLoad™ at contact* was higher in the high scoring tackles. *PlayerLoad™* has, once again, shown to be important when monitoring player contact. Using external load measurements along with tackle technique assessments allows coaches to understand the dynamic of the tackle further resulting in the ability to optimise tackle training, monitor contact and preparing players for competition.

4.6 Additional files:

Table S4.1. *Mean and 95% confidence intervals (95%CI) of subjective measurements for each category set. Data were reported in arbitrary units (AU). Three technical scoring categories: Low scoring tackle set (≤ 44 AU), medium scoring tackle set (45 - 51 AU) and high scoring tackles (≥ 52 AU).*

				Low versus Medium		**Low versus High**		**High versus Medium**	
Internal load measurements (AU)	Low scoring tackle set *(95%CI)*	Medium scoring tackle set *(95%CI)*	High scoring tackle set *(95%CI)*	Effect Size	Interpretation	Effect Size	Interpretation	Effect Size	Interpretation
Mental fatigue	34.4 (22.8 to 46.1)	42.8 (29.4 to 56.2)	33.4 (18.3 to 48.5)	0.3	Small	0.04	Trivial	0.4	Small
Neuromuscular fatigue	43.3 (34.5 to 52.1)	46.9 (31.7 to 62.2)	46.6 (30.4 to 62.8)	0.2	Small	0.1	Trivial	0.01	Trivial
Rating of Perceived Exertion	5.1 (4.0 to 6.2)	6.5 (5.3 to 7.8)	6.4 (5.2 to 7.6)	0.6	Moderate	0.6	Moderate	0.1	Trivial
Rating of Perceived Challenge	4.3 (3.3 to 5.4)	6.2 (4.8 to 7.5)	5.8 (5.0 to 6.7)	0.9	Moderate	0.8	Moderate	0.2	Small

Chapter 5: Conclusions

5.1 Introduction

The main aim of this thesis is to investigate the relationship between tackle technique and external load of a simulated tackle. In order to appropriately achieve this, reviewing the literature on how collisions are quantified as well as reviewing what we know about coaches in rugby union, rugby league and rugby sevens was completed.

1) How are collision frequencies and intensities quantified for rugby union and rugby sevens?

A systematic review was used to address this question. The main method for quantifying collisions was video-based analysis. Integrating both video-based analysis and microtechnology is recommended to ensure accuracy and utilise all variables. Metrics and grouping variables between training and matches should be consistent to allow for comparisons between groups. Per minute, rugby sevens players perform more tackles and ball carries into contact than rugby union players and forwards experienced more tackles than backs (12.8 [7.5 – 18.1] tackles and 7.6 [4.3 – 10.9] tackles, respectively). Another key finding in this chapter is that forwards experience more very heavy impacts (52.5 [29.8 – 75.2] vs. 41.7 [26.4 – 57.0] *very heavy* impacts) and severe impacts (10.8 [4.4 – 17.1] vs. 6.7 [5.1 – 8.4] *severe* impacts) than backs in rugby union. Comparing training and matches will improve our understanding of the link between training and matches. More studies that quantify collisions is needed to establish this relationship. The main take away from this chapter is the frequency and intensity of collisions in training and matches may lead to adaptations for a "collision-fit" player and lend themselves to general training principles such as periodisation for optimum collision adaptation.

2) What do we know about rugby union, rugby league and rugby sevens coaches?

The Arksey and O'Malley's five stage scoping review process was used and enhanced by Levac et al's framework. *Coach knowledge, Coach pedagogies* and *Coach development* were the three main themes in this review. One of the main findings in for *Coach knowledge* was a positive trend in coach's knowledge of injuries, specifically concussions. In previous years, coaches had poor concussion knowledge which led to players who were concussed being managed poorly. Therefore, their knowledge of identifying concussions, understanding the gravity of a concussion and the return to play protocol is essential. To ensure this continues practical educational input should be provided for our coaches to protect the welfare of our rugby players. In the *Coach pedagogy* theme, the main finding was a shift from coach-centred learning to player-centred learning. Although, coaches are reluctant for this change it helps develop players to make their own decisions and read the game for themselves. There are many variables and aspects to monitoring players in both the training and match setting. This can cause coaches to be lost in a sea of data and not focus on the essential variables. Coaches thought monitoring both the training load and the training responses of the

athletes very important. Coaches also think session RPE was effective for monitoring performance and preventing injury. Coaches tend to use this variable to guide periodisation, especially the taper period for players. Another important aspect of monitoring players is utilizing performance analysis. Unfortunately, due the lack of funds and availability of resources this results in the lack of feedback and a more subjective approach instead of the results one would get from performance analysis.

3) What are the differences in external load variables for different levels of tackling technique?

External load was investigated via video-based analysis, markerless motion capture, and a Catapult device while a player was tackling the collision sport simulator. A Random Forest plot model was used to determine the relative importance of these variables at contact, where *PlayerLoad™* was shown to be the most important in relation to tackle technique. High proficiency tackles produce more *power of the shoulder at contact* and *PlayerLoad™*. These findings suggest that if a player is in the optimum position going into contact, they will produce a more *powerful* tackle. It also suggests that players with a high tackle proficiency are experiencing more work at contact than a player who has poor tackle technique. *Force and acceleration of the shoulder at contact* was higher in the low scoring tackles. Although, players produce higher force in the lower scoring tackles, it can be suggested that they are not executing the force in the correct way or place. Even though internal load variables were not significantly different between the technical scoring categories, sport practitioners and coaches should still use internal load measurements to adjust their training. Using both internal and external load measurements along with tackle technique assessments allows coaches to understand the dynamic of the tackle further resulting in the ability to optimise tackle training, monitor contact and prepare players for competition.

5.2 Practical implications

From the findings in this study, coaches can understand the frequency and intensity of collisions that players experience or perform in rugby union and rugby sevens. Coaches can further adjust training demands to ensure that their players are 'collision fit' and are adequately prepared for match demands. This decreases the chance of injury and will improve performance. Researchers and coaches know and acknowledge the gap in the research for coaches in rugby football and where we need to build and focus on. These findings, additionally, highlight the importance of tackle technique and what an impact it has on the game and dominance of a tackle. Lastly, the importance of monitoring players and how *PlayerLoad™* is a variable that is important to monitor for players.

5.3 Future studies

Future studies can investigate into side tackles since this study only investigated front-on tackles. An interesting study would be researching the internal and external load of tackles on the field scenario or in a match setting. Although the collision sport simulator has been proven to replicate front-on tackles it would be interesting to see if researchers would get similar results. Lastly, future studies should see if there are any changes in external and internal load in a mental and neuromuscular fatigue induced scenario.

5.3 Limitations

- The main limitation in the literature review chapters were lack of consistency in grouping variables amongst the studies. This limitation was predominately challenging for the meta-analysis.
- Gaps in the literature also made it challenging to make conclusions on certain themes in the literature such as *Coach development*.
- Throughout the study chapter, there was a few technical issues with the devices which caused a few data files to be inaccurate.
- Data collection and data processing using the 3D markerless motion capture method is a limitation within the study chapter.
- All tests were based in a lab-based setting on the collision sport simulator which is used to investigate further into the rugby tackle in a controlled and safe environment. Although the simulator has been proven to replicate a one-on-one tackle the next step would be investigating external load and tackling technique on the field.
- This study only investigated front-on tackles.
- Another limitation of this study is the not investigating the dominant and non-dominant shoulders and should be investigated in future studies.

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