



Biomechanics of Rugby Tackle Techniques in Youth and Adult Players: A Systematic Review of Age-Specific Injury Risk and Performance Implications

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Abstract

Background Tackling is a vital skill in rugby that greatly influences both performance outcomes, such as carry distance and possession gain, and injury risk, such as the frequency of concussions and cervical injuries. Approximately 72% of head impacts in rugby occur during tackles, leading to concussions and cervical trauma. Technical skill in tackle mechanics is therefore central to player safety.

Objectives This systematic review evaluates tackle biomechanics across age groups to identify differences in technique and injury patterns and to inform age-specific coaching strategies.

Methods This systematic review was registered with PROSPERO (ID CRD420251103973) and adhered to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 guidelines. PubMed, SPORTDiscus, Web of Science, ScienceDirect and Google Scholar were searched without date restrictions. Studies analysing tackle biomechanics, injury mechanisms or performance outcomes in youth or adult rugby players were eligible. Two reviewers independently screened titles, abstracts and full texts. Risk of bias was assessed using the Downs and Black checklist. Thirty-two studies met the inclusion criteria.

Results Across the 32 included studies, three patterns emerged. First, tackler head-in-front positioning was associated with a five- to eight-fold increase in per-tackle concussion risk and was more common in youth players than adults. Second, dominant-shoulder tackles consistently produced lower head accelerations than non-dominant tackles, with this safety advantage eroding under match-induced fatigue. Third, youth players showed lower tackle proficiency scores than adults, characterised by reduced hip and knee flexion, less leg drive and more frequent arm-only contact. Across studies, evidence quality was moderate; few studies used non-injury controls to support causal claims.

Conclusions Age-specific coaching strategies are warranted to optimise tackle safety and performance. Emphasising correct head positioning, dominant-shoulder engagement and lower-limb mechanics may mitigate injury risk in youth rugby. The current evidence base supports associations rather than firm causal claims; future case-control studies that compare injury and non-injury tackles within the same match environment would strengthen this evidence.

1 Background

Tackling is a fundamental aspect of rugby performance and a primary contributor to injury across all levels of the sport. In youth rugby union, tackling accounts for up to 60% of all injuries and approximately 62% of concussions, with the highest burden reported among 13- to 18-year-olds [1, 2]. In rugby league, the incidence of concussion ranges from 4.6 to 14.7 per 1000 player-hours [3]. Among adults, tackling is responsible for up to 72% of head injuries, particularly those involving head-to-head or head-to-knee contact [4]. These statistics highlight tackling as a critical area of focus

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Key Points

Head-in-front tackling raises per-tackle concussion risk roughly five- to eight-fold and is more common in youth players than in adults.

Dominant-shoulder tackles consistently produce lower head accelerations than non-dominant tackles, but that advantage erodes under fatigue.

Age-appropriate coaching that targets head placement, shoulder engagement and lower-limb mechanics is needed to convert biomechanical insight into safer tackle execution

for both injury prevention and skill development. Although tackling is common to all forms of rugby (union, league and sevens), the physical and biomechanical demands vary considerably across levels of play [5]. Adult players experience higher tackle volumes and forces because of greater mass, speed and game intensity [6, 7]. Although youth players (those under approximately 16 years of age) typically experience a lower overall match-injury rate per player-hour than adults, they may face a higher per-tackle risk of head and cervical injury during contact events [8, 9]. This per-tackle vulnerability has been attributed to factors associated with the adolescent growth spurt, including reduced motor coordination, balance and reaction time, as well as less consistent technique under fatigue or time pressure [10, 11]. These developmental characteristics may manifest in technical terms as an upright trunk posture, a narrow base of support, mismatched foot-to-shoulder alignment at contact, suboptimal head positioning and ineffective shoulder engagement [10, 11]. These technical errors may also reflect limited exposure to coaching or apprehension about contact, rather than maturation alone [10]. Consequently, applying adult-derived technical models to younger cohorts may be inappropriate and even harmful in some instances.

Technical proficiency and biomechanics are consistently identified as key determinants of injury risk and tackle effectiveness across age groups [5]. The tackler's movement pattern can be divided into three phases: 'pre-impact', 'impact' and 'post-impact' [12, 13]. The tackle event itself also involves the ball carrier, whose pre-engagement sighting, body positioning and approach speed influence the technical demands placed on the tackler. During the pre-impact phase, muscle activation in the tackler follows a sequential 'bottom-up' pattern, beginning with lower-limb stabilisation and force generation and progressing upwards to the torso [12]. During the impact phase, forces are mainly transmitted through the shoulder girdle and upper trunk, with additional

load on the lateral cervical muscles [12, 14]. Maintaining stable body positioning, aligning the head laterally, and engaging the cervical and shoulder muscles in anticipation help support effective force absorption [12, 14]. In the post-impact phase, the tackler maintains control through continued leg drive and upper-body engagement to complete the tackle and bring the ball carrier to ground [12]. Each phase is governed by complex interactions between joint angles, body orientation and segmental velocities [12]. Among these, head placement, trunk angle and shoulder engagement at contact are especially influential in determining whether the tackler accepts and transfers force safely [9, 15, 16]. Youth players frequently exhibit high-risk patterns such as upright posture, head-in-front technique or passive arm-only engagement, particularly under fatigue or time pressure [9].

Several review articles have advanced the understanding of tackle-related injury mechanisms, but key limitations remain. For example, a previous systematic review examined three-dimensional biomechanics research on rugby tackles [5]. The review highlights important methodological advancements and identifies critical kinematic variables such as hip flexion, trunk inclination and head proximity to the point of contact [5]. However, it did not compare findings between youth and adult populations, nor does it explore how developmental status might influence biomechanical strategy during tackling [5]. The review focuses on measurement technologies more than on applied coaching implications, limiting its translational impact [5].

In contrast, a recent review provides a comprehensive overview of injury epidemiology, risk factors and prevention strategies in youth rugby union [17]. The review highlights that the tackle is the most common phase of play linked to injury in youth cohorts and discusses modifiable risk factors such as poor head placement, upright posture and delayed decision making. However, while it underscores the importance of coaching in mitigating injury risk, the review does not examine the biomechanical characteristics of these risky behaviours or compare them to adult tackling mechanics [17]. The authors call for better integration between biomechanical insight and coaching practice but do not provide a systematic evaluation of movement strategies across age groups, thereby limiting the review's ability to inform precise, developmentally appropriate technical instruction [17].

Anthropometric and physical profiling work has shown that body mass, sprint momentum and strength capacity increase significantly from U16 to U21 levels among English academy rugby union players [18]. More recent profiling work confirms and extends those findings in larger and more contemporary academy and elite-development cohorts with particular attention to repeated high-speed efforts and collision exposure [19]. These physical

changes affect tackle performance and injury risk, but the existing profiling work stops short of linking physical development to actual in-game tackle biomechanics or technique adaptation. The implications for skill execution in contact, therefore, remain unclear [18, 19].

Taken together, these reviews establish important foundations for tackling in youth rugby but also expose a critical analytical gap: no existing synthesis directly compares the biomechanical execution of tackling between youth and adult players, nor contextualises those differences within the physical, developmental and coaching domains. This gap matters in practice because adult-derived technical models continue to be applied to younger cohorts without a clear evidence basis for that transfer. It also matters in methodological terms: most of the available studies report on injury events alone, without sampling non-injury tackles from the same match environment, leaving the field unable to distinguish between technique features that are merely common in injury events and technique features that causally predict them [17]. The current review addresses both gaps by synthesising age-stratified tackle biomechanics and by reporting, for each included study, whether the design supports inference at the level of association or causation.

1.1 Objectives

This systematic review aims to critically evaluate and compare the biomechanical characteristics of tackling between youth and adult rugby players. A secondary aim is to identify age-specific differences in technique and performance implications to inform safer, more effective tackle coaching practices. We hypothesised that, relative to adults, youth players would show systematically different head, shoulder and lower-limb kinematics at contact, and that these kinematic differences would correspond to higher per-tackle head and cervical injury rates.

2 Methods

2.1 Search Strategy

This systematic review was registered on PROSPERO on 16 June, 2025 (registration ID CRD420251103973; available at <https://www.crd.york.ac.uk/PROSPERO/view/CRD420251103973>) and reported in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 statement; the completed PRISMA 2020 checklist is provided as Table S2 of the Electronic Supplementary Material (ESM). A systematic search was conducted on 20 December, 2024 to

identify peer-reviewed studies examining tackling biomechanics, injury prevention strategies and performance metrics in rugby. A further search was performed on 5 May, 2025 to check for new publications, from which no additional articles were identified. Following feedback during the review process, a further search was completed in June 2026, and four additional studies were added. Electronic databases included PubMed, SPORTDiscus, Web of Science, ScienceDirect and Google Scholar, all of which were searched without date restrictions. The databases were searched using free-text Boolean syntax rather than controlled-vocabulary headings (e.g. Medical Subject Headings). Free-text searching was chosen to capture biomechanical and tackle-specific terminology that is not consistently indexed in controlled vocabularies and to ensure consistent application of search strings across databases that use different controlled-vocabulary systems. Google Scholar was searched as a sensitivity check for grey literature and to track forward citations from the seed papers identified in the indexed-database searches. Given known reproducibility concerns with Google Scholar, the first 400 ranked results were screened, and any unique inclusions were treated as supplementary instead of primary search results. Reference lists of the retrieved articles were also manually screened for additional eligible studies.

The following Boolean search syntax was used:

(Rugby) AND (tackling OR tackle OR collision) AND (adults OR “senior players” OR children OR youth) AND (“joint angles” OR kinematics OR biomechanics OR “safety factors” OR “injury prevention” OR “performance metrics” OR concussion)

This search strategy was designed to strike a balance between inclusivity and the relevance of potential articles. The term “rugby” was deliberately kept broad to capture both rugby union and rugby league, which share similar demands for tackling and biomechanical characteristics. Modified or non-contact versions (e.g. Sevens, Tag) were excluded during screening based on context. The inclusion of “tackle”, “tackling” and “collision” ensured that both specific and general descriptions of contact events were captured. Population terms such as “children”, “youth”, “adults” and “senior players” were selected to reflect typical age categorisations within rugby development systems. Although “junior” was not included as a stand-alone term, studies using that classification were captured under broader terms such as “youth”. Keywords such as “biomechanics”, “joint angles” and “kinematics” were chosen to focus on quantitative movement analysis, while “safety factors”, “injury prevention” and “performance metrics” reflected applied outcomes of biomechanical relevance. Terms such as “technique” and “mechanism” were not included in the search string because of an overlap with

biomechanical descriptors and to minimise unrelated results from broader usage in other fields. “Concussion” was included as it represents a common and well-reported outcome in tackle-related studies. Although other injuries were not explicitly listed, relevant studies discussing broader injury prevention in the context of tackle mechanics were still captured through screening.

2.2 Study Inclusion and Exclusion Criteria

Two reviewers (HE, MB) independently evaluated the studies identified in the search, with discrepancies resolved through discussion or by involving a third reviewer (BG) if consensus could not be reached. Studies were eligible for inclusion if they were published in peer-reviewed journals, investigated rugby tackling biomechanics, injury mechanisms or performance outcomes, included participants identified as male or female youth or adult rugby players, employed biomechanical assessment methods (video analysis, marker-based or markerless motion capture, wearable sensors or injury surveillance), were published in English and had full-text availability. For the purposes of this review, youth participants were operationally defined as players under 18 years of age, or studies labelled U13, U16, U18, junior or academy in the source paper. Adult participants were defined as players aged 18 years or older, or as participants in studies labelled senior, amateur, semi-professional, elite or professional. Studies that explicitly spanned both age categories were retained and analysed both within and across age strata where the source data permitted. Studies were excluded if they did not explicitly focus on tackling techniques or injury prevention, solely examined non-tackling aspects of rugby, or were reviews, conference abstracts, editorials or other non-peer-reviewed literature.

2.3 Study Selection and Data Extraction

Two reviewers (HE, MB) independently screened the 1205 records remaining after deduplication by title and abstract. Disagreement occurred on 15 records (98.8% agreement, Cohen’s unweighted kappa = 0.88); these were resolved by discussion. Seventy-one full-text articles were retrieved and independently assessed for eligibility by both reviewers. Agreement was reached on 68 of 71 records (95.8%, Cohen’s unweighted kappa = 0.91); the three disagreements were resolved by discussion. In June 2026, HE, MB and BL selected four additional studies after reviewing the first 100 articles from an expanded search and reassessing the initial 1205 records. This process ensured methodological rigour and reduced the risk of missing relevant studies that met the inclusion criteria. The full PRISMA diagram is shown in Fig. 1.

Two reviewers (HE and MB) independently conducted data extraction using a standardised extraction form that captured study characteristics (design, methodology), participant demographics (sex, age, playing experience, competitive level), biomechanical parameters (joint angles, kinematics, head positioning), injury metrics (incidence rates, injury types, mechanisms), and performance outcomes related to tackle efficacy and success rates. Study authors were contacted to clarify any incomplete data. Studies with unresolved ambiguities or insufficient data after contact were excluded.

2.4 Methodological Quality

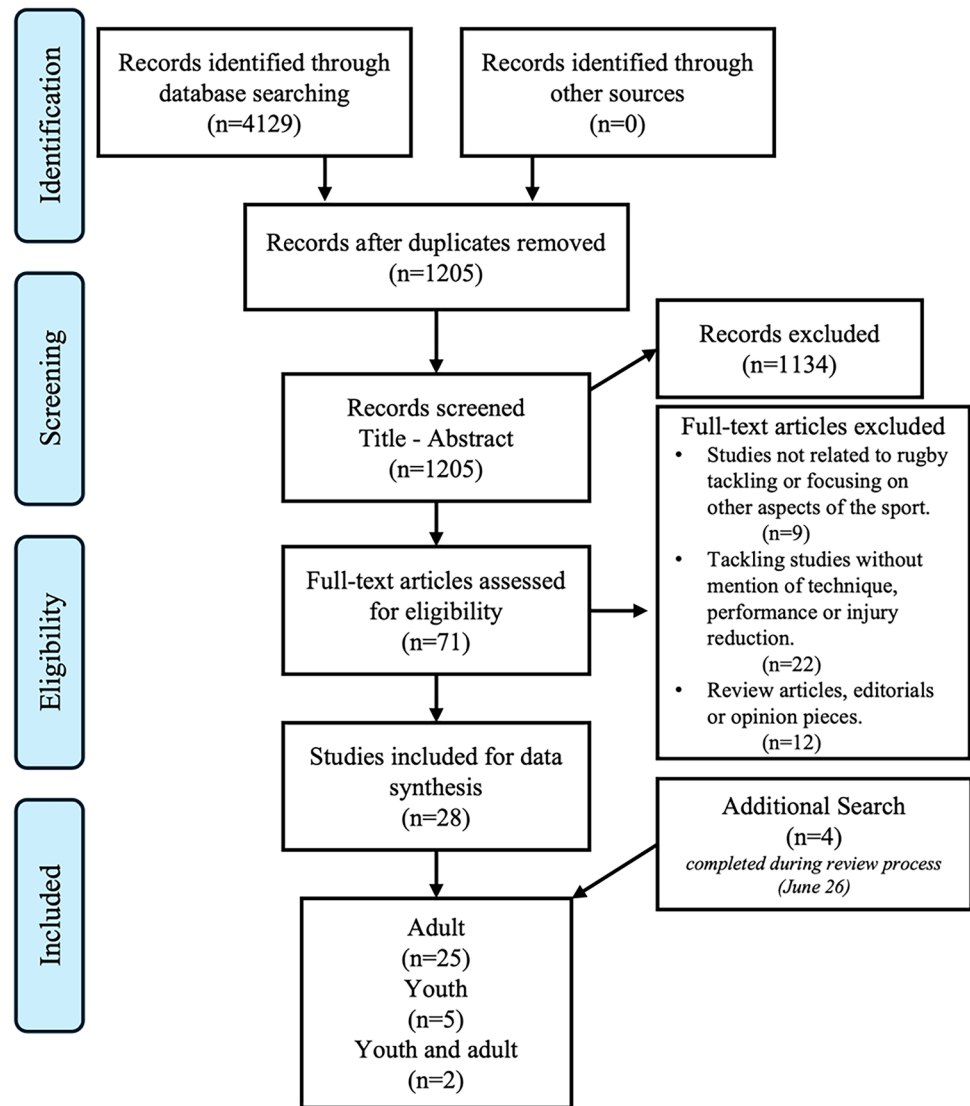
Two reviewers (HE and AG) independently assessed methodological quality using the Downs and Black checklist [20]. This validated tool assesses reporting quality, internal validity (bias and confounding), external validity and statistical power [20]. Each study was scored on these domains, providing an overall quality score and a profile of methodological strengths and weaknesses, with scores that ranged from 0 to 28. Reviewer disagreements were resolved through consensus discussions or a third party (BG). Detailed scores and risk-of-bias ratings for each included study are provided in Table 1. The checklist was applied uniformly across studies to ensure consistency in scoring. Studies were not excluded based on methodological quality; quality scores were used to characterise the evidence base rather than as an inclusion threshold.

2.5 Data Synthesis

After completing the full-text screening, data from the included studies were organised into a structured table that captured key aspects such as study design, participant characteristics (age, sex, level of play), rugby code, biomechanical variables, injury outcomes, data collection methods (e.g. video analysis, motion capture) and significant findings.

A narrative synthesis approach, following established narrative-synthesis guidance [21], was adopted to address methodological heterogeneity across the studies, particularly regarding populations, biomechanical variables measured and data collection techniques. The findings were categorised into three broad areas: (1) tackle biomechanics and joint kinematics; (2) technique-related risk factors; and (3) injury prevention and coaching implications. Within each category, themes were inductively identified by analysing patterns across joint angles, posture during contact, head position and technical execution in different age groups. Where applicable, findings were differentiated by age category (youth vs adult) and qualitative comparisons were made regarding differences in movement strategies or injury mechanisms. Quantitative data (e.g. angular measurements,

Fig. 1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) diagram adhered to for including articles in this review



force outputs and segmental velocities) were summarised descriptively owing to the variability in measurement tools and reporting standards among the studies. No formal meta-analysis was performed because of the differences in study designs and outcome reporting.

The synthesis was validated by repeatedly checking the extracted themes and findings against the original papers to ensure an accurate representation of context and meaning. Coaching and injury prevention implications were reported only when authors explicitly linked biomechanical observations to practical outcomes.

3 Results

A total of 4129 articles were identified through the initial database search, with no additional records found from other sources (Fig. 1). After removing duplicates, 1205

records remained for screening. The titles and abstracts of these records were reviewed, resulting in the exclusion of 1134 articles. The full texts of 71 articles were retrieved and assessed for eligibility. Of these, 43 articles were excluded for reasons such as not focusing on rugby tackling, lacking discussion of technique, performance or injury reduction, or being review articles, editorials or opinion pieces. Following an updated search in June 26, an additional four studies were added to the final count. Ultimately, 32 studies met the inclusion criteria, comprising 25 studies in adult participants [4, 12, 22–43], five studies in youth [2, 15, 44–47], and two studies that included both youths and adults [9, 48]. An updated search to June 2026, conducted during revision, identified four further eligible studies [41–43, 48] that had not been retrieved in the original search; no other new eligible studies were found.

Table 1 Downs and Black risk of bias checklist for 32 included studies [20]

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
Ogata et al. [22]	1	1	1	1	0	1	1	0	0	1	0	0	0	0	0
Edwards et al. [23]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
Edwards et al. [24]	1	1	1	1	0	1	1	0	1	1	1	1	1	0	0
Parmley et al. [25]	1	1	1	1	0	1	1	0	1	1	1	0	0	0	0
Kawasaki et al. [9]	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0
Edwards et al. [26]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
Edwards et al. [27]	1	1	1	1	1	1	1	0	0	1	1	1	1	0	0
Gardner et al. [28]	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0
Suzuki et al. [29]	1	1	1	1	0	1	1	1	0	1	1	1	1	0	1
Suzuki et al. [30]	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1
Hendricks et al. [31]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
Kawasaki et al. [32]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
Suzuki et al. [33]	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1
Tanabe et al. [34]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
Hendricks et al. [35]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	0
Sobue et al. [36]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
Seminati et al. [12]	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1
Burger et al. [44]	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1
Burger et al. [45]	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1
Hendricks et al. [15]	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1
Burger et al. [2]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
Hendrick et al. [37]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
King et al. [38]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
Gabbett et al. [46]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
Quarrie et al. [39]	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1
Hendricks et al. [40]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
Kerr et al. [47]	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1
Tucker et al. [4]	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Fuller et al. [41]	1	1	1	1	1	1	1	1	0	1	1	0	1	0	0
McIntosh et al. [48]	1	1	1	1	1	1	1	1	0	1	1	0	1	0	0
Davidow et al. [43]	1	1	1	1	0	1	1	0	1	1	1	1	0	0	0
Davidow et al. [42]	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1
Total	32	32	32	32	7	32	32	16	27	32	31	27	6	2	22
Study	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Total		
Ogata et al. [22]	1	1	1	0	1	1	1	0	0	0	1	1	15		
Edwards et al. [23]	1	1	1	1	1	1	1	0	0	0	0	0	18		
Edwards et al. [24]	1	1	1	1	1	1	1	0	0	0	0	0	18		
Parmley et al. [25]	1	1	1	1	0	1	1	0	0	0	0	0/1	15		
Kawasaki et al. [9]	1	1	1	0	1	1	1	0	0	0	0	0	17		
Edwards et al. [26]	1	1	1	1	1	1	0	0	0	0	0	0	17		
Edwards et al. [27]	0	1	1	1	1	1	1	0	0	0	0	0	17		
Gardner et al. [28]	1	1	1	1	1	1	1	0	0	0	0	0	18		
Suzuki et al. [29]	1	1	1	0	1	1	1	0	0	0	0	0	18		
Suzuki et al. [30]	1	1	1	1	1	1	1	0	0	0	0	0	19		
Hendricks et al. [31]	1	1	1	1	1	1	1	0	0	0	0	0	18		
Kawasaki et al. [32]	1	1	1	1	1	1	1	0	0	0	0	0	18		
Suzuki et al. [33]	1	1	1	1	1	1	1	0	0	0	0	1	20		
Tanabe et al. [34]	1	1	1	1	1	1	1	0	0	0	0	0	18		
Hendricks et al. [35]	1	1	1	1	1	1	1	0	0	0	0	0	17		

Table 1 (continued)

Study	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Total
Sobue et al. [36]	1	1	1	1	1	1	1	0	0	0	0	0	18
Seminati et al. [12]	1	1	1	1	1	1	1	0	0	0	0	0	19
Burger et al. [44]	1	1	1	1	1	1	1	0	0	0	0	0	19
Burger et al. [45]	1	1	1	1	1	1	1	0	0	0	0	0	19
Hendricks et al. [15]	1	1	1	1	1	1	1	0	0	0	0	0	19
Burger et al. [2]	1	1	1	1	1	1	1	0	0	0	0	0	18
Hendrick et al. [37]	1	1	1	1	1	1	1	0	0	0	0	0	18
King et al. [38]	1	1	1	1	1	1	1	0	0	0	0	0	18
Gabbett et al. [46]	1	1	1	1	1	1	1	0	0	0	0	0	18
Quarrie et al. [39]	1	1	1	1	1	1	1	0	1	1	1	1	24
Hendricks et al. [40]	1	1	1	1	1	1	1	0	0	0	0	0	18
Kerr et al. [47]	0	0	1	1	1	1	1	0	0	0	1	0	19
Tucker et al. [4]	0	0	1	1	1	1	1	0	0	1	1	0	22
Fuller et al. [41]	1	0	1	0	1	1	1	0	0	0	0	1	18
McIntosh et al. [48]	1	0	1	0	1	1	1	0	0	1	0	0	17
Davidow et al. [43]	1	1	1	1	1	1	1	0	0	0	0	0	17
Davidow et al. [42]	1	1	1	1	1	1	1	0	0	0	1	0	21
Total	29	28	32	27	33	32	31	0	1	3	6	4	

Downs and Black checklist scoring: 1 = item met, 0 = item not met. Two reviewers (HE, AG) independently scored each item; agreement was 100% across all assessed studies [20]

3.1 Risk of Bias

Scores for each Downs and Black checklist item and the overall quality index for the 32 studies were calculated (Table 1). Agreement was achieved on 100% of the articles examined by HE and AG across the assessed studies. Two studies were categorised as high risk of bias, scoring between 13 and 15 [22, 25]. Twenty-six studies were classified as having a moderate risk of bias with scores that ranged from 17 to 19 [2, 9, 12, 15, 23, 24, 26, 27, 29–32, 34–38, 40, 41, 43–48]. Four studies were categorised as low risk of bias, achieving scores of 20 and 24, respectively [4, 33, 39, 42]. The highest score recorded was 24, indicating that while some studies demonstrated stronger methodological quality, a considerable proportion exhibited a moderate risk of bias.

Across the 32 studies, the methodological quality profile was skewed toward the moderate range. The same items tended to be inadequately addressed across studies, particularly external validity (items 11 and 12), blinded outcome assessment (item 15) and adjustment for confounding (item 25). A priori sample-size justification (item 27) was rarely undertaken. Items capturing the reporting of aims outcomes and statistical variability were met by almost all included studies. This pattern is consistent with the predominantly observational descriptive nature of this field and is taken into account when weighing the strength of inference for each finding in the sections that follow (Table 2).

3.2 Study Characteristics

The studies covered diverse age groups that ranged from youth (U13, U16, U18) [2, 9, 15, 44–47] to adult players at collegiate/university [29, 33, 36, 42], amateur [12, 23, 27, 42], semi-professional [12, 27] elite and professional levels [4, 9, 22, 24–26, 28, 31, 32, 34, 35, 37–40, 43, 49]. Tackle events studied varied greatly, from smaller samples of a total of 66 tackles [32] to extensive studies involving up to approximately 140,249 tackles [39]. Twenty-eight studies examined exclusively male rugby players, with only two including both male and female individuals [22, 47]. Data collection primarily utilised three-dimensional motion capture [23, 24, 26, 27, 32, 34, 47], video analysis [9, 15, 25, 28–31, 33, 35, 37–41, 44, 45, 48, 50], accelerometry [22], Global Positioning System tracking [25] and pressure sensors [12]. Tackle types studied included front-on [4, 12, 15, 23, 25–27, 32–35, 37, 39, 40, 42, 43, 45, 47, 51, 52], side-on [4, 15, 37, 40, 43, 44], high [4, 22, 27, 51, 52], middle [4, 22, 27], low [4, 22, 27, 32, 51, 52], dominant and non-dominant shoulder tackles [4, 12, 22, 42], smother [4, 33, 35, 39, 45], jersey [4, 33, 35, 39, 45] and collision tackles [4, 33, 35, 39, 45]. This distribution means that high-resolution kinematic data are available almost exclusively for adult cohorts in laboratory or marker-based contexts, whereas youth data stem predominantly from video-coded match observations.

Across the included studies, two structural patterns shaped what the evidence base could and could not show.

Table 2 Characteristics of studies

Study	Group	Sex	Age (years $\pm$ SD)	Level	Duration	Method	Tackle type
Ogata et al. [22]	39 rugby players	36 M, 3 F	22.4 $\pm$ 5.5	University/semi-professional/professional	N/A	Tackling an 80-kg bag; accelerometer analysis	High, middle and low tackles (dominant, non-dominant shoulder)
Edwards et al. [23]	15 amateur rugby players	M	24.3 $\pm$ 6.1	Amateur	3-h sessions	3D motion capture	DNRL, SNRL, DTS, SPL
Edwards et al. [24]	15 rugby players	M	Adult	Elite	3-h sessions	3D motion capture	DNRL, SNRL, DTS, SPL
Parmley et al. [25]	44 professional rugby league players	M	Adult	Professional	Two matches	Video and GPS analysis	Front-on tackles
Kawasaki et al. [9]	1800 rugby players (U18, U22, elite)	M	U18: 17.4 $\pm$ 0.7, U22: 20.8 $\pm$ 1.1, elite: 27.8 $\pm$ 3.5	Youth to professional	60 matches	Video analysis	Tackles categorised by height, direction and head position
Edwards et al. [26]	15 Rugby players	M	Adult	Elite	Three hours	3D motion capture	Front-on
Edwards et al. [27]	15 Amateur/semi-professional players	M	24.3 $\pm$ 6.1	Amateur/semi-professional	Three hours	3D motion capture	Front-on; upper torso, mid-torso, lower torso
Gardner et al. [28]	446 HIA tackles; 5694 non-HIA tackles	M	Adult	Professional	Two seasons	Video analysis	Varied
Suzuki et al. [29]	340 Collegiate rugby players	M	Adult	Collegiate	Five seasons	Video analysis	Varied
Suzuki et al. [30]	557 Collegiate rugby players	M	18–24	Collegiate	Eight seasons	Video analysis	Varied
Hendricks et al. [31]	4799 Tackle events; 1405 ruck events	M	Adult	Elite	Three tournaments	Video analysis	varied
Kawasaki et al. [32]	13 Elite rugby players	M	23.8 $\pm$ 3.8	Elite	Multiple sessions	3D motion capture	Shoulder tackle (normal, low, opposite leg, low + opposite leg)
Suzuki et al. [33]	402 Collegiate rugby players	M	18–24	Collegiate	Six seasons	Video analysis	Front-on/arm/collision/jersey/lift/shoulder/smother tackle
Tanabe et al. [34]	15 Elite rugby players	M	22.3 $\pm$ 1.9	Elite	Controlled laboratory study	3D motion capture	Shoulder/arm/head-in-front tackle
Hendricks et al. [35]	4479 Tackles from elite tournaments	M	Adult	Elite	One season	Video analysis	Arm/collision/jersey/lift/shoulder/smother/tap tackle
Sobue et al. [36]	3970 One-on-one tackles	M	19.8 $\pm$ 1.3	University	Two seasons	Video analysis and survey	Varied
Seminati et al. [12]	15 Community/university rugby players	M	23.5 $\pm$ 5.1	Amateur-semi-professional	Laboratory experiment	Impact forces- pressure sensors on bag	Shoulder tackle (dominant, non-dominant, moving)

Table 2 (continued)

Study	Group	Sex	Age (years $\pm$ SD)	Level	Duration	Method	Tackle type
Burger et al. [44]	49 Tackle-related injuries	M	17.5 $\pm$ 0.6	Youth	Three tournaments	Video analysis	Front-on/side-on
Burger et al. [45]	84 Tackle-related injuries	M	Youth	Youth elite	Three tournaments	Video analysis	Front-on/arm/collision/ jersey/lift/shoulder (aligned, diving, opposite leading leg, same leading leg)/ smother/tap tackle
Hendricks et al. [15]	10 Concussions, 83 non-injury events	M	U18	Youth	Three tournaments	Video analysis	Front-on/side-on
Burger et al. [2]	3652 Youth players	M	U13, U16, U18	Youth	Two tournaments	Injury surveillance	Varied
Hendrick et al. [37]	60 Tackles from 9 matches	M	Adult	Elite	One season	Video analysis	Front-on/side-on
King et al. [38]	80 Professional rugby league matches	M	Adult	Professional	One season	Retrospective video analysis	Varied
Gabbett et al. [46]	41 Junior rugby league players	M	Elite: 16.0 $\pm$ 0.2, Sub-elite: 15.9 $\pm$ 0.6	Youth elite and sub-elite	Single session	Tackling drill with scoring	Varied
Quarrie et al. [39]	140,249 Tackles from 434 matches	M	Adult	Professional	Three seasons	Video analysis	Front-on/arm/collision/ jersey/lift/shoulder/ smother tackle
Hendricks et al. [40]	60 Tackles from 9 matches	M	Adult	Elite	One season	Video analysis	Front-on/side-on
Kerr et al. [47]	P1: 10 Collegiate rugby players P2: 20 collegiate rugby players P3: 20 high school rugby players	P1: 8 M, 2 F/P2: 8 M, 12 F P3: 12 M, 8 F	P1: 21.4 P2: 21.1/ P3:16	Collegiate and high school	One session/P	Accelerometer and video analysis	Front-on
Tucker et al. [4]	464 HIAs from professional rugby matches	M	Adult	Professional rugby union	One season	Video analysis	Front-on, angled, side-on, tackles from behind, active/passive shoulder, illegal/high tackles
Fuller et al. [41]	645 male players	M	Adult senior professional	Senior Premiership professional	Two seasons	Video analysis	Arm, collision, jersey, lift, shoulder, smother, tap (front-on, side-on); high vs low impact force

Table 2 (continued)

Study	Group	Sex	Age (years $\pm$ SD)	Level	Duration	Method	Tackle type
McIntosh et al. [48]	Cross-section of male rugby union players	M	Youth and adult: U15, U18, U20, Grade open-age, Super 12/14+ Wallaby elite	U15, U18, U20, Grade, elite	77 game halves	Video analysis	Shoulder active, shoulder passive, jersey, ankle tap, smother, arm short-long; one-on-one vs simultaneous vs sequential
Davidow et al. [43]	313 Head-impact tackle events (157 head-impacted players, 156 impacting players) and 170 role- and tackle-type-matched injury-free control tackles	Male (not explicitly stated; men's professional/semi-professional rugby union)	Adult	Professional and semi-professional (New Zealand Rugby and South African Rugby Union match footage)	N/A (retrospective video analysis)	Retrospective video analysis	Front-on and side-on (head-impacted vs injury-free successful tackles)
Davidow et al. [42]	19 players; 887 tackles (four sets of six tackles per condition: three dominant, three non-dominant shoulder)	Male	Adult (playing experience 17 ± 4 years)	Senior amateur club (South Africa Super League A, Western Cape)	N/A (single session, randomised crossover)	Tackling proficiency video analysis on a contact simulator	Simulated front-on tackles, dominant and non-dominant shoulder (fatigue vs control)

3D three-dimensional, *DNRL* dominant national rugby league tackle, *DTS* dominant torso stick tackle, *F* female, *GPS* Global Positioning System, *HIA* Head Injury Assessment, *M* male, *N/A* not applicable, *P* phase, *SD* standard deviation, *SNRL* smother national rugby league tackle, *SPL* smother, pop, lock tackle, *U13/U16/U18/U20/U21/U22* under-13 to under-22 years of age groups

First, adult-only cohorts [4, 9, 12, 22–43, 48] (25 studies) outnumbered youth cohorts [2, 9, 15, 44–48] (7 studies). Second, female participants were represented in only two [22, 47] of the 32 studies, with the remaining 30 being male only [2, 4, 9, 12, 15, 23–41, 44–46, 48].

3.3 Quantitative and Qualitative Findings

Table 3 reports tackle types and associated biomechanical variables, including peak head and trunk acceleration, trunk and neck angles, and shoulder positioning, along with identified injury risk factors and key performance outcomes. High and middle tackles demonstrated greater peak head acceleration compared with low tackles, with higher peak head accelerations (27.4 g and 27.7 g, respectively) compared with low tackles (23.4 g) [22]. Tackles with the dominant shoulder generated lower peak head acceleration (23.0 ± 13.7 g) than those with the non-dominant side (30.4 ± 21.3 g) [22]. Two studies assessed tackle severity using the Head Injury Assessment protocol, a formalised multi-stage system developed by World Rugby to manage suspected concussions [4, 52]. Proper tackler technique correlated with reduced head injury (Head Injury Assessment) incidence, particularly in correctly executed front-on and lower-body tackles: relative to successful tackles, tackles in which the tackler's head was impacted scored lower for placing the head on the correct side of the ball-carrier (0.5, 95% confidence interval [CI] 0.3–0.6 vs 0.8, 95% CI 0.6–0.9), for arm usage to grip and compete for possession (0.7, 95% CI 0.6–0.9 vs 0.9, 95% CI 0.8–1.0), and for maintaining a straight back with the centre of gravity forward of the support base (0.5 vs 0.9, 95% CI 0.7–1.0) [43]. These technique–injury associations were consistent with additional video-analysis studies [15, 28, 44].

Incorrect head positioning and inadequate tracking of the ball carrier notably increased concussion risks [2, 9, 29, 30, 33, 36], with 31.5 concussions per 1000 tackles reported for incorrect head positioning compared with 1.1 per 1000 for correct head positioning ($p < 0.01$); although the phi coefficient was small ($\Phi = 0.20$), this reflects the rarity of concussion rather than a weak association [36]. Concussion risks were assessed primarily through video analysis of tackle events, with key risk factors quantified using logistic regression models based on tackler technique, head placement and body contact dynamics [29, 40]. Tackles using smother techniques reduced tackle breaks by 60% and offloads by 30%, reinforcing the value of technically sound shoulder-first engagement [31]. Table 3 shows dominant shoulder tackles consistently exhibited safer shoulder mechanics and lower head accelerations compared with non-dominant shoulder tackles [12, 23, 24, 26, 27, 32, 34].

Positional differences influenced tackle outcomes, with backs typically tackling at higher speeds compared with

forwards, correlating with distinct injury profiles [25, 37, 38, 40]. One study found backs tackled at higher speeds than forwards, with average tackler speeds reaching 2.82 ± 1.07 m/s and ball-carriers reaching 4.73 ± 1.12 m/s; this discrepancy resulted in tacklers decelerating into contact (-1.26 ± 1.36 m/s²) while ball-carriers accelerated (0.67 ± 1.01 m/s²), contributing to increased trunk loading and potential postural instability during high-speed tackles [25].

Table 4 reports the technical and biomechanical characteristics of injury and non-injury tackles in youth rugby, highlighting the influence of head position, body posture, shoulder involvement and tackle context. Injury-prone tackles were frequently characterised by head-in-front positioning, upright body posture and arm-only contact, all of which were associated with increased concussion and cervical injury risk [2, 9, 26, 28]. For example, head-in-front tackles were shown to increase concussion odds by 3.93–7.81 times [9], aligning with broader review findings that improper head and shoulder engagement consistently elevate injury risk [9, 15, 44].

Junior elite players demonstrated higher tackling proficiency than sub-elites [46, 49]. Reporting success rates of $65.7 \pm 12.5\%$ in elite juniors compared with $54.3 \pm 16.8\%$ in sub-elites [46]. These differences were linked to superior acceleration in a 10-m sprint (1.81 ± 0.08 s vs 1.94 ± 0.13 s) and lower-body power in a vertical jump test (51.6 ± 7.7 cm vs 46.7 ± 7.0 cm) reinforcing the importance of physical qualities such as leg drive and power in effective tackle execution [46]. This is supported by the findings in Table 4, where non-injury tackles commonly involved same-side shoulder and leg contact, low body position and full-arm-wrap traits, which are more likely to be present in physically stronger, better-conditioned athletes [46, 49]. One study demonstrated that video instruction improves tackle technique in novice and skilled youth rugby players, with skilled players showing more consistent improvement [47]. The most notable differences were found in knee flexion with skilled male individuals: 77.2° pre $\rightarrow$ 117.6° post* and skilled female players: 64.2° pre $\rightarrow$ 142.9° post* compared with novice players results showing a knee flexion change of male players: 65.6° pre $\rightarrow$ 67.6° post and female players: 62.6° pre $\rightarrow$ 87.0° post [47].

One study showed that injuries were also more frequent in the final quarter of youth matches where 35% of all injuries and 44% of head/neck injuries occurred, suggesting a technique breakdown under fatigue [2]. In adult players, a randomised cross-over study found that tackling proficiency on the non-dominant shoulder declined under physical fatigue, while dominant-shoulder proficiency was unaffected [42]. Analyses emphasised pre-contact positioning, head-up posture, proficient arm wrapping, and effective leg drive to reduce injuries and enhance tackle effectiveness in youth and adults [28–31, 35, 39, 45]. In summary,

Table 3 Biomechanical and injury risk factors of the adult rugby tackle

Study	Tackle type	Head and trunk	Shoulder	Impact forces (kN)	Injury risk factors	Key outcome
Ogata et al. [22]	Low/upper body	Acceleration (g) Head = 27.4 (19.4)/27.7 (17.0)/23.4 (14.6) g* Trunk = 12.8 (13.7)/10.7 (4.8)/12.3 (7.9) g* Acceleration (g) Head = 23.0 (13.7)/30.4 (21.3) g* Trunk = 12.6 (9.4)/11.0 (5.4) g*	Angle (°) Trunk = Extension = 16.4 ± 22.2/12.2 ± 25.2 Head-up trunk extension on dominant side		High > low head acceleration; middle = high for head, but lower trunk acceleration Higher head acceleration on non-dominant side	Lower head acceleration in low tackles; middle tackles more stable for trunk Greater neck instability with non-dominant tackles
Edwards et al. [23]	D/ND		Angle (°) Dominant Abduction 3.3–8.4° *		Higher abduction and reduced trunk control on non-dominant side increase shoulder injury risk	Dominant side showed safer biomechanics with reduced shoulder abduction and improved posture
Kawasaki et al. [9]	Low/upper body				1.13 × higher risk of concussion when tackle was below the hip* Concussion risk 3.93 × (front-on), 7.81 × (side-on), 5.77 × (all)	Tackling below the hip in side-on tackles increases concussion risk Head-in-front tackles consistently increase concussion risk across tackle types
Edwards et al. [26]	Hip (NRL)/mid-torso (TS)/mid/upper (SPL)/upper (SNRL)	Acceleration (g) Head = 6.2 ± 2.3 (Dom-NRL)/4.7 ± 1.7 (DomTS)* 3.9 ± 1.4 (SPL)* 4.4 ± 1.9 (SNRL)* g Less head flexion in SPL vs DNRL and DTS* Acceleration (g) Head = NRLD = 6.2 ± 2.3/ ND = 5.9 ± 2.1 g; TS D = 4.7 ± 1.7/ND = 4.5 ± 1.6 D had less head flexion and thoracolumbar flexion*			Higher head acceleration in hip-level tackles; upright posture in upper torso tackles increases risk D tackles showed improved posture and lower head kinematics	Midtorso (DTS) and mid/upper (SPL) techniques reduced tackler head acceleration D side safer; ND = more head/trunk flexion and risk
Edwards et al. [27]	D/ND				Non-dominant side = altered body position, greater forward speed at contact* 3.2 × higher risk of HIA when tackler was upright vs bent*	ND side slightly less controlled posture HIA upper
Gardner et al. [28]	Low/upper body					

Table 3 (continued)

Study	Tackle type	Head and trunk	Shoulder	Impact forces (kN)	Injury risk factors	Key outcome
Kawasaki et al. [32]	Low/upper body	Angle (°) Trunk = inclination: -8.4/3.9* Neck = extension: 40.7/34.6	Angle (°) Abduction: 66.2/59.3		Low tackles = more downward inclination, slouched posture	Low tackle posture may impair visibility and increase injury risk
	Same-leg/opposite-leg (dominance comparison)	Angle (°) Trunk = Rotation: 9.2/1.3*; Bending: -3.0/ -21.7* Neck = Bending: -5.6/-8.2; Rotation: -7.0/0.4			Opposite-leg tackles = less square posture, altered trunk mechanics	Opposite-leg tackles show more trunk rotation and lateral bending, increasing instability
Seminati et al. [12]	D/N/D	Angle (°) Trunk = Bending: 23°/18°* Neck = Flexion = 22/27; Lateral bending = 12/18		2.84 (0.74)/2.44 (0.64)*	ND tackles showed more neck flexion/lateral bending; lower trunk lateral bend	ND tackles = controlled posture, neck flexion; D better aligned with technique guidelines
	Stationary/dynamic (D)	Angle (°) Trunk = lateral bending: 23/20* Neck = flexion: 22/27*		2.84 (0.74)/3.40 (0.86)	Dynamic = force and neck flexion; increased risk if posture not controlled Injury incidence (per 1000 tackles). Low = 1.8, upper = 0.7	Dynamic tackling generates more load; requires better neck posture to reduce injury risk Injury incidence lower
Quarrie et al. [39]	Low/upper body				Tackles from behind had 2.2× higher replacement rate than front tackles*	Injury risk from tackles made from behind or side vs front-on
	Front vs side vs behind					
Tucker et al. [4]	Front-on, passive/active shoulder, smother	High energy transfer tackles significantly more likely to cause HIA Upright tacklers had 1.5 times higher risk; upright ball carrier had 2.13 times higher risk			Front-on tackles, high-speed tackles, accelerating tacklers; head-to-head impacts significantly more likely to cause injury	Lowering tackle height and bent at waist body position reduces injury risk; interventions recommended by World Rugby

Table 3 (continued)

Study	Tackle type	Head and trunk	Shoulder	Impact forces (kN)	Injury risk factors	Key outcome
Fuller et al. [41]	Arm/collision/shoulder	98% of tacklers and ball carriers entered the tackle with head-up posture. The 3 ball carriers with chin-on-chest position did not sustain head or neck injuries	Shoulder tackles in double-tackles: second tackler 2.3 × more likely to sustain a head/neck injury (RR 2.27, 95% CI 1.22–4.23, $p=0.010$)*	High-impact tackles: ball carrier 2.9 × and first tackler 3.2 × more likely to be injured (RR 2.92 and 3.19; both $p<0.001$)*	Collision tackles: ball carrier 3.1 × higher injury risk in one-on-one (RR 3.09); first tackler 10.5 × and second tackler 29.9 × higher risk in double tackles (RR 10.47 and 29.90; both $p<0.001$)*. High speed into tackle: ball carrier 1.6 ×, first tackler 1.9 ×, second tackler 5.1 × higher injury risk (RR 1.60, 1.85, 5.07; all $p\leq 0.008$)*	Collisions and high-speed entries are the main injury drivers; high tackles are severely under-penalised by referees (penalised in only 5.9% of general-play vs 16.7% of injury events)
	Head position/body region struck	Head-in-front position: first tackler 1.8 × and second tackler 2.4 × more likely to be injured than tacklers placing the head safely (RR 1.77 and 2.44; $p=0.020$ and $p=0.031$)*. 50% of ball-carrier head/neck injuries occurred during front-on tackles			Head/neck contact in tackle: ball carrier 2.7 ×, first tackler 22.3 ×, second tackler 28.8 × more likely to be injured than when contacting other regions (RR 2.71, 22.30, 28.75; all $p<0.001$)*. Midfield backs 1.7 × more likely than other positions to be injured when tackling (RR 1.66, 95% CI 1.18–2.34, $p=0.003$)*	Head/neck contact and head-in-front positioning are the dominant adult injury mechanisms; midfield backs face the highest tackling injury risk

Table 3 (continued)

Study	Tackle type	Head and trunk	Shoulder	Impact forces (kN)	Injury risk factors	Key outcome
Davidow et al. [43]	Front-on and side-on (head impact vs injury free)				Head-in-front/incor- rect head placement, reduced arm usage (punch-and-wrap), poor body position (straight back, centre of gravity forward of base) and lower overall tackler technical proficiency	Tackler technical profi- ciency significantly lower in head-impact tackles than successful tackles (front-on tackler 9.8 vs 12.3 of 16; $p < 0.001$, ES = 0.8). Ball-carriers in head-impact tackles also scored lower than suc- cessful ball-carriers (6.4 vs 9.4 of 14; $p < 0.0001$, ES = 1.1). Both ball- carrier and tackler show a technical deficiency when a head impact occurs
Davidow et al. [42]	Simulated front-on, domi- inant and non-dominant shoulder (fatigue vs control)		Dominant vs non-domi- nant shoulder compared via proficiency (no kinematics reported)		Physical fatigue and non-dominant-shoulder tackling: proficiency declines under fatigue, particularly on the non- dominant side	Non-dominant-shoulder tackling proficiency (of 9) was lower under fatigue than control at set 2 (7.3 vs 7.6; $p = 0.06$; ES = 0.3) and set 3 (7.3 vs 7.7; $p = 0.006$; ES = 0.5); dominant- shoulder proficiency was unaffected. Physical fatigue degrades non- dominant tackling tech- nique (small effects)

BC ball carrier, *CI* confidence interval, *D* dominant side, *DNRL* dominant NRL tackle, *DTS* dominant torso stick tackle, *ES* effect size, *g* g-force (multiples of gravitational acceleration), *HIA* head injury assessment, *kN* kilonewton, *ND* non-dominant side, *NRL* National Rugby League tackle, *RR* risk ratio, *SNRL* smother NRL tackle, *SPL* smother, pop, lock tackle, *T1* first tackler, *T2* second tackler, *TS* torso stick, * significance at $p < 0.05$

Table 4 Youth rugby tackle findings with adult comparison

Study	Tackle context	Head and spine position/technique error	Body position	Shoulder	Identified risk factors	Key outcome	Comparison with adult studies
Burger et al. [44]	Front-on/side/behind	Poor shoulder contact and head placement was common in injury tackles	Head to correct side, shoulder contact, leg drive, arm wrap = non-injury events	Shoulder drive = injury rate	Lower tackle and ball-carry proficiency scores in injury events	Higher technique scores associated with non-injury tackles* Front-on tackles-technique scores	Adult tacklers exhibit higher proficiency in contact posture and shoulder engagement, consistent with findings from previous research where non-injury tackles demonstrated better alignment and technique [15]
Kawasaki et al. [9]	Head-in-front/correct	Head-in-front tackles had 3.93–7.81 × higher concussion risk 5.77 × higher overall risk compared with correct head placement*	Below-hip tackles - injury risk 1.13 × compared with chest/torso*	Smother tackles (upper body) — injury risk and are more prevalent in elite-level players	Head-in-front tackles increase concussion risk (11.26 injuries/1000 tackles)	Correct head placement reduces injury risk	Adults show higher neck forces and greater head kinematics in head-in-front tackles, supporting youth finding of a 3.93–7.81 × increase in concussion risk [26]
Burger et al. [2]	U13/U18 comparison	Frequent injury mechanism = Tackler's head/neck making initial contact, arm-only tackles, failure to bring the ball carrier to ground Non-injury tackles = ↑ shoulder involvement, ↑ postural control, ↑ correct head placement	Fatigue in later quarters affects body position and reactions	Arm contact without shoulder drive observed in 44.7% of injury tackles	More time-loss injuries in U13; fatigue = higher injury in later quarters	Younger players and fatigue linked to higher injury rate Poor head position and lack of leg drive increased the likelihood of head and neck injury	Contrasts with previous adult studies finding no decline in adult tackle quality across repeated efforts, whereas youth players showed reduced postural control under fatigue [46] Matches adults studies, poor technique raises concussion odds [15]
Burger et al. [45]	All tackle types across four quarters		Fatigue contributed to compromised posture, especially in later quarters		Fatigue and poor body position in late-game tackles associated with higher injury rate	Fatigue appears to reduce postural control and tackling effectiveness, increasing injury risk	Adults showed stable tackle technique across fatigue, suggesting better fatigue resilience compared with youth [46]

Table 4 (continued)

Study	Tackle context	Head and spine position/technique error	Body position	Shoulder	Identified risk factors	Key outcome	Comparison with adult studies
Hendricks et al. [15]	Injury/non-injury	Correct head placement = 60% of non-injury/25% of injury 2.4 × greater likelihood of injury when head placement was incorrect Injury tackles showed key kinematic flaws: poor head position, no leg drive and absence of sequential body movement (shoulder → arms → wrap)	Non-injury tackles ↑ technical proficiency score* Non-injury tackles were more effective, consistently bringing the ball carrier to ground, while injury tackles were often incomplete	Shoulder drive and arm wrap reduced concussion risk	Technical errors in rucking/tackling = higher concussion likelihood	Non-injury tackles had better contact technique scores	Aligns with adult studies, technical consistency reduces injury [23]
Kerr et al. [47]	Front-on	Acceleration (g) Head = 29.9 g (11.3)	Angle (°) Left hip 98.5 (21.7), right hip 97.7 (21.5), left knee 122.5 (25.8) and right knee 108.0 (28.8)	Acceleration (g) Left 37.7 (11.1)/right 36.2 (12.1)			
	Pre/post-intervention	Acceleration (m/s ²) Head + 15.4 m/s ² (6.88)* Repetitions = -5.24 m/s ² * Spine = -51.8 (46.8) Repetitions = 11.2 (13.7) cervical spine (147 25.8) °	Angle (°) Hip: skilled = pre 73.1 (22) post 68.5 (21.7) Novice = pre 65.5 (14.3) post 73.6 (15.2) Knee: skilled = pre 77.2 (28.9) post 117.6 (35.8)* Novice = pre 64.3 (7.9) post 79.3 (28.3)	Acceleration (m/s ²) Skilled = pre 482.4 (155.4) post 381.1 (112.4) Novice = pre 400.3 (102.7) post 411.7 (113.7)			

Table 4 (continued)

Study	Tackle context	Head and spine position/technique error	Body position	Shoulder	Identified risk factors	Key outcome	Comparison with adult studies
McIntosh et al. [48]	Cross-section U15 to elite (five levels of play)	Tackler head position coded for every tackle but not significantly associated with injury within this sample; contact with the tackler's head had the highest descriptive game-injury incidence per body region	Younger players (U15–U20) stayed on their feet more than older players and used more passive shoulder tackles; less stable contact postures in youth	Active shoulder tackles more than doubled with U15 → 31% elite). Arm-only ("short-long") tackles more common in youth (14% U15, 11% U18, 12% U20) than adults (5% Grade, 8% elite)	U15 schoolboys 72% lower per-tackle injury risk than elite adults (OR 0.28, 95% CI 0.08–0.93, $p=0.04$)*. Two or more tacklers vs one: 67% higher injury risk (OR 1.67, 1.08–2.59, $p=0.02$)*. Simultaneous contact vs one-on-one: more than doubled the injury risk (OR 2.12, 1.16–3.89, $p=0.02$)*. No single tackle technique reached significance	U15 schoolboy rugby is significantly different to and safer in the tackle than adult rugby; multi-player simultaneous contact is the strongest contextual injury risk factor	Game injuries per 100 tackle events 2–4 × higher in adult cohorts (1.0 Grade, 1.5 elite) than in U15 schoolboys (0.4). IRB-compliant tackles also more frequent in adults (63% Grade, 67% elite) than U15 (49%)

BC ball carrier, CI confidence interval, D dominant side, IRB International Rugby Board, ND non-dominant side, NRL National Rugby League tackle, OR odds ratio, SVRL smother NRL tackle, SPL smother, pop, lock tackle, T1 first tackler, T2 second tackler, T3 torso stick, U13/U18/U22 under-13, under-18, under-22 age groups, *significance at $p < 0.05$, ↑ increased

studies consistently demonstrated that enhanced technical proficiency in tackling, particularly correct head and trunk alignment, optimal shoulder and arm usage, and effective lower body mechanics, reduced injury risks and improved performance outcomes across various levels of play [15, 35, 44, 45].

Synthesising across the 32 studies, three findings are supported by convergent evidence. The convergent findings are that tackle head-in-front positioning increases per-tackle concussion risk across both youth and adult cohorts, reported with consistent direction and magnitude (incidence-rate ratios between 3.93 and 7.81) [9, 44, 45, 48]. Dominant-shoulder tackles consistently result in lower head accelerations compared with non-dominant tackles, a finding that has been consistently replicated [12, 22, 27, 34]. Youth players consistently demonstrate lower tackle proficiency scores than adults across video-coded outcome measures, with the gap most pronounced in pre-contact body position and shoulder engagement [15, 35, 44, 45].

4 Discussion

This systematic review synthesises current evidence on rugby tackle biomechanics across youth and adult populations. Because most included studies are observational, descriptive, or laboratory based, and few quantified non-injury comparators sampled from the same competitive environment, the findings should be interpreted as descriptions of associations and risk-factor distributions rather than as direct causal evidence for specific technique-modification interventions. Tackling remains a vital aspect of rugby, influencing performance while also contributing substantially to injury risk.

4.1 Age-Specific Differences in Head Positioning and Injury Risk

Youth rugby players appear disproportionately affected by head and cervical injuries, potentially owing to consistently suboptimal head positioning and greater head accelerations during tackles [36]. Peak head acceleration in a youth front-on tackle has a mean of 29.9 g, which is greater than 6.6 g in semi-professional adult players [23, 47]. Greater head acceleration likely increases the risk of cervical injuries and concussion, especially in conjunction with incorrect head positioning [23, 47]. Video analysis of 14,809 tackles revealed that U18 players placed their head in front of the ball-carrier in 15.9% of tackles (≈ 159 per 1000) [9]. In contrast, elite adult players did so in only 10.2% (≈ 102 per 1000), with U22 athletes intermediate at 13.7% (≈ 137 per 1000) [9]. Relative to correct head placement, head-in-front tackling raised concussion risk by 3.93 times in front-on

tackles, 7.81 times in side-on tackles and 5.77 times across all tackle directions [9]. Although overall concussion incidence per 1000 tackles is highest in professionals (4.0) and lowest in U18 players (1.9), youth athletes employ the hazardous head-in-front technique $\sim 56\%$ more often than adults [9]. Thus, young players are not inherently safer when they adopt this technique; their per-tackle risk of concussion increases by ~ 5 – 8 times, underscoring the need for targeted coaching to eliminate head-in-front tackles at junior levels [9, 51, 52]. This discrepancy likely reflects inexperience, as youths may have fewer total hours of play and training than adults. Furthermore, these findings may stem from biomechanical and developmental immaturity, including reduced neuromuscular control, coordination deficits and underdeveloped muscular strength, yet this has not been adequately explored and requires future investigation to confirm [36, 53–55].

A central mechanism contributing to injury is head-in-front tackling, where the tackler's head is placed in front of the ball-carrier's torso or hips [9]. This technique was more commonly observed in youth players in the studies reviewed and is a critical risk factor [9]. A previous study showed that instructional videos significantly improved tackling biomechanics in experienced collegiate players, particularly by increasing knee flexion angles and reducing cervical spine acceleration [47]. However, the same intervention paradoxically increased head acceleration in younger, less experienced athletes. This contrast may reflect a developmental difference: while skilled players were able to integrate video instruction into technically sound movement patterns, including optimal knee flexion, younger athletes appeared to benefit more from physical repetition, suggesting they had not yet internalised key biomechanical cues such as flexed knee positioning and spatial tracking [12]. Notably, side-on tackles with head-in-front placement were found to increase concussion risk by up to 7.81 times, particularly when combined with poor shoulder and arm engagement [9, 29]. Such technical errors frequently co-occurred with ineffective spatial tracking and delayed decision making, which may reflect underlying developmental constraints in sensorimotor integration [9, 29, 39]. Adult players typically adjust their approach and align their heads behind or to the side of the ball-carrier [9, 29]. Youth players, however, often fail to do so, exposing themselves to greater impact forces at the neck and head. This trend persists even when controlling for tackle height or approach speed, underscoring a gap in execution rather than just physical capacity [26, 49].

Youth players may be more likely to misread tackle cues and commit to poor head positions under pressure, particularly in open-field or fatigued situations. During youth rugby tournaments, the incidence of head and neck injuries increased in the later stages, which was attributed to technical deterioration caused by fatigue and stress [44, 45].

This pattern supports the interpretation that head placement errors in younger players are partly cognitive, linked to the ability to sustain attention during play, especially later in a game [44, 45]. This could impair a player's response to stimuli, such as a ball-carrier changing direction, leading to increased reaction time and less time to achieve knee and hip flexion and generate leg drive before a tackle [44, 45]. In adult players, physical fatigue has been shown to degrade tackling technique under controlled laboratory conditions, highlighting the need for similar studies in youth players [42].

Considering these findings, targeted coaching interventions should prioritise early and sustained development of safe head placement strategies. Youth tackle training research recommends that tackle training should involve progressive exposure to tackle scenarios which gradually increase in complexity and resemble the demands of competition [56]. Training, therefore, should incorporate decision-making drills involving variable cues, 1v1 tackling drills, and gradual contact progressions from pads to live scenarios to help youth players develop sensorimotor control and establish stable, repeatable head alignment habits [56]. As detailed in the following section, these deficits often co-exist with postural and lower-limb inefficiencies, meaning technical improvements must be taught in an integrated full-body context.

4.2 Biomechanical Differences Influencing Tackle Effectiveness Between Youth and Adult Players

This review highlights biomechanical differences between youth and adult rugby players that could influence tackle effectiveness and injury risk. Youth players demonstrated notably diminished leg drive and acceleration at contact, both key components of effective technique [46, 49]. This likely contributes to lower tackling proficiency found in youths. In this context, proficiency refers to performance on a standardised tackling assessment that scores technical execution across criteria such as head placement, shoulder contact, body alignment and leg drive [46, 49]. Proficiency scores in junior elite players averaged 65.7%, sub-elite juniors dropped to 54.3% and adult National Rugby League players averaged 89.3% [46, 49]. Differences in proficiency scores track with the reduced acceleration and lower-body power of younger players, which constrain their tackle success [46, 49]. This gap is consistent with code-specific match demands: Global Positioning System- and video-based analyses show National Rugby League players absorb up to 1.2 collisions/min as a consequence of the 13-a-side format, six-tackle rule and 10-m offside line that encourage one-on-one drives and repeated contact [57, 58]. In contrast, Rugby Union's ruck-and-maul contest spreads collisions across the 15-man pack [46, 59]. Tight-five forwards peak at 0.73–0.89

collisions/min, while backs average only 0.28–0.41 collisions/min, meaning league juniors are exposed earlier to collision-focused conditioning that may underpin their higher tackle proficiency [46, 59]. Maintaining leg drive after contact substantially improved outcomes, increasing the likelihood of dislodging the ball or forcing a turnover by 53% [31]. Tacklers who approached contact too slowly or without momentum faced a 43% tackle-break rate [38], emphasising the critical role of lower-limb biomechanics over mere body mass in effective tackle execution [46]. Given that the ability to exert force very fast is a key predictor of tackle success, the reduced force outputs typical of younger athletes may constrain their ability to generate collision momentum, potentially diminishing tackle effectiveness and heightening injury risk [46, 49, 50].

Adult players generally displayed greater hip and knee flexion during tackles, thereby lowering their centre of gravity and enabling a forward-leaning braced-trunk posture [48, 49, 52]. This position is associated with enhanced stability, more effective force absorption and reduced cervical spine acceleration, contributing to both performance and safety [40, 47]. Skilled collegiate players, following instructional video interventions, exhibited significantly greater knee flexion angles and reduced cervical spine acceleration compared with novices, who failed to replicate these biomechanical adjustments despite the same instructions [47]. This suggests that biomechanical proficiency in tackling, particularly in lower-limb flexion, is a marker and a mechanism of expertise [47]. Moreover, leg drive and body positioning (e.g. low stance with forward trunk lean) are critical determinants of tackle success, further reinforcing the importance of these physical and technical attributes in skilled performers [60]. These biomechanical advantages appear to emerge with experience and physical maturity; youth players may lack the neuromuscular control and lower-limb strength required to adopt and sustain such postures under dynamic conditions. Training should emphasise the practice of these techniques with less-experienced players requiring more repetition to encourage safer techniques, to improve hip and knee flexion angles, along with developing lower limb power. The end goal here is to encourage expertise in tackling across all age groups, which is correlated with performance and injury reduction.

Furthermore, youth players often tackled from an upright position with reduced flexion, leading to lower proficiency scores in injury-causing tackles (7.00 ± 1.95 ; 44%) compared with non-injury tackles (9.35 ± 2.56 ; 58%) [44]. This biomechanical inefficiency compromises performance and safety, likely owing to underdeveloped postural control and strength. Embedding structured strength and movement-control programmes into youth training is critical for developing the lower-limb power and postural stability required for safe effective tackling [61]. A cluster randomised controlled

trial in schoolboy rugby found that teams performing a three times-weekly neuromuscular warm-up reduced overall match injuries by 72% and concussion by 59% compared with controls [61]. Insufficient preparatory movement, such as fewer approach steps before contact, can hinder the spatial set-up resulting in suboptimal body alignment upon tackle impact [36]. Tackles made at hip level resulted in significantly greater head acceleration (27.7 g vs 23.4 g), further illustrating the protective benefits of proficient lower-limb positioning during execution. The elevated centre of gravity and lack of preparatory action in youth players may impede their change-of-direction speed, complicating their ability to align with and react to ball carriers, crucial elements for effective tackling [2]. This underscores the necessity for conditioning programmes to improve acceleration, agility and reactive strength [46].

Shoulder engagement and upper-body techniques further differentiated the two groups of interest in this review. Adults more frequently executed ‘shoulder-first’ tackles, achieving proficiency scores averaging $\sim 10.1/12$, compared with $\sim 8.6/12$ in academy youth players [50]. Youth players often relied on arm-style tackles or chest-first contacts, leading to lower-impact transfers and a higher risk of missed tackles. In side-on tackles, U18 players frequently employed hazardous head-in-front techniques, which can increase concussion risk by up to 7.81 times [9]. Head-in-front means the tackler’s head is placed forwards and often sustains the initial impact [9]. When this impact is received from hard areas of the ball-carrier, for example the knee, elbow or hip, concussions are more likely to occur [9]. Conversely, elite adult players more often utilised safer smother tackles, with the head positioned to the side and arms fully wrapped, at a rate of 29.7% compared with 21.1% in U18 players [9]. These patterns illustrate a potential developmental learning curve in skill acquisition, revealing that youth players often lack the biomechanical sophistication and situational adaptability needed to consistently apply safe and effective techniques over time [36]. Findings highlight the compounded risk posed by suboptimal tackling form in youth rugby, where poor head placement alone can escalate injury rates from 2.7 to 69.4 per 1000 tackles [36]. The combined injury risk and performance deficits become even more pronounced when coupled with reduced leg drive, poor shoulder contact and an upright posture [36]. Consequently, coaches should implement structured age-specific training programmes that focus on technical development throughout the body, especially head positioning, shoulder alignment and explosive leg drive, under both fresh and fatigued conditions.

Head-in-front tackles raise concussion odds by 3.93–7.81 times [9], and arm-only contacts increase overall concussion risk by 2.7 times [1]. These findings underscore the potential value of coaching cues that could be utilised to teach young players how to wrap the ball-carrier’s arms rather

than drive through the torso [1, 9]. Framing the tackle this way shifts the aim from forceful collision to exploiting space [1, 9]. In elite match play, “smother” tackles aimed at the mid-torso/upper-arm can increase gain-line success by ~ 3 – 4 times [16] while laboratory work shows the same contact height reduces peak tackler head accelerations by $\sim 23\%$ [26]. The difficulty with encouraging a smother tackle is that it requires the tackler to control the ball carrier through contact, which is only achievable in certain scenarios [16]. Often, the tackler may have to give ground to the ball carrier in preparation for this tackle so that the wrap around the ball and ball carrier can be achieved [23]. Therefore, this method may inherently be safer because it requires more preparation. However, the smother tackle is situation dependent and might not be effective in all tackling scenarios [23]. Additionally, it is an advanced technique that requires greater technical training and match experience [23]. Tackle types can be situation specific; multiple tackle types must be taught effectively at the youth level, with an emphasis on pre-tackle across all types of tackle [23]. Given that youth players are still developing neuromuscular coordination, controlled-contact scenarios and decision-making drills can help reinforce good habits under pressure [50]. Improving skill competency fosters autonomy, giving players more time to react to the ball-carrier, improve their set-up position and select the correct tackle type for the scenario [50]. These strategies may lower injury incidence while improving technical proficiency, facilitating safer transitions into the adult game.

4.3 Dominant Versus Non-Dominant Shoulder Biomechanics and Fatigue

Significant biomechanical differences exist between dominant and non-dominant shoulder tackles, with potentially important implications for player safety and effectiveness. Tackles executed with the dominant shoulder were associated with significantly fewer head and neck injuries, and players showed a consistent preference for initiating contact with their dominant side, which is reflected in more technically correct posture and improved success rates [43]. A previous study has shown that shoulder tackles performed with the dominant shoulder result in significantly lower head acceleration (23.0 ± 13.7 g) than those performed with the non-dominant shoulder (30.4 ± 21.3 g; $p < 0.01$) [26]. Another study supporting this showed that non-dominant shoulder tackles are associated with increased neck flexion and lateral bending, both of which deviate from the recommended tackle posture and heighten the risk of injury [12]. The study showed that dominant-side tackles generated significantly higher peak impact forces (2.84 ± 0.74 kN) than non-dominant tackles (2.44 ± 0.64 kN), indicating superior mechanical efficiency and impact management

[12]. Muscle activation patterns revealed greater anticipatory engagement on the dominant side, suggesting better neuromuscular preparation. These findings could be due to enhanced coordination, strength and proprioceptive feedback associated with the dominant limb and reduced familiarity or technical control when tackling with the non-dominant shoulder [12]. Training should address these asymmetries in shoulder preference through practice, ensuring it focuses on tackle mechanics when using the non-dominant shoulder, with real-time feedback to enhance proficiency and increase symmetry [12].

Demonstrating the effects of unilateral loading on tackle biomechanics, a previous study found that youths who tackled with the lead leg on the same side as the contacting shoulder generated greater leg drive and shoulder contact [1]. This alignment allows the tackler to absorb and transfer force from a more stable position, resulting in higher impact forces but more safely managed [1]. This demonstrates that the side on which most of the load is taken plays a role in tackle safety for youths [1]. Although direct comparisons between youth and adult players regarding the effects of dominant versus non-dominant shoulder tackling are limited, the current biomechanical findings suggest that muscle activation patterns are more refined and anticipatory on the dominant side [62]. The ages of 9–12 years in boys and 8–11 years in girls represent a critical window for motor coordination development, during which general neuromuscular patterns and technical skill acquisition are most adaptable [62]. This is said to be the window of accelerated adaptation of motor coordination, during which targeted intervention can lead to more efficient and permanent neuromuscular patterns [62]. Therefore, rugby coaches should incorporate unilateral neuromuscular training at this stage to help youth players develop symmetrical activation patterns across both shoulders, potentially mitigating the risk of later asymmetry-related injuries [62].

Fatigue further exacerbates biomechanical inefficiencies during non-dominant shoulder tackles, leading to a potential progressive decline in technical quality and increased injury risk as a match continues [42]. Under fatiguing conditions, non-dominant shoulder tackles display marked deterioration in control, exacerbating adverse joint kinematics and elevating peak head accelerations [10, 42]. This trend may be attributed to diminished neuromuscular control, compromised coordination and impaired decision-making processes as fatigue accumulates throughout game play [10, 42]. This decline in neuromuscular control under fatigue likely reflects reduced motor unit recruitment and firing frequency, particularly in high-threshold units critical for explosive movement [63]. Additionally, fatigue impairs proprioception and disrupts central motor planning, leading to slower, less coordinated responses, effects that are more pronounced on the non-dominant side, potentially owing to weaker cortical

representation and less rehearsed movement patterns [63]. Consequently, fatigue significantly increases the risks associated with non-dominant shoulder tackles, highlighting the need for conditioning protocols that maintain technical integrity under fatigue [10, 42]. Supporting this assertion, a previous study identified fatigue, performance anxiety and inexperience as key factors that impair young players' technical execution, especially in open-field play and under high-pressure conditions [47]. The combination of these factors can amplify technical flaws and injury susceptibility, particularly in less-experienced youth athletes [42].

From a coaching perspective, these findings suggest the need for interventions that explicitly promote proficiency in using both dominant and non-dominant sides, bridging the gap created by the asymmetry [47]. Coaches should integrate structured drills focusing on balanced shoulder engagement and emphasise correct head positioning, particularly when executing tackles from the non-dominant side. Conditioning programmes could simulate fatigue conditions encountered during matches, reinforcing correct tackle mechanics to ensure sustained biomechanical effectiveness throughout the game. In addition to mitigating the effects of fatigue on motor unit recruitment and firing rates, strength and conditioning programmes can incorporate cluster sets during compound movements to enhance motor unit recruitment across repeated near-maximal efforts, meaning the effects of fatigue when tackling may be less pronounced as strength endurance improves [64]. Addressing these critical biomechanical disparities through targeted training and conditioning will likely enhance player safety and reduce injury incidence, particularly concussive and cervical injuries associated with asymmetric tackle execution under fatigue conditions [29, 42].

4.4 Methodological Considerations in Tackle Biomechanics Research

Four studies in this review [9, 41, 45, 48] share a methodological lineage. The earliest established the cross-sectional video-analysis approach to tackle characteristics in rugby union, using a categorical coding protocol to compare tackle techniques across levels of play [48]. A subsequent study applied a similar video-coded categorical framework to a cohort of senior professionals over two seasons, using risk ratios to compare injured and general-play tackles [41]. The most recent and largest extended the approach to a much larger contemporary sample of 14,809 tackles, stratified by U18, U22 and professional cohorts [9]. All rely on visual coding of categorical risk-factor variables rather than on quantitative kinematics. Retaining them is defensible on the basis that they triangulate the same approach across different populations, eras and outcome definitions; readers should nevertheless interpret their findings as a single

methodologically coherent strand rather than as fully independent replications [9, 41, 45, 48].

The remaining 28 studies are divided between in-laboratory marker-based motion capture [23, 24, 26, 27, 32, 34, 47], simulated tackles against weighted bags or sleds, and on-field video analysis with finer-grained kinematic coding [9, 15, 25, 28–31, 33, 35, 37–41, 44, 45, 48, 50]. Laboratory studies provide high-resolution kinematic and kinetic data but at the cost of ecological validity; the decision-making, opponent unpredictability and approach speed variability of live play are absent [23, 24, 26, 27, 32, 34, 47]. Match video studies are ecologically valid but constrained by camera angles, frame rates and an inability to quantify segmental kinematics [9, 15, 25, 28–31, 33, 35, 37–41, 44, 45, 48, 50]. Markerless motion capture and instrumented mouthguards are emerging as hybrid methodologies that may bridge this gap [65, 66]. For now, the heterogeneity of methods means that no single study can be expected to yield definitive recommendations on technique modification on its own; the strength of the present review lies in identifying findings that converge across method types and populations [67].

4.5 Limitations

While this review provides key insights into tackle biomechanics, it is important to acknowledge several limitations. Variability in study designs, methodologies and participant characteristics may limit direct comparability across findings, particularly when assessing differences in tackling techniques between youth and adult players. Of the 32 studies that met the inclusion criteria, 25 were conducted in adult participants [4, 12, 22–41] and only five in youth [2, 15, 44–47]. Two studies included both youths and adults [9, 42, 43, 48], and two studies used female participants [22, 47]. These trends demonstrate the disparity between the number of studies examining youth and female tackling and those focused on adults. Additionally, as this review relied exclusively on peer-reviewed sources, there is a potential publication bias, which may exclude relevant but unpublished data or alternative perspectives on tackling in youth rugby.

A more general limitation, raised across the included evidence, is that injury-event observational studies, the dominant methodology in this field, typically describe characteristics of injury events without systematically comparing them to characteristics of non-injury events sampled from the same competitive environment. It has been previously stated that combining biomechanical and epidemiological approaches within a case–control framework, with non-injury controls matched on play context, is essential before associations identified through injury surveillance can be translated into causal injury-prevention recommendations [67]. Of the studies included in this review, four [9, 41, 45, 48] most closely approach this design by comparing injury

tackles to general-play tackles; the remaining studies report on injury events alone or on biomechanics in non-injury contexts, such as laboratory simulations. Overall, case–control designs comparing injury and non-injury tackles within the same match environment are already used in the field of rugby injury prevention, but applying them more consistently may further strengthen the evidence [67].

Despite these constraints, this systematic review offers a robust evaluation of rugby tackling techniques and contributes valuable insights into performance, safety considerations and coaching strategies for injury prevention. A specific limitation of the methodological quality assessment used here is that the Downs and Black checklist was originally designed for both randomised and non-randomised intervention studies [20]. Downs and Black items, such as randomisation, allocation concealment, blinding of intervention and outcome assessment, and compliance with the intervention, are not applicable to the predominantly observational, biomechanical and video-coded study designs in this review [20]. This reduces the maximum achievable score and compresses the range of meaningful differences in scores between studies, limiting the tool's ability to discriminate methodological quality within the observational biomechanics literature. Items 11–13 (external validity) are also difficult to apply consistently to laboratory-based biomechanical studies, where ecological validity is intentionally constrained [20]. Domain-specific quality appraisal tools such as the Joanna Briggs Institute checklists for cross-sectional and case-series studies, or biomechanical-specific tools, may yield more discriminating quality assessments in future reviews of this literature [68]. In conducting this review, every effort was made to synthesise the available data in an unbiased and systematic manner; interpretive bias may nevertheless be present, particularly given the limited number of youth-specific studies and the heterogeneity of study designs.

5 Conclusions

Across 32 included studies, three findings emerged with reasonably consistent support across cohorts and study designs: tackler head-in-front positioning is associated with a five- to eight-fold increase in per-tackle concussion risk and is more common in youth players than adults; dominant-shoulder tackles produce lower head accelerations than non-dominant tackles, with this advantage eroding under fatigue; and youth players show lower technical proficiency than adults across video-coded tackle outcome measures. The overall strength of evidence is moderate at best: four studies were rated low risk of bias, 26 moderate and two high; most designs are observational and lack non-injury comparators sampled from the same match environment. Age-specific coaching

that emphasises proper head placement, engagement of the dominant shoulder and lower-limb mechanics is justified. However, trials involving technique modifications with injury endpoints and case–control biomechanical studies are necessary before definitive causal recommendations can be made with confidence [67].

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Consent to Participate Not applicable.

Consent for Publication Not applicable.

Availability of Data and Material All data analysed during this systematic review are derived from the published articles cited in the References list and are publicly available through their respective journals. The screening log, full search strings, PRISMA 2020 checklist, and Downs and Black scoring sheets are provided as ESM and Tables attached. Additional materials are available from the corresponding author on reasonable request.

Code Availability Not applicable.

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References

- Hendricks S, Sarembok M, Jones B, Till K, Lambert M. The tackle in South African youth rugby union: gap between coaches' knowledge and training behaviour. *Int J Sports Sci Coach*. 2017;12(6):708–15.
- Burger N, Lambert MI, Viljoen W, Brown JC, Readhead C, Hendricks S. Tackle-related injury rates and nature of injuries in South African Youth Week tournament rugby union players (under-13 to under-18): an observational cohort study. *BMJ Open*. 2014;4(8):e005556.
- Kirkwood G, Parekh N, Ofori-Asenso R, Pollock AM. Concussion in youth rugby union and rugby league: a systematic review. *Br J Sports Med*. 2015;49(8):506–10.
- Tucker R, Raftery M, Kemp S, Brown J, Fuller G, Hester B, et al. Risk factors for head injury events in professional rugby union: a video analysis of 464 head injury events to inform proposed injury prevention strategies. *Br J Sports Med*. 2017;51(15):1152–7.
- Edwards S, Lee R, Fuller G, Buchanan M, Tahu T, Tucker R, et al. 3D biomechanics of rugby tackle techniques to inform future rugby research practice: a systematic review. *Sports Med Open*. 2021;7(1):39.
- Woods CT, Robertson S, Sinclair WH, Till K, Pearce L, Leicht AS. A comparison of game-play characteristics between elite youth and senior Australian National Rugby League competitions. *J Sci Med Sport*. 2018;21(6):626–30.
- Bleakley C, Tully M, O'Connor S. Epidemiology of adolescent rugby injuries: a systematic review. *J Athlet Train*. 2011;46(5):555–65.
- Freitag A, Kirkwood G, Schärer S, Ofori-Asenso R, Pollock AM. Systematic review of rugby injuries in children and adolescents under 21 years. *Br J Sports Med*. 2015;49(8):511–9.
- Kawasaki T, Kawakami Y, Nojiri S, Hasegawa Y, Kuroki M, Sobue S, et al. Risk factors for concussion in under 18, under 22 and professional men's rugby union: a video analysis of 14,809 tackles. *Sports Med Open*. 2023;9(1):95.
- Quatman-Yates CC, Quatman CE, Meszaros AJ, Paterno MV, Hewett TE. A systematic review of sensorimotor function during adolescence: a developmental stage of increased motor awkwardness? *Br J Sports Med*. 2012;46(9):649–55.
- Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33:159–74.
- Seminati E, Cazzola D, Preatoni E, Trewartha G. Specific tackling situations affect the biomechanical demands experienced by rugby union players. *Sports Biomech*. 2017;16(1):58–75.
- Hendricks S, Lambert M. Tackling in rugby: coaching strategies for effective technique and injury prevention. *Int J Sports Sci Coach*. 2010;5(1):117–35.
- Cheng C-H, Lin K-H, Wang J-L. Co-contraction of cervical muscles during sagittal and coronal neck motions at different movement speeds. *Eur J Appl Physiol*. 2008;103:647–54.
- Hendricks S, O'Connor S, Lambert M, Brown J, Burger N, Mc Fie S, et al. Contact technique and concussions in the South African under-18 coca-cola craven week rugby tournament. *Eur J Sport Sci*. 2015;15(6):557–64.
- Tierney GJ, Simms CK. Can tackle height influence tackle gain-line success outcomes in elite level rugby union? *Int J Sports Sci Coach*. 2018;13(3):415–20.
- West SW, Shill IJ, Bailey S, Syrydiuk RA, Hayden KA, Palmer D, et al. Injury rates, mechanisms, risk factors and prevention strategies in youth rugby union: what's all the ruck-us about? A systematic review and meta-analysis. *Sports Med*. 2023;53(7):1375–93.
- Darrall-Jones JD, Jones B, Till K. Anthropometric and physical profiles of English academy rugby union players. *J Strength Cond Res*. 2015;29(8):2086–96.
- Till K, Hendricks S, Scantlebury S, Dalton-Barron N, Gill N, den Hollander S, et al. A global perspective on collision and non-collision match characteristics in male rugby union: comparisons by age and playing standard. *Eur J Sport Sci*. 2023;23(7):1131–45.

20. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health*. 1998;52(6):377–84.
21. Popay J, Roberts H, Sowden A, Petticrew M, Arai L, Rodgers M, Britten N, Roen K, Duffy S. Guidance on the conduct of narrative synthesis in systematic reviews. A product from the ESRC methods programme Version. 2006;1(1):b92.
22. Ogata Y, Soejima T, Hara K, Takahata H, Ando Y, Yamashita A, et al. Effects of tackle height and shoulder preference on head and trunk acceleration in rugby. *Int J Sports Sci Coach*. 2024;17479541241252967.
23. Edwards S, Tucker R, Quarrie K, Tahu T, Gardner AJ. Tacklers' shoulder abduction and flexion at contact alter when engaging in different front-on, one-on-one tackle instructions from an expert coach. *J Sci Med Sport*. 2024;27(7):472–9.
24. Edwards S, Gardner AJ, Tahu T, Quarrie K, Fuller GW, Strangman G, et al. A tackler correctly adhering to the tackle instruction in a front-on, one-on-one torso alters the peak inertial head kinematics of the ball carrier's but not the tackler's. *J Sci Med Sport*. 2025;28(3):242–8.
25. Parmley J, Jones B, Whitehead S, Rennie G, Hendricks S, Johnston R, et al. The speed and acceleration of the ball carrier and tackler into contact during front-on tackles in rugby league. *J Sports Sci*. 2023;41(15):1450–8.
26. Edwards S, Gardner AJ, Tahu T, Fuller G, Strangman G, Levi CR, et al. Tacklers' head inertial accelerations can be decreased by altering the way they engage in contact with ball carriers' torsos. *Med Sci Sports Exerc*. 2022;54(9):1560.
27. Edwards S, Tahu T, Buchanan M, Tucker R, Fuller G, Gardner AJ. Three-dimensional mechanics of the rugby tackle, does the ball carrier alter their movement into contact in response to the tackler's position? *Int J Sports Sci Coach*. 2022;17(2):298–308.
28. Gardner AJ, Iverson GL, Edwards S, Tucker R. A case-control study of tackle-based head injury assessment (HIA) risk factors in the National Rugby League. *Sports Med Open*. 2021;7:1–11.
29. Suzuki K, Nagai S, Iwai K, Ogaki R, Furukawa T, Takemura M. Analysis of tackling events leading to mild cervical injuries in collegiate rugby union. *Int J Sport Health Sci*. 2020;18:48–56.
30. Suzuki K, Nagai S, Iwai K, Furukawa T, Mukai N, Miyakawa S, et al. Characteristics and factors of concussion events for tacklers in collegiate rugby union. *Scand J Med Sci Sports*. 2020;30(1):185–92.
31. Hendricks S, Sin DW, van Niekerk T, den Hollander S, Brown J, Maree W, et al. Technical determinants of tackle and ruck performance in international rugby sevens. *Eur J Sport Sci*. 2020;20(7):868–79.
32. Kawasaki T, Tanabe Y, Tanaka H, Murakami K, Maki N, Ozaki H, et al. Kinematics of rugby tackling: a pilot study with 3-dimensional motion analysis. *Am J Sports Med*. 2018;46(10):2514–20.
33. Suzuki K, Nagai S, Ogaki R, Iwai K, Furukawa T, Miyakawa S, et al. Video analysis of tackling situations leading to concussion in collegiate rugby union. *J Phys Fitness Sports Med*. 2019;8(2):79–88.
34. Tanabe Y, Kawasaki T, Tanaka H, Murakami K, Nobuhara K, Okuwaki T, et al. The kinematics of 1-on-1 rugby tackling: a study using 3-dimensional motion analysis. *J Shoulder Elbow Surg*. 2019;28(1):149–57.
35. Hendricks S, van Niekerk T, Sin DW, Lambert M, den Hollander S, Brown J, et al. Technical determinants of tackle and ruck performance in international rugby union. *J Sport Sci*. 2018;36(5):522–8.
36. Sobue S, Kawasaki T, Hasegawa Y, Shiota Y, Ota C, Yoneda T, et al. Tackler's head position relative to the ball carrier is highly correlated with head and neck injuries in rugby. *Br J Sports Med*. 2018;52(6):353–8.
37. Hendricks S, Karpul D, Nicolls F, Lambert M. Velocity and acceleration before contact in the tackle during rugby union matches. *J Sport Sci*. 2012;30(12):1215–24.
38. King D, Hume AP, Clark T. Video analysis of tackles in professional rugby league matches by player position, tackle height and tackle location. *Int J Perform Anal Sport*. 2010;10(3):241–54.
39. Quarrie KL, Hopkins WG. Tackle injuries in professional rugby union. *Am J Sports Med*. 2008;36(9):1705–16.
40. Hendricks S, Karpul D, Lambert M. Momentum and kinetic energy before the tackle in rugby union. *J Sports Sci Med*. 2014;13(3):557.
41. Fuller CW, Ashton T, Brooks JH, Cancea RJ, Hall J, Kemp SP. Injury risks associated with tackling in rugby union. *Br J Sports Med*. 2010;44(3):159–67.
42. Davidow D, Redman M, Lambert M, Burger N, Smith M, Jones B, et al. The effect of physical fatigue on tackling technique in Rugby Union. *J Sci Med Sport*. 2020;23(11):1105–10.
43. Davidow D, Quarrie K, Viljoen W, Burger N, Readhead C, Lambert M, et al. Tackle technique of rugby union players during head impact tackles compared to injury free tackles. *J Sci Med Sport*. 2018;21(10):1025–31.
44. Burger N, Lambert MI, Viljoen W, Brown JC, Readhead C, Hendricks S. Tackle technique and tackle-related injuries in high-level South African rugby union under-18 players: real-match video analysis. *Br J Sports Med*. 2016;50(15):932–8.
45. Burger N, Lambert MI, Viljoen W, Brown JC, Readhead C, Den Hollander S, et al. Mechanisms and factors associated with tackle-related injuries in South African youth rugby union players. *Am J Sports Med*. 2017;45(2):278–85.
46. Gabbett TJ, Jenkins DG, Abernethy B. Physiological and anthropometric correlates of tackling ability in junior elite and subelite rugby league players. *J Strength Cond Res*. 2010;24(11):2989–95.
47. Kerr HA, Ledet EH, Ata A, Newitt JL, Santa Barbara M, Kahanda M, et al. Does instructional video footage improve tackle technique? *Int J Sports Sci Coach*. 2018;13(1):3–15.
48. McIntosh AS, Savage TN, McCrory P, Fréchède BO, Wolfe R. Tackle characteristics and injury in a cross section of rugby union football. *Med Sci Sports Exerc*. 2010;42(5):977–84.
49. Gabbett T, Ryan P. Tackling technique, injury risk, and playing performance in high-performance collision sport athletes. *Int J Sports Sci Coach*. 2009;4(4):521–33.
50. Den Hollander S, Lambert M, Jones B, Hendricks S. Tackle and ruck technique proficiency within academy and senior club rugby union. *J Sport Sci*. 2019;37(22):2578–87.
51. Tierney GJ, Denvir K, Farrell G, Simms CK. The effect of tackler technique on head injury assessment risk in elite rugby union. *Med Sci Sports Exerc*. 2018;50(3):603–8.
52. Tierney GJ, Denvir K, Farrell G, Simms CK. The effect of technique on tackle gainline success outcomes in elite level rugby union. *Int J Sports Sci Coach*. 2018;13(1):16–25.
53. Spear LP. Adolescent neurodevelopment. *J Adolesc Health*. 2013;52(2):S7–13.
54. Williams MD, Ramirez-Campillo R, Chaabene H, Moran J. Neuromuscular training and motor control in youth athletes: a meta-analysis. *Percept Mot Skills*. 2021;128(5):1975–97.
55. Myer GD, Faigenbaum AD, Edwards NM, Clark JF, Best TM, Sallis RE. Sixty minutes of what? A developing brain perspective for activating children with an integrative exercise approach. *Br J Sports Med*. 2015;49(23):1510–6.
56. Hendricks S. Trainability of junior rugby union players: invited review. *South Afr J Sports Med*. 2012;24(4):122–6.
57. Gabbett TJ, Jenkins DG, Abernethy B. Physical collisions and injury in professional rugby league match-play. *J Sci Med Sport*. 2011;14(3):210–5.

58. Gabbett TJ, Jenkins DG, Abernethy B. Physical demands of professional rugby league training and competition using microtechnology. *J Sci Med Sport*. 2012;15(1):80–6.
59. Reardon C, Tobin DP, Tierney P, Delahunt E. The worst case scenario: locomotor and collision demands of the longest periods of gameplay in professional rugby union. *PLoS ONE*. 2017;12(5):e0177072.
60. Hendricks S, Matthews B, Roode B, Lambert M. Tackler characteristics associated with tackle performance in rugby union. *Eur J Sport Sci*. 2014;14(8):753–62.
61. Hislop MD, Stokes KA, Williams S, McKay CD, England ME, Kemp SP, et al. Reducing musculoskeletal injury and concussion risk in schoolboy rugby players with a pre-activity movement control exercise programme: a cluster randomised controlled trial. *Br J Sports Med*. 2017;51(15):1140–6.
62. Balyi I, Hamilton A. Long-term athlete development: trainability in childhood and adolescence. *Olympic Coach*. 2004;16(1):4–9.
63. Pethick J, Tallent J. The neuromuscular fatigue-induced loss of muscle force control. *Sports*. 2022;10(11):184.
64. Haff GG, Burgess S, Stone MH. Cluster training: theoretical and practical applications for the strength and conditioning professional. *Prof Strength Cond*. 2008;12:12–7.
65. Kanko RM, Laende E, Selbie WS, Deluzio KJ. Inter-session repeatability of markerless motion capture gait kinematics. *J Biomech*. 2021;121:110422.
66. Tooby J, Weaving D, Al-Dawoud M, Tierney G. Quantification of head acceleration events in rugby league: an instrumented mouthguard and video analysis pilot study. *Sensors (Basel)*. 2022;22(2):584.
67. Finch CF, Ullah S, McIntosh AS. Combining epidemiology and biomechanics in sports injury prevention research: a new approach for selecting suitable controls. *Sports Med*. 2011;41(1):59–72.
68. Moola S, Munn Z, Tufanaru C, Aromataris E, Sears K, Sfetcu R, Currie M, Qureshi R, Mattis P, Lisy KM, Mu PF. Chapter 7: Systematic reviews of etiology and risk. *JBIM manual for evidence synthesis*, vol 10. JBI; 2020.
69. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2020;372:n71.