

Biomechanics of Rugby Tackling in Amateur Youth Players

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1 Table of Contents

<i>Figures and Tables</i>	6
2 Abbreviations	8
<i>Acknowledgements</i>	10
1 Introduction	11
1.1 Abstract	11
1.2 Background	13
1.2.1 Rugby as a sport	13
1.2.2 Tackling	14
1.2.3 Tackle injuries	16
1.2.4 Tackling Techniques and Safety	17
1.2.5 Tackling development	19
1.2.6 Methodologies used in tackle research	21
1.2.7 Summary	22
1.3 Rationale	23
1.4 Aim & Objectives	24
Aim:	24
1.4.1 Objectives:	24
1.5 Research Questions	24
1.6 Significance of the Research	24
1.7 Structure	25
2 Biomechanics of Rugby Tackle Techniques in Youth and Adult Players: A Systematic Review of Age-Specific Injury Risk and Performance Implications	26

2.1	Abstract	27
2.2	Background	29
2.3	Methods	32
2.3.1	Search Strategy.....	32
2.3.2	Study Inclusion and Exclusion Criteria	33
2.3.3	Study Selection and Data Extraction.....	34
2.3.4	Methodological Quality.....	35
2.3.5	Data Synthesis.....	35
2.4	Results	36
2.4.1	Risk of Bias	38
2.4.2	Study Characteristics	41
2.4.3	Quantitative and Qualitative Findings.....	44
2.5	Discussion	52
2.5.1	Age-Specific Differences in Head Positioning and Injury Risk.....	53
2.5.2	Biomechanical Differences Influencing Tackle Effectiveness Between Youth and Adult Players.....	55
2.5.3	Dominant vs. Non-Dominant Shoulder Biomechanics and Fatigue.....	60
2.5.4	Limitations	63
2.6	Conclusion	64
3	<i>Investigating Tackle Kinematics of Amateur Youth Rugby Players Using Theia3D</i>	67
3.1	Abstract	67
3.2	Introduction	69

3.3	Methodology	73
3.3.1	Participants.....	73
3.3.2	Study Design	75
3.3.3	Equipment.....	76
3.3.4	Tackle Assessment Protocol.....	77
3.3.5	Biomechanical data processing	78
3.3.6	Statistical analysis	79
3.4	Results.....	80
3.5	Discussion	85
3.6	Limitations	89
3.7	Practical Application.....	90
3.8	Conclusion.....	91
4	<i>Discussion</i>	93
4.1	Research Question 1: How do tackle kinematics vary by age in adolescent to adult rugby players?	94
4.2	Research Question 2: What characterises the biomechanical execution of a tackle in adolescents and what are the coaching implications for improving safety and performance?	96
4.2.1	Limitations	99
4.2.2	Future Directions	100
4.3	Conclusion.....	101
5	<i>Appendices.....</i>	103
5.1	Ethics & Data Collection Forms	113

5.2	Research Proposal.....	114
5.2.1	KEY CONTACTS.....	115
5.2.2	Summary.....	116
	Methods.....	122
5.2.3	Data management	131
5.2.4	Participant involvement and engagement.....	131
5.2.5	131
5.2.6	How will the data be analysed and by whom	131
5.2.7	Data Protection and Confidentiality.....	132
5.2.8	How will data be used and stored?.....	133
5.2.9	Dissemination of results of this research.....	134
6	Reference List	172

Figures and Tables

Figure 2. PRISMA diagram adhered to for including articles in this review	37
Table 1. Downs and Black risk of bias checklist for 28 included studies (43).....	39
Table 2. Characteristics of the 28 Reviewed Studies, Including Demographics (Group, Sex, Age, and Level), Methodology (Duration and Method), and Tackling Variables Studied	42
Table 3. Biomechanical and injury risk and performance factors of the adult rugby tackle including comparison by tackle type	46
Table 4. Biomechanical and Qualitative Analysis of Youth Rugby Tackling Compared to Adults	50
Table 5. Participant Characteristics (n=15).....	74
Figure 3. Camera Configuration for Tackle Assessment Protocol	75
Figure 4. Tackle Assessment Protocol Set-Up	77
Figure 5. Visual 3D Kinematic Model of the Rugby Tackle.....	79
Figure 6. Average Trunk Segment Angles with Standard Error Bars in Degrees (°) for Rugby Tackle contact in Flexion, Lateral Flexion and Axial Rotation	81
* = Statistically significant differences (P<0.05).....	81
Abbreviation: LND; Low Non-Dominant, L: Low, RND: Regular Non-Dominant, R: Regular.....	81
Figure 7. Average Trunk Angles with Standard Error Bars in Degrees (°) for Rugby Tackle Contact in Flexion, Lateral Flexion, and Axial Rotation.....	82
* = Statistically significant differences (P<0.05).....	82
Abbreviations: LND; Low Non-Dominant, L; Low, RND; Regular Non-Dominant, R; Regular.....	82

Figure 8. Average Neck Angles with Standard Error Bars in Degrees (°) for Rugby Tackle Contact in Flexion, Lateral Flexion and Axial Rotation.....	83
* = Statistically significant differences (P<0.05).....	83
Abbreviation: LND; Low Non-Dominant, L: Low, RND: Regular Non-Dominant, R: Regular.....	83
Figure 9. Average Flexion Angles with Standard Error Bars in Degrees (°) for Rugby Tackle Contact in non-dominant and dominant Ankle, Knee and Hip.....	84
Abbreviation: LND; Low Non-Dominant, L: Low, RND: Regular Non-Dominant, R: Regular.....	84
Table 6. Key Findings from Chapters with Practical Applications	93
Table 7. All extracted data from the 28 studies included in the systematic review ...	104

2 Abbreviations

Abbreviation	Definition
1RM	One-repetition maximum
3D	Three-dimensional
AI	Artificial intelligence
C3D	Coordinate 3D file format used for biomechanical motion data
CI	Confidence interval
COM	Centre of mass
D	Dominant (shoulder side)
DNRL	Dominant National Rugby League (tackle technique classification)
DTS	Dominant, Torso Stick (tackle technique classification)
GDPR	General Data Protection Regulation
GPS	Global Positioning System
HIA	Head Injury Assessment
ICC	Intraclass correlation coefficient
IMU	Inertial measurement unit
IRR	Incidence rate ratio
kN	Kilonewton
L	Low (target height condition)
LND	Low non-dominant (target height × shoulder condition)
LTPD	Long-term player development
m/s ⁻²	Metres per second squared (unit of acceleration)

ND	Non-dominant (shoulder side)
NRL	National Rugby League
OR	Odds ratio
P	Probability value (p-value)
PARQ	Physical Activity Readiness Questionnaire
PIS	Participant Information Sheet
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
R	Regular (target height condition)
RND	Regular non-dominant (target height × shoulder condition)
SD	Standard deviation
SNRL	Smother National Rugby League (tackle technique classification)
SPL	Smother, Pop, Lock (tackle technique classification)
TS	Torso Stick (tackle technique classification)

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1 Introduction

1.1 Abstract

Tackling is a fundamental component of rugby union and rugby league, with consequences for both performance and player safety. In youth rugby, the tackle is the leading cause of concussions, and common technical errors, such as head-in-front positioning, may be modifiable through coaching. Despite this, a clear account of safe tackling mechanics in youth remains limited. This thesis investigates tackle ability and kinematic characteristics in youth rugby and translates those findings into coachable insights. First, an introduction to what is currently known about tackle-related injury risk and technique, the methodological challenges of quantifying collision biomechanics, and how markerless motion capture can be used to study youth tackle kinematics. Second, a systematic review compares adolescents with adults to identify age-related differences in head placement, trunk and lower-limb flexion, shoulder-led contact, arm wrap, and associated head-loading risk. Third, an experimental study using Theia3D quantifies adolescent kinematics under controlled conditions across four coached executions defined by target height (regular or low) and shoulder side (dominant or non-dominant). Finally, evidence from both studies is synthesised to answer two questions: 1) how do tackle kinematics vary by age from adolescents to adults, and 2) what characterises the biomechanical execution of a safe tackle in adolescents, and what are the coaching implications for improving safety. The systematic review found that youth players often demonstrate head-in-front positioning, whereas adults show deeper hip and knee flexion and a more stable, lower-limb driven tackle shape. The experimental study found that target height was the primary determinant of tackle execution at contact; low targets increased trunk and neck flexion, and centre-of-mass velocity did not differ across conditions, indicating that these postural changes were not explained by approach speed.

Overall, this progression from synthesis to experiment provides an objective, biomechanical foundation for adolescent coaching and identifies clear priorities for future work linking technique changes to head-loading and injury outcomes.

1.2 Background

1.2.1 *Rugby as a sport*

Rugby is a popular global team sport with two main codes: rugby union and rugby league (1). Rugby union is the most played and supported, with over 8 million players across 130+ countries, including the UK (1). In contrast, rugby league, though strong in regions like northern England and eastern Australia, has ~300,000 players worldwide (2). Rugby league and union together have a following of roughly 800 million people worldwide, whilst their major events draw large audiences(3). The 2019 Rugby World Cup (rugby union's premier tournament) was watched by over 850 million television viewers globally (a record, and about 26% higher than the preceding 2015 tournament), with nearly 45 million tuning in for the final match (3). By comparison, the entire 2021 Rugby League World Cup reached around 30 million viewers (1).

Rugby's appeal spans all ages and sexes, supported by strong youth systems and a rapidly growing women's segment (1). More than half of all players globally are children, with ~57% of rugby participants under 13 years old, reflecting the sport's popularity at youth levels (1). Females now account for nearly one-quarter of the player base worldwide, and participation is expanding with the number of registered women players jumping by 38% in 2023, outpacing the 26% growth in male players that year (1). Geographically, the sport's traditional heartlands remain in countries such as the British Isles, France, South Africa, Australia, Argentina and New Zealand. Still, rugby has spread worldwide, with World Rugby now counting 132 national member unions across six continents (1). Grassroots initiatives continue to introduce the game in new markets; for instance, youth programmes in Asia added over one million new rugby participants in the lead-up to the 2019 World Cup (3). Such

a broad base of participants and fans firmly cements rugby union's status as one of the world's major sports in terms of participation and viewership (1, 3).

1.2.2 Tackling

In rugby, a tackle is a fundamental defensive action where a defender (the tackler) attempts to stop the ball-carrier's forward progress by bringing them to the ground or otherwise halting their movement and potentially the opposing team's attack (4). Tackling is not only crucial for disrupting the opponent's attack but also creates an opportunity to contest for possession (4). Mastering safe and effective tackling technique is vital, as it is one of the most high-risk skills in the sport, with approximately 55–60% of all injuries in adult rugby occurring during tackle situations (4). Consequently, around 72% of all rugby concussions are sustained during the tackle (4). Many of these serious injuries happen when the tackler's head collides with a hard part of the ball-carrier's body (or vice versa), with common mechanisms including head-to-head impacts and a tackler's head hitting the ball-carrier's elbow, hip, or knee (4, 5). These statistics underscore why proper tackling form (e.g. keeping



Figure 1. Sequence of a mid/lower trunk shoulder tackle

the head to the side and the “eyes up”) is heavily emphasised in an effort to uphold safety and reduce injury (4, 5).

Tackling involves a complex, rapid sequence of biomechanical events divided into three distinct phases: pre-contact, contact (the instant the tackler first touches the ball-carrier or bag) , and post-contact. During pre-contact, the tackler typically lowers their body position and engages their legs and core muscles (i.e. a “bottom-up” recruitment) to drive forward and strongly into the tackle (Figure 1.) (4, 6). At the moment of contact, the tackler usually leads with the shoulder (aiming for a relatively low target such as the opponent’s thighs) while wrapping the arms around the legs (4). The force of collision is briefly absorbed by both players’ bodies, deforming tissues at the contact points and sending impact (the collision-loading phase around contact when forces and accelerations are transmitted) forces through the tackler’s body and down into the ground (4). Immediately after contact, the tackler continues to drive with their legs and use their arms in a wrapping motion, working to bring the ball-carrier to ground in an effort to impede the ball carrier and compete for possession (4). Throughout this process, players often brace their neck muscles to stabilise the head and protect the cervical spine during the impact (4). Most players have a preferred or dominant shoulder for tackling and these dominant-side tackles tend to generate the greater impact forces (7). Studies have measured ~5.3 kN of impact force produced by the tackler to the contact point in frontal tackles on the dominant side which is roughly 15% higher than using the non-dominant side (7). There are also different tackle techniques depending on the given match situation and angle of approach; for example, a “front-on” tackle (hitting the ball-carrier front-on with the shoulder) versus a side-on tackle (from an angle), or a “smother” tackle where the tackler wraps up the ball-carrier’s upper body and ball in an effort to prevent

any offloads and slow play (4). Each of these tackle variations requires proper execution to be effective and safe, reinforcing the need for dedicated practice and coaching in tackling skills.

1.2.3 Tackle injuries

Tackling is the predominant cause of injury in rugby. In youth rugby, roughly half to two-thirds of injuries occur in tackle events, accounting for ~55% of injuries in male players and over 71% in females (8). A recent study monitoring under-19 schoolboys in Ireland found that 66.7% of match injuries occurred during tackles, with the tackler being injured 33% more often than the ball carrier (9). Tacklers often sustain injuries; therefore, it is important to examine their risk separately from that of the ball-carrier (9). Head impacts are of particular concern in youth rugby because adolescents are uniquely predisposed to sustaining these injuries (10). Sport-related concussion is a traumatic brain injury caused by a blow to the head, neck, or body that transmits an impulsive force to the head(11). Compared to adults, youths have proportionally larger heads, weaker cervical musculature and incomplete neural development, which makes head accelerations from impact more pronounced (10). Video studies of professional rugby show that tackles cause 76% of all head injury assessments (HIA) (5). Importantly, an HIA represents an assessment triggered by suspected concussion rather than a confirmed concussion diagnosis, and not all HIAs result in a diagnosed concussion (12). Within those tackle impacts, the tackler suffers most of the injuries, with roughly 72% of tackle-related head impacts being experienced by the tackler, while the most common high-risk scenario is a head-to-head collision (5, 13). These head-to-head contacts have the greatest propensity for injury and produce the largest share of tackler head impacts, with 11.3 HIAs happening per 1000 tackle events and 78% of these being to the tackler (13). In contrast, HIAs resulting from the tackler's head and the opponent's elbow or knee colliding

were far less frequent, with 6.35 head-to-elbow and 3.09 head-to-knee impacts per 1000 tackles recorded (13). These contacts injured the tackler in 100% and 61% of cases, respectively (13). As the HIA protocol is not used in children and adolescents, these professional data are best interpreted as a mechanistic context for how tackle type can drive suspected head injury events, rather than as direct estimates of youth concussion incidence (12).

In summary, tackling is by far the leading cause of head impacts in rugby, and the tackler is disproportionately affected in these cases. This evidence, especially in youth players, motivates focus on the tackler's technique because concussions in adolescents can also prolong recovery and might even impair academic performance, the consequences of which can extend well beyond sport (10). This evidence underscores the urgency of examining the tackler's risk, specifically, since most head impacts in tackles are sustained by the defending player (4, 5). By studying how and when tacklers sustain impacts, this research aims to inform training to make tackling safer for the defending player (5).

1.2.4 Tackling Techniques and Safety

Rugby injury risk studies show that most concussions occur during tackles, often when technique lapses (e.g. poor head placement), leading to head impacts (4, 14). Improper tackle form involves a variety of common errors that elevate the risk of injuries such as concussions and cervical stress and reduce the chances of preventing the attacking team from progressing (14). One major fault is tackling with the head in a suboptimal position, for example, placing the head in front of the oncoming ball carrier or dropping the head downward before the point of contact (14). When the tackler places the head in front of the ball carrier or looks down, the cervical spine moves into combined flexion with lateral flexion

and rotation (15). This reduces the normal lordotic curve and its ability to absorb shock at the neck, so impact forces are transmitted along the neck rather than through the shoulder (15, 16). The player also loses visual tracking of the opponent, which increases the likelihood of head-to-knee or head-to-hip contact (15). These postures are linked to greater head acceleration and much higher concussion risk than head-to-the-side, eyes-up (15). Tackles with incorrect head placement have been shown to carry significantly higher concussion risk, in the amount of eight times greater odds compared to when using correct form (17).

An upright trunk orientation that produces a high contact height above the shoulder increases the probability of head-to-head or shoulder-to-head/neck collisions. Due to the associated head and cervical-spine injury risk, this action is prohibited in the Laws of the Game (18). Insufficient hip and knee flexion leads to greater anterior trunk inclination and thoracolumbar flexion, accompanied by cranio-cervical flexion and a downward gaze (19). This configuration narrows the visual field and reduces time-to-contact estimation, producing spatial errors at impact, for example, selecting an incorrect contact point and failing to wrap the lower limbs at contact. These errors expose the head to high-momentum knee impacts at collision (20). Additionally, not using the arms to wrap, such as attempting a shoulder-only impact, is both ineffective and illegal and can result in the ball carrier breaking free, also putting the tackler at risk of injury since there is no controlled grip attempted on the opponent (21). Overall, what is “suboptimal” in tackle technique comes down to breaking the fundamental and established safety guidelines, such as placing the head in the wrong place, utilising an unstable body position or adopting improper use of the arms (4, 14, 22). These flaws not only endanger the tackler, leading to concussions and cervical injuries, but also typically lead to negative performance outcomes such as missed tackles or penalties against the tackler (14, 22). For example, a high or head-on tackle with poor form can often draw a

penalty or yellow/red card, whereas a low, well-executed tackle is both safer and more likely to succeed in halting the attacking progress of the opponent (14, 22).

1.2.5 Tackling development

Tackle technique in rugby shows developmental progression from youth to adulthood as players' physical and cognitive capacities mature. Younger children are smaller and weaker, resulting in less momentum in collisions (23). Under-15 schoolboy players have significantly lower tackle injury rates than adult professionals, largely due to the lower impact forces at youth levels of the sport (23). As adolescents grow, increases in body mass and approach speed raise the energy available at contact because energy grows with the square of speed (23). If the technique is suboptimal, more of that energy is delivered to the head and neck through poor contact geometry and load paths (23).

It is important to note that tackling is a complex motor skill that is not necessarily determined solely by size and physical qualities (24). One study of teenage players found no strong link between standard physical metrics (e.g., speed and power) and tackle success, underscoring the contention that skill and decision-making abilities are critical even among youth players (24). Cognitive and perceptual abilities also improve with age, with older players anticipating ball-carrier movements and timing tackles better, whereas younger players often struggle with split-second judgments (e.g. head positioning), potentially due to ongoing neural and neuromuscular development and motor awkwardness associated with the onset of the growth spurt due to puberty (25, 26). For example, an 8-year-old might struggle to align their shoulder and stabilise their neck properly during a tackle (26). However, by around 12 years old, technique, safety, and reliability tend to improve as reaction time, coordination, and spatial awareness develop through practice (26).

Children's anatomical characteristics, such as proportionally larger heads, weaker neck muscles, may increase vulnerability to head impacts and make it harder to consistently maintain proper form under stress (26). Alternatively, by late adolescence (14-18 years), most players have greater neuromuscular control, stronger core muscles and necks, and broader tactical understanding, thus facilitating more effective and stable tackles to be executed (25, 26). However, by this time, they also operate in a higher-impact rugby environment, meaning that sound technique and physical preparedness remain paramount for handling the increased collision forces and preventing cervical injuries and concussions (27). As athletes mature, their tackle performance benefits from improved strength and game sense, but these advances must be accompanied by refined technique to ensure proficiency and safety across developmental stages. While previous studies show younger players (12-13 years) may have a lower overall risk of injury compared to older players (14-18 years), the biomechanical differences in tackle execution between these age groups are not well understood (23, 28-30). Along with the previously mentioned risks of tackling pre-puberty, the period of puberty causes rapid physical and cognitive changes, which can impair coordination and could potentially influence how players learn and perform tackling techniques (25, 31). Therefore, identifying the right time during development to teach and refine tackling skills is essential for balancing skill development with injury prevention during these critical years (31).

Despite extensive coaching frameworks and age-appropriate training guidance (32-34), the empirical base for understanding how adolescent tacklers organise their posture under specific constraints remains limited. Existing resources emphasise prescriptions, but rarely quantify which joint actions or contact geometries differ by age or laterality, or how fatigue-related form loss maps to kinematic changes at contact (27, 35). Cultural tendencies to prioritise collision dominance over head placement further underline the need for objective,

coachable markers tied to posture rather than general advice (26, 36). These gaps motivate the present thesis: first, a systematic review to delineate youth–adult differences in key technical features and risk mechanisms; second, an adolescent experiment that isolates target height and shoulder side using 3-D motion analysis; and finally, a synthesis that translates those findings into precise coaching priorities for 12–18-year-olds.

1.2.6 Methodologies used in tackle research

Rugby tackle research has traditionally relied on video analysis and expert observation to quantify technique and injury risk. Researchers systematically label match footage to categorise each tackle (for example, recording head and body position) and often supplement this with “tackle proficiency” scoring (37). Tackle proficiency scoring uses a checklist of core technical actions, such as bent knees, a straight back, correct head placement, shoulder contact to the midsection, arm wrap, and leg drive (17). Each item is scored a 1 (correct) or 0 (incorrect), producing a total score that reflects overall execution quality (17). This system is reliable in both training and match settings and has strong links to performance outcomes: players with higher scores demonstrate lower injury rates and a greater proportion of successful tackles (38). Coaches use the scores to target deficiencies (e.g., poor head position), and research shows proficiency improves with age and experience, with senior players typically scoring higher than juniors (38). Proficiency scoring, therefore, offers a practical and evidence-based way of distinguishing safe, effective tackles from unsafe ones, supporting both injury prevention and performance development (38). Tackle proficiency scores provide real-game context but have limitations, depending on camera quality and being subjective to the rater and the specific tackle scenario being studied. In laboratory settings, 3D motion-capture systems such as Vicon can generate detailed

kinematic and kinetic data and are regarded as the 'Gold Standard' for studying tackle biomechanics (39). However, the laboratory settings required for using 3D motion capture systems are limited to staged drills in controlled environments, such as a bag tackle; therefore, ecological validity is restricted (39). In practice, traditional rugby tackle analysis methods often balance real-world applicability using video or observation and detailed measurement techniques like motion capture, each with its own limitations in reliability and sensitivity (39).

Emerging technologies are now building on these previously used approaches. For example, AI-driven video analytics such as Theia3D and machine-learning tools are being developed and show strong validity and reliability for biomechanical analysis of human movement (40). Theia3D, a markerless motion capture system, has demonstrated close agreement with marker-based systems across tasks such as gait, squatting and landing, with sagittal-plane joint angles differing by only $\sim 3^\circ$ and intraclass correlations exceeding 0.80 in most cases (41). Agreement tends to be highest for hip and knee flexion–extension, with lower reliability observed in transverse-plane and ankle joint motions. Recent sport-specific evaluations show Theia3D accurately captures joint and centre-of-mass trajectories during dynamic actions, with segment orientation errors $< 12.5^\circ$ (42). Theia3D presents a promising avenue for capturing tackle kinematics in ecologically valid environments, particularly where traditional laboratory setups are impractical.

1.2.7 Summary

With the increasing emphasis on reducing concussion rates in adolescent rugby players across the world, the need for evidence-based training strategies is more urgent than ever. This research is both timely and essential for understanding injury risk in youth rugby as

it will be the first to use Theia3D technology to analyse the kinematics of a youth rugby tackle. By gaining a deeper understanding of tackle mechanics, this research will inform the development of coaching techniques that encourage safer tackling practices. A secondary objective of the study is to shed light on the developmental window for acquiring safe tackling skills. The developmental window refers to a proposed sensitive period during which changes in growth, coordination, and training exposure may make tackle skill acquisition more responsive to coaching. This thesis does not identify a definitive “optimal” window but evaluates adolescent technique and highlights where youth-specific biomechanical evidence is currently limited. Identifying this window could lead to further exploration of why certain age groups are better suited for learning these techniques. The outcomes of this research may contribute to improved coaching practices, reducing the risk of concussions and other injuries in youth rugby. Furthermore, the findings may provide critical data for creating age-appropriate training protocols that enhance both performance and long-term player safety, shaping the future of youth rugby training programmes and injury prevention strategies.

1.3 Rationale

There is a pressing need to understand youth tackle technique and to identify the age or developmental window during which players exhibit the greatest tackle skill acquisition potential. This information can inform coaching practices and long-term player development (LTPD) models, promoting safer and more effective teaching methods. The current literature is limited by its reliance on subjective technique scoring, inconsistent definitions of tackle proficiency and a lack of kinematic data in adolescent populations.

By integrating markerless 3D motion capture technology (Theia3D) into the assessment of tackle kinematics, this research aims to provide precise biomechanical data to distinguish between frequently used tackle cues in young athletes. This enables an objective

comparison of tackle ability and movement patterns, providing novel insights into youth rugby development.

1.4 Aim & Objectives

Aim: To investigate the effect of age on tackle ability and kinematics in amateur rugby players, aged 12 to 18, using three-dimensional motion analysis.

1.4.1 Objectives:

1. To compare tackle ability and technique characteristics in youths and adults via a systematic review (Chapter 2).
2. To analyse kinematic differences in body position and joint angles during four different tackle executions (Chapter 3).
3. To identify any correlations between age and kinematic performance indicators, including the comparison of adult to youth (Chapter 2).
4. To inform coaching strategies and developmental models for youth rugby based on biomechanical findings (Chapters 2 & 3).

1.5 Research Questions

- How do tackle kinematics vary by age in adolescent to adult rugby players? (Chapter 2).
- What characterises the biomechanical execution of a safe tackle in adolescents, and what are the coaching implications for improving safety? (Chapters 2&3)

1.6 Significance of the Research

This thesis makes an original contribution by addressing a methodological and applied gap in youth tackle research, where technique evaluation has often relied on subjective

scoring and where advanced three-dimensional biomechanical methods can be difficult to apply during collision tasks. The work is novel in two ways. First, it synthesises evidence comparing youth and adult tackling biomechanics to identify technique characteristics most consistently associated with safer and more effective execution, while highlighting where age-related evidence remains limited. Second, it complements this synthesis with an experimental analysis of adolescent tackle kinematics under common coaching constraints (target height and shoulder side) using markerless three-dimensional motion capture, providing an objective framework for quantifying how instructed technique changes alter body posture and joint configurations during contact tasks. The intended impact is to translate broad coaching cues into measurable kinematic indicators that can inform age-appropriate training progressions and generate testable hypotheses for future studies linking technique, head loading, and injury risk under more representative live-contact conditions.

1.7 Structure

Chapter 2 presents a systematic review of the literature on tackle technique and biomechanics, with a specific focus on age-related differences and youth development. Chapter 3 details the experimental study, including methodology, participant recruitment, data collection using Theia3D and statistical analysis. Chapter 4 concludes the work by synthesising the findings, discussing practical implications for coaching and youth development, and offering recommendations for future research.

2 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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2.1 Abstract

Background: Tackling is a vital skill in rugby that greatly influences both performance outcomes, such as reducing opposition carry distance and increasing possession gain, and injury risk, such as frequency of concussions and cervical injuries. Since up to 72% of head impacts happen during tackles, leading to concussions and cervical trauma, technical skill in tackle mechanics is crucial for reducing injury risk (5). This study systematically explores tackle biomechanics across different age groups to identify differences in technique and injury patterns, aiming to guide age-specific coaching strategies to enhance safety and performance.

Methods: The systematic review adhered to PRISMA guidelines, utilising PubMed, SPORTDiscus, Web of Science, ScienceDirect, and Google Scholar databases. Studies analysing tackle biomechanics, injury-prevention methods, and performance metrics in youth and adult players were included. Biomechanical data, including joint angles, kinematics and head positioning were extracted alongside injury rates and technical performance outcomes. Video analyses, motion capture systems and accelerometer data were synthesised to compare tackle execution across age groups. Risk of bias was assessed using the Downs and Black checklist to evaluate the quality of the included studies (43).

Results: Youth rugby players exhibited higher rates of improper head positioning than adults, increasing head and cervical injury risk (69.4 vs. 2.7 per 1,000 tackles) (44). Youth players often performed high-risk tackles due to limited biomechanical control and experience. Adults showed better technique, as indicated by technical proficiency scores and biomechanical indicators such as greater hip and knee flexion angles and greater leg drive, which improve tackle success rate and ball-carrier tracking, but experienced higher injury rates due to increased tackle volumes and forces. Though perceived as safer, low tackles

increased head-to-knee impacts while midsection tackles reduced such risks. Age-specific training significantly improved technical proficiency, especially in the pre-contact and impact phases of the tackle.

Conclusion: This review underscores the necessity of age-specific coaching strategies to optimise tackle safety and performance. Emphasising proper head positioning, pre-impact stabilisation, and midsection targeting can mitigate injury risks while enhancing tackle skill acquisition. These findings support evidence-based training protocols to bridge the gap between safety and technical development, particularly in youth rugby.

Keywords: Tackle Technique, Biomechanics, Rugby, Youth Rugby, Concussion Risk, Injury Prevention

2.2 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 (45, 46). In rugby league, the incidence of concussion ranges from 4.6 to 14.7 per 1,000 player-hours (8). Among adults, tackling is responsible for up to 72% of head injuries, particularly those involving head-to-head or head-to-knee contact scenarios (5). These statistics highlight tackling as a critical area of focus for both injury prevention and skill development in rugby. Despite tackling being common to all codes of rugby (union, league and sevens), the physical and biomechanical demands vary considerably across levels of play (39). Adult players experience higher tackle volumes and forces due to greater player mass, speed and game intensity (47, 48). However, youth players may be at a disproportionate risk due to factors such as neuromuscular immaturity (developing strength and motor-unit control that can reduce joint stabilisation during fast, high-load actions), underdeveloped motor control (less refined coordination and postural regulation, particularly during rapid changes in body position), and reduced technical consistency (greater trial-to-trial variability in executing the same technique under similar task demands) (25, 49). These developmental characteristics may manifest as unbalanced stances, poor head positioning and ineffective shoulder engagement during contact (25, 49). Consequently, applying adult-derived technical models to younger cohorts may be inappropriate and even harmful in some instances.

Technical and biomechanical proficiency are consistently identified as key determinants of injury risk and tackle effectiveness across age groups (39). The tackle can be divided into three phases: 'pre-impact', 'impact' and 'post-impact' (16). During the pre-impact

phase, muscle activation follows a sequential, “bottom-up” pattern, beginning with lower-limb stabilisation and force generation, which progresses upwards through the torso (16). During the impact phase, forces transfer primarily through the shoulder or neck to the ball-carrier, necessitating stable body positioning, lateral head alignment and anticipatory co-contraction of cervical and shoulder musculature to absorb these forces effectively (16, 50). In the post-impact phase, the tackler maintains control through continued leg drive and upper-body engagement to complete the tackle with the objective of bringing the ball carrier to ground (16, 50). Each phase is governed by complex interactions between joint angles, body orientation and segmental velocities (16, 50). Among these, head placement, trunk angle and shoulder engagement at contact are especially influential in determining whether the tackler accepts and transfers force safely (20, 51, 52). 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 (20).

Several review articles have advanced the understanding of tackle-related injury mechanisms, but key limitations remain. For example, Edwards et al. (2021) conducted a systematic review of 3D biomechanics in rugby tackle research (39). The review highlighted important methodological advancements and identified critical kinematic variables such as hip flexion, trunk inclination and head proximity to the point of contact (39). However, it did not compare tackle characteristics between youth and adult populations, nor did the authors explore how developmental status (the overall stage of growth and training, including biological maturation, physical capacity, and coordination) might influence biomechanical strategy during tackling (39). The review focused more on measurement technologies than on applied coaching implications, somewhat limiting its translational impact in sport (39).

In contrast, West et al. (2023) provided a comprehensive overview of injury epidemiology, risk factors and prevention strategies in youth rugby union (8). The review highlighted that the tackle is the most common phase of play linked to injury in youth cohorts and discussed modifiable risk factors such as poor head placement, upright posture and delayed decision-making (8). However, while it underscored the importance of coaching in mitigating injury risk, the review did not examine the biomechanical characteristics of these risky behaviours or compare them to adult tackling mechanics (8). The authors called for better integration between biomechanical insight and coaching practice but did not provide a systematic evaluation of movement strategies across age groups, limiting the review's ability to inform precise, developmentally appropriate technical instruction (8). Darrall-Jones et al. (2015) previously described valuable anthropometric and physical profiling data across age categories in English academy rugby union players (53). Their findings show that body mass, sprint momentum and strength capacity increase significantly from U16 to U21 levels (53). These physical changes may impact tackle performance and injury risk, but the researchers stop short of linking physical development to actual in-game tackle biomechanics or technique adaptation; thus, while developmental trends are well described, their implications for skill execution in contact remain unclear(53).

Taken together, these reviews reveal important foundations on the topic of tackling in youth rugby but also highlight a critical gap: no existing synthesis directly compares the biomechanical execution of tackling across age groups or contextualises these differences within physical, developmental and coaching domains. This limits the ability of coaches and practitioners to design age-appropriate tackle training and injury prevention strategies. Accordingly, 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 in youth players. Findings from video analysis, markered motion capture, accelerometry, injury surveillance data and coaching practices will be evaluated to provide comprehensive insights into tackle mechanics and their implications for player safety and skill development, supporting the creation of evidence-based, age-appropriate coaching strategies.

2.3 Methods

2.3.1 Search Strategy

A systematic search was conducted on 20th December 2024 to identify peer-reviewed studies examining tackling biomechanics, injury prevention strategies, and performance metrics in rugby. A further updated search was performed on the 5th May 2025 to check for new publications from which no additional articles were identified. Electronic databases, including PubMed, SPORTDiscus, Web of Science, ScienceDirect, and Google Scholar, were searched without date restrictions. Reference lists of retrieved articles were also screened manually 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 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 the terms “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 standalone term, studies using that classification were captured under broader terms like “youth”. Keywords like “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 due to 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.

2.3.2 Study Inclusion and Exclusion Criteria

Two reviewers (HE, MB) independently evaluated the studies from the search process, with discrepancies resolved through discussion or involvement of 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 were male or female youth or adult rugby players. Employed biomechanical assessment methods (e.g., video analysis,

marked or markerless motion capture, wearable sensors, or injury surveillance) and studies were published in English and had full-text availability. The review focused on the tackling mechanism from the tackler's perspective and included studies that examined the mechanisms of performance and injury risks. 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.

2.3.3 Study Selection and Data Extraction

A single reviewer (HE) reviewed titles and abstracts. Two independent reviewers (HE and MB) screened full texts using the described eligibility criteria. Any discrepancies were resolved through consensus or consultation with a third reviewer (BG). Out of the 73 articles screened for inclusion, there was an overall agreement of 95.9% between the raters, resulting in a Cohen's unweighted Kappa statistic of 0.92, indicating almost perfect agreement between the two raters (49). This resulted in the final selection of 28 articles.

Two reviewers (HE and MB) independently conducted data extraction using a standardised 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. The study authors were contacted to clarify the incomplete data. Studies with unresolved ambiguities or insufficient data after contact were excluded.

2.3.4 Methodological Quality

Two reviewers (HE and AG) independently assessed methodological quality using the Downs and Black checklist (43). This validated tool assesses reporting quality, internal validity (bias and confounding), external validity and statistical power (43). Each study was scored on these domains, providing an overall quality score and a profile of methodological strengths and weaknesses, with scores ranging 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 the supplementary materials. The checklist was applied uniformly across studies to ensure consistency in scoring.

2.3.5 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 significance of findings.

A narrative synthesis approach was adopted to address the methodological heterogeneity across the studies, especially 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 in joint angles, posture during contact, head position and technical execution across 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, force outputs, segmental velocities) were summarised descriptively due 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 articles 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.

2.4 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 1,134 articles. The full texts of 71 articles were retrieved and assessed for eligibility. Of these, 43 articles were excluded for reasons such as a lack of focus on rugby tackling, no discussion of technique, performance, or injury reduction, or being review articles, editorials or opinion pieces. Ultimately, 28 studies met the inclusion criteria, comprising 22 studies conducted in adult participants (5, 16, 18, 19, 44, 54-69), five studies in youth (46, 51, 70-73) and two study that included both youth and adults (20).

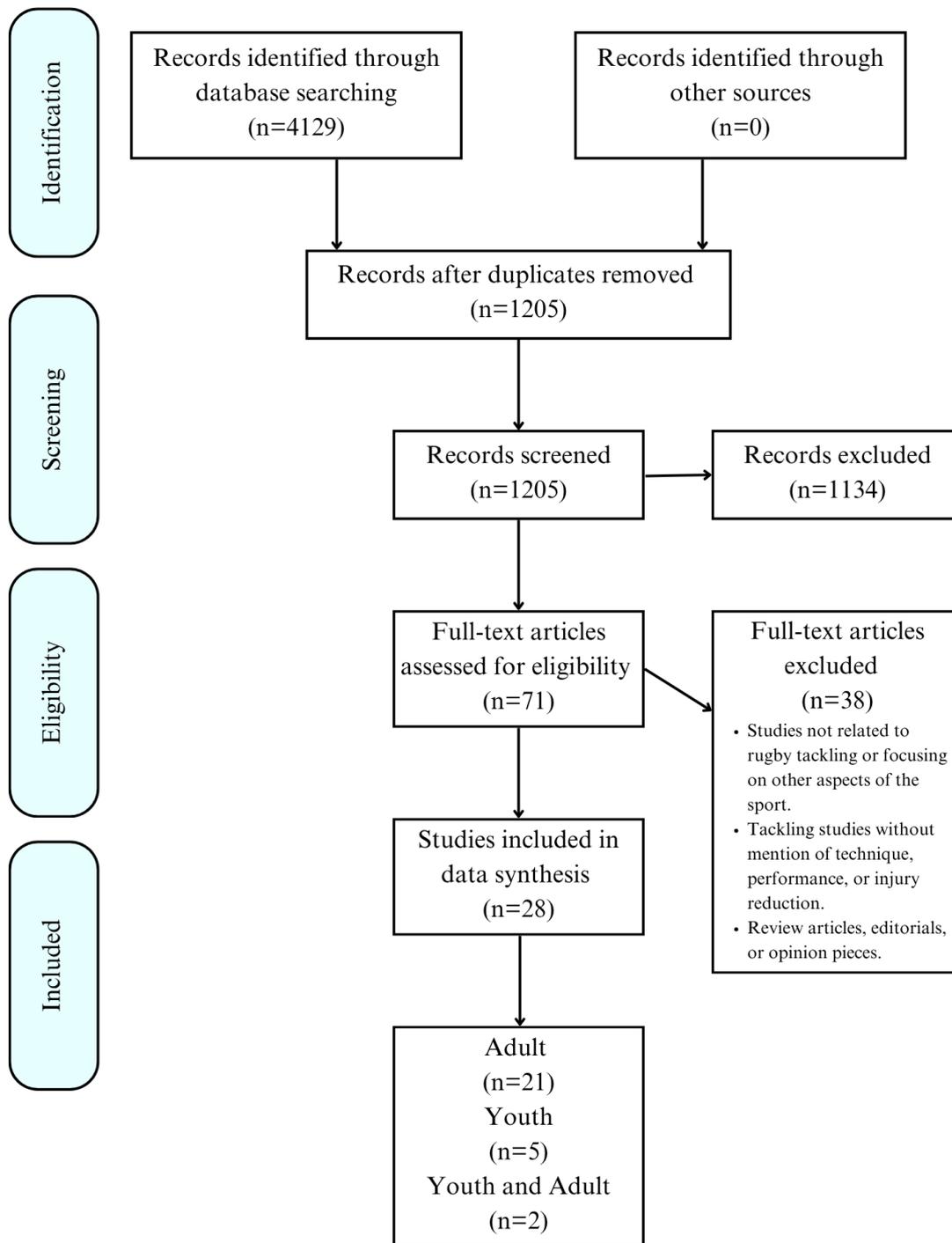


Figure 2. PRISMA diagram adhered to for including articles in this review

2.4.1 Risk of Bias

The scores of each Downs and Black checklist item and the overall quality index for the 28 studies were completed (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 (54, 57). 23 studies were classified as having a moderate risk of bias, with scores ranging from 17 to 19 (16, 18-20, 44, 46, 51, 55, 56, 58, 60-62, 64-67, 69-75). Three studies were categorised as having a low risk of bias, achieving scores of 20 and 24, respectively (5, 63, 68). The highest methodological score recorded was 24, indicating that while some studies demonstrated stronger methodological quality, a considerable proportion exhibited a moderate risk of bias (Table 1.)

Table 1. Downs and Black risk of bias checklist for 28 included studies (43)

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Total
Ogata et al(54)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	0/0	1/1	0/0	0/0	0/0	0/0	1/1	1/1	1/1	0/0	1/1	1/1	1/1	0/0	0/0	0/0	1/1	1/1	15	
Edwards et al(55)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Edwards et al(56)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/1	18
Parnley et al(57)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	0/0	0/0	0/0	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	0/0	0/0	0/0	0/0	0/1	15
Kawasaki et al (20)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	0/0	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	0/1	17
Edwards et al (18)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	17
Edwards et al(58)	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	0/0	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	17
Gardner et al(59)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Suzuki et al(60)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Suzuki et al(61)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	19
Hendricks et al(62)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Kawasaki et al(19)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Suzuki et al (63)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	1/1	20
Tanabe et al(64)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18

De Hollander et al(76)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Hendricks et al (65)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	17
Sobue et al (44)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Seminati et al(16)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	19
Burger et al(70)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	19
Burger et al(71)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	19
Hendricks et al(51)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	19
Burger et al(46)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Hendrick et al (66)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
King et al (67)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Gabbett et al(72)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Quarrie et al(68)	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	1/1	1/1	1/1	1/1	24
Hendricks et al(69)	1/1	1/1	1/1	1/1	0/0	1/1	1/1	0/0	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	0/0	0/0	18
Kerr et al (73)	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	0/0	1/1	0/0	19
Tucker et al (5)	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	1/1	1/1	1/1	1/1	0/0	0/0	1/1	1/1	0/0	22

2.4.2 Study Characteristics

The studies covered diverse age groups, ranging from youth (U13, U16, U18) (20, 46, 51, 70-73) to adults at collegiate/university (44, 60, 63, 77), amateur (16, 55, 58), semi-professional (16, 58) elite and professional levels (5, 18-20, 54, 56, 57, 59, 62, 64-69, 75, 78). Tackle events studied varied greatly, from smaller samples of 66 tackles (19) to extensive studies involving up to 140, 249 tackles (68). Twenty-six studies exclusively examined male rugby players with only two studies including both male and female participants(54, 73). Data collection primarily utilised 3D motion capture (18, 19, 55, 56, 58, 64, 73), video analysis (20, 51, 57, 59-63, 65-71, 76), accelerometer (54), GPS tracking (57), and pressure sensors (16). Tackle types studied included front-on (5, 16, 18, 19, 51, 55, 57, 58, 63-66, 68, 69, 71, 73, 77-80), side-on (5, 51, 66, 69, 70, 78-80), high (5, 54, 58, 79, 80), middle (5, 54, 58), low (5, 19, 54, 58, 79, 80), dominant and non-dominant shoulder tackles (5, 16, 54, 77), smother(5, 63, 65, 68, 71), jersey grab (5, 63, 65, 68, 71) and collision tackles (5, 63, 65, 68, 71).

Table 2. Characteristics of the 28 Reviewed Studies, Including Demographics (Group, Sex, Age, and Level), Methodology (Duration and Method), and Tackling Variables Studied

Study	Group	Sex	Age (Years±SD)	Level	Duration	Method	Tackle Type
Ogata et al(54)	39 rugby players	36 M, 3 F	22.4 ± 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(55)	15 amateur rugby players	M	24.3 ± 6.1	Amateur	3-hour sessions	3D motion capture	DNRL, SNRL, DTS, SPL
Edwards et al(56)	15 rugby players	M	Adult	Elite	3-hour sessions	3D motion capture	DNRL, SNRL, DTS, SPL
Parnley et al(57)	44 professional rugby league players	M	Adult	Professional	Two matches	Video and GPS analysis	Front-on tackles
Kawasaki et al (20)	1800 rugby players (U18, U22, Elite)	M	U18: 17.4 ± 0.7, U22: 20.8 ± 1.1, Elite: 27.8 ± 3.5	Youth to Professional	60 matches	Video analysis	Tackles categorised by height, direction, and head position
Edwards et al (18)	15 rugby players	M	Adult	Elite	Three hours	3D motion capture	Front-on
Edwards et al(58)	15 amateur/semi-professional players	M	24.3 ± 6.1	Amateur/Semi-Pro	Three hours	3D motion capture	Front-on, ; upper torso, mid torso, lower torso
Gardner et al(59)	446 HIA tackles; 5,694 non-HIA tackles	M	Adult	Professional	Two seasons	Video analysis	Varied
Suzuki et al(60)	340 collegiate rugby players	M	Adult	Collegiate	Five seasons	Video analysis	Varied
Suzuki et al(61)	557 collegiate rugby players	M	18-24	Collegiate	Eight seasons	Video analysis	Varied
Hendricks et al(62)	4,799 tackle events; 1,405 ruck events	M	Adult	Elite	Three tournaments	Video analysis	varied
Kawasaki et al(19)	13 elite rugby players	M	23.8 ± 3.8	Elite	Multiple sessions	3D motion capture	Shoulder Tackle (Normal, Low, Opposite-Leg, Low + Opposite-Leg)
Suzuki et al (63)	402 collegiate rugby players	M	18-24	Collegiate	Six seasons	Video analysis	Front-on/ Arm / Collision / Jersey / Lift / Shoulder / Smother Tackle
Tanabe et al(64)	15 elite rugby players	M	22.3 ± 1.9	Elite	Controlled lab study	3D motion capture	Shoulder / Arm / Head-in-Front Tackle
Hendricks et al (65)	4,479 tackles from elite tournaments	M	Adult	Elite	One season	Video analysis	Arm / Collision / Jersey / Lift / Shoulder / Smother / Tap Tackle
Sobue et al (44)	3,970 one-on-one tackles	M	19.8 ± 1.3	University	Two seasons	Video analysis & survey	Varied
Seminati et al(16)	15 community/university rugby players	M	23.5 ± 5.1	Amateur-Semi-Pro	Lab experiment	Impact Forces- Pressure sensors on bag	Shoulder Tackle (Dominant, Non-Dominant, Moving)

Burger et al(70)	49 tackle-related injuries	M	17.5 \pm 0.6	Youth	Three tournaments	Video analysis	Front-on/side-on
Burger et al(71)	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(51)	10 concussions, 83 non-injury events	M	U18	Youth	Three tournaments	Video analysis	Front-on/Side-on
Burger et al(46)	3,652 youth players	M	U13, U16, U18	Youth	Two tournaments	Injury surveillance	Varied
Hendrick et al (66)	60 tackles from 9 matches	M	Adult	Elite	One season	Video analysis	Front-on/side-on
King et al (67)	80 professional rugby league matches	M	Adult	Professional	One season	Retrospective video analysis	Varied
Gabbett et al(72)	41 junior rugby league players	M	Elite: 16.0 \pm 0.2, Subelite: 15.9 \pm 0.6	Youth elite & sub-elite	Single session	Tackling drill with scoring	Varied
Quarrie et al(68)	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(69)	60 tackles from 9 matches	M	Adult	Elite	One season	Video analysis	Front-on/side-on
Kerr et al (73)	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	Youth, Collegiate & High School	One session/P	Accelerometer and video analysis	Front-on
Tucker et al (5)	464 head injury assessments (HIA) 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

Dominant National Rugby League (DNRL) Smother National Rugby League (SNRL) Dominant, Torso Stick (DTS) Smother, Pop, Lock (SPL) Phase (P)

2.4.3 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 accelerations compared to low tackles, with higher peak head accelerations (27.4g and 27.7g, respectively) compared to low tackles (23.4g) (54). Tackles executed with the dominant shoulder generated lower peak head accelerations ($23.0 \pm 13.7\text{g}$) than those on the non-dominant side ($30.4 \pm 21.3\text{g}$)(54). Five studies assessed tackle severity using the Head Injury Assessment (HIA) protocol, a formalised, multi-stage system developed by World Rugby to manage suspected concussions (5, 51, 59, 70, 79, 80). Proper head positioning, specifically placing the head on the correct side (head-impacting player mean: 0.3, 95% CI: 0.05–0.55; successful tackles mean: 0.8, 95% CI: 0.53–1.0), effective arm usage involving wrapping the arms to grip and compete for possession (head-impacting player mean: 0.3, 95% CI: 0.05–0.55; successful tackles mean: 0.8, 95% CI: 0.53–1.0), and maintaining optimal body posture characterised by a straight back with the centre of gravity forward of the support base (head-impacting player mean: 0.7, 95% CI: 0.45–0.95; successful tackles mean: 0.8, 95% CI: 0.67–1.0) correlated with reduced head injury (HIA) incidence, particularly in correctly executed front-on and lower-body tackles (78). These findings were consolidated in five additional studies (51, 59, 70, 79, 80).

Incorrect head positioning and inadequate tracking of the ball carrier notably increased concussion risk (20, 44, 46, 60, 61, 63). Sobue et al. (2018) reported 31.5 concussions per 1000 tackles with incorrect head positioning compared with 1.1 per 1000 tackles with correct head positioning ($p < 0.01$), reporting a small effect size ($ES = 0.2$) (44). 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 (60, 69). Tackles using smoother techniques reduced tackle breaks by 60% and offloads by 30%, reinforcing the value of technically sound shoulder-first engagement (62). Table 3 shows dominant shoulder tackles consistently exhibited safer shoulder mechanics and lower head accelerations compared to non-dominant shoulder tackles (16, 18, 19, 55, 56, 58, 64).

Positional differences influenced tackle outcomes, with backs typically tackling at higher speeds compared to forwards, correlating with distinctive injury profiles (57, 66, 67, 69). Parnley et al. (57) showed that 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.

Table 3. Biomechanical and injury risk and performance factors of the adult rugby tackle including comparison by tackle type

Study	Tackle Type	Head and Trunk	Shoulder	Impact Forces (kN)	Injury Risk Factors	Key Outcome
Ogata et al(54)	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*			High > Low head acceleration; middle = high for head, but lower trunk acceleration	Lower head acceleration in low tackles; middle tackles more stable for trunk
	D/ND	Acceleration (g) Head = 23.0 (13.7) / 30.4 (21.3) g* Trunk = 12.6 (9.4) / 11.0 (5.4) g*			Higher head acceleration on non-dominant side	Greater neck instability with non-dominant tackles
Edwards et al(55)	D / ND	Angle (°) Trunk = Extension = 16.4 ± 22.2/ 12.2 ± 25.2 - head-up trunk extension on dominant side	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 (20)	Low / Upper body				1.13× higher risk of concussion when tackle was below the hip*	Tackling below the hip in side-on tackles increases concussion risk
	Head-in-front of ball-carrier				Concussion risk 3.93× (front-on), 7.81× (side-on), 5.77× (all)	Head-in-front tackles consistently increase concussion risk across tackle types
Edwards et al (18)	Hip (NRL)/ Midtorso (TS) / Mid/Upper (SPL) / Upper (SNRL)	Acceleration (g) Head = 6.2±2.3 (DomNRL) / 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*			Higher head acceleration in hip-level tackles; upright posture in upper torso tackles increases risk	Midtorso (DTS) and mid/upper (SPL) techniques reduced tackler head acceleration
	D / ND	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*			D tackles showed improved posture and lower head kinematics	D side safer; ND = more head/trunk flexion and risk
Edwards et al(58)	D / ND				Non-dominant side = altered body position, greater forward speed at contact *	ND side slightly less controlled posture
Gardner et al(59)	Low / Upper body				3.2× higher risk of HIA when tackler was upright vs bent*	HIA- Upper
Kawasaki et al(19)	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(16)	D / ND	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°		2.84 (0.74) / 3.40 (0.86)	Dynamic = force and neck flexion; increased risk if posture not controlled	Dynamic tackling generates more load; requires better neck posture to reduce injury risk

Neck= Flexion: 22 / 27*

Quarrie et al(68)	Low / Upper body Front vs Side vs Behind		Injury incidence (per 1000 tackles) Low = 1.8 Upper=0.7 Tackles from behind had 2.2× higher replacement rate than front tackles*	Injury Incidence -Lower - injury risk from tackles made from behind or side vs front-on
Tucker et al (5)	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.

National Rugby League (NRL) Smother National Rugby League (SNRL) Torso Stick (TS) Smother, Pop, Lock (SPL) D (Dominant) ND (Non-Dominant)
(*) = P value <0.05

Table 4 reports 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 (18, 20, 46, 59). For example, head-in-front tackles were shown to increase concussion odds by 3.93 to 7.81 times (20), aligning with broader review findings that improper head and shoulder engagement consistently elevate injury risk (20, 51, 70).

Junior elite players demonstrated higher tackling proficiency than sub-elite players (72, 75). Gabbett et al. (2010) reported success rates of $65.7 \pm 12.5\%$ in elite juniors compared to $54.3 \pm 16.8\%$ in sub-elite players (72). These differences were linked to superior acceleration in 10m 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) (72), reinforcing the importance of physical qualities like leg drive and power in effective tackle execution. This is reflected by the data in Table 4 where non-injury tackles commonly involved same-side shoulder and leg contact, low body position, and full arm wrap traits are more likely present in physically stronger, better-conditioned athletes (72, 75). Further, junior elite players exhibited higher tackling proficiency than junior sub-elite players, with acceleration and muscular power being key performance indicators (72, 75). Kerr et al (2018) demonstrated that video instruction improves tackle technique in novice and skilled youth rugby players with skilled players showing more consistent improvement (73). The most notable differences were found knee flexion in skilled males went from 77.2° pre intervention to 117.6° post and skilled female players: 64.2° pre to 142.9° post* compared with novice players results showing a knee flexion change of males of 65.6° pre to 67.6° post and females 62.6° pre to 87.0° post (73).

Injuries were also more frequent in the final quarter of youth matches, as shown by Burger et al. (46) who reported that 35% of all injuries and 44% of head/neck injuries occurred at this time thus suggesting technique breakdown under fatigue. Analyses emphasised pre-contact positioning, head-up posture, proficient arm wrapping and effective leg drive in reducing injuries and enhancing tackle effectiveness in youth and adults (59-62, 65, 68, 71, 79, 80). In summary, studies consistently demonstrated that better 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 (5, 16, 18-20, 44-46, 51, 54-73, 75-80).

Table 4. Biomechanical and Qualitative Analysis of Youth Rugby Tackling Compared to Adults

Study	Tackle Context	Head and Spine Position / Technique Error	Body Position	Shoulder	Identified Risk Factors	Key Outcome	Comparison with adult studies
Burger et al(70)	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 Hendricks et al. (2015), where non-injury tackles demonstrated better alignment and technique
Kawasaki et al (20)	Head-in-front / Correct	Head-in-front tackles had 3.93–7.81× higher concussion risk 5.77× higher overall risk compared to correct head placement*	Below-hip tackles - injury risk 1.13x 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	Edwards & Gardner (2022) reported higher neck forces and greater head kinematics in head-in-front tackles, supporting Kawasaki et al.'s youth finding of a 3.93–7.81× increase in concussion risk.
Burger et al(46)	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 Gabbett et al. (2010), who found no decline in adult tackle quality across repeated efforts, whereas youth players showed reduced postural control under fatigue. Matches Hendricks & O'Connor (2015) – poor technique raises concussion odds
Burger et al(71)	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 (Gabbett et al., 2010) showed stable tackle technique across fatigue, suggesting better fatigue resilience compared to youth
Hendricks et al(51)	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	Aligned with Edwards & Tucker (2024) – technical consistency reduces injury

Kerr et al (73)	Front-on	Acceleration (g) Head = 29.9G (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)	Kerr et al (73)	Front-on
	Pre/ post intervention	Acceleration (m/s ²) Head +15.4m/s ² (6.88)* Repetitions = -5.24m/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)		Pre/ post intervention
National Rugby League (NRL) Smother National Rugby League (SNRL) Torso Stick (TS) Smother, Pop, Lock (SPL) D(Dominant) ND (Non-Dominant)						
(*) = P value <0.05						

2.5 Discussion

This systematic review synthesises current evidence on rugby tackle biomechanics offering insights that may enhance player safety and performance across youth and adult populations. Tackling is recognised as a fundamental component of rugby and is closely linked to performance and injury risk, most notably concussions and cervical injuries (44). By comparing biomechanical characteristics, including peak velocity, leg drive, head position, trunk, knee and hip angles between youth and adult players, this review identifies potential developmental and technical differences that might influence coaching practices to improve tackle safety and effectiveness.

Four main findings were observed from the reviewed literature: (i) youth rugby players frequently exhibited poorer head positioning, potentially increasing their susceptibility to head and cervical injuries compared to adult players correct head placement, especially head-in-front tackling, appeared to heighten concussion risks, suggesting a need for tailored coaching interventions (20); (ii) adult players generally demonstrated more advanced biomechanical techniques, including greater lower-limb drive, optimal hip and knee flexion and effective upper-body engagement whilst youth players often showed upright postures and limited leg drive which might reflect developmental factors influencing tackle performance and injury risk (72, 75). (iii) Tackles executed with the dominant shoulder typically exhibited safer techniques with lower head accelerations and better stability compared to those with the non-dominant shoulder, highlighting possible benefits from balanced training strategies aimed at bilateral proficiency (78). (iv) Lastly, fatigue appeared to reduce tackling effectiveness, particularly in youth players, potentially exacerbating biomechanical inefficiencies and elevating injury likelihood, indicating the value of conditioning programmes focused on maintaining technique under fatiguing conditions (25, 77). Collectively, these findings support the consideration of

evidence-based, age-specific coaching approaches that integrate biomechanical education with practical skills training to potentially improve player technique and, by extension, tackle success and safety.

2.5.1 Age-Specific Differences in Head Positioning and Injury Risk

Youth rugby players appear disproportionately affected by head and cervical injuries, potentially due to consistently suboptimal head positioning and greater head accelerations during tackle execution (44). A kinematic study of youth rugby players during a front-on tackle found peak head acceleration of 29.9g, which is greater than that reported for semi-professional adult players 6.6g. This greater head acceleration likely increases the risk of cervical injuries and concussion, especially in conjunction with incorrect head positioning (55, 73).

The head-in-front tackling style, whereby the tackler's head is placed in front of the ball-carrier's torso or hips, is identified as a central mechanism contributing to injury (20). Video analysis of 14,809 tackles showed that under-18 players placed their head in front of the ball-carrier in 15.9% of tackles (≈ 159 per 1,000) (20). In contrast, elite adult players did so in only 10.2% (≈ 102 per 1,000), and U22 athletes at 13.7% (≈ 137 per 1,000) (20). Crucially, head-in-front positioning appears to amplify concussion risk across all age groups, yielding 11.3 concussions per 1,000 tackles versus 1.5/1,000 for correct head placement furthermore these tackles had an incidence-rate ratio (IRR) of 3.93-, 7.81- and 5.77-times higher risk for concussions than correct head tackles in the front-on, side-on, and all directions of tackles, respectively (20). Although overall concussion incidence per 1,000 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 do (20), when using this

technique, their per-tackle risk of concussion increases by ~5-8 times, underscoring the need for targeted coaching that eliminates head-in-front tackles at junior levels (20, 79, 80). This discrepancy likely reflects inexperience because youths tend to have accumulated fewer total playing/training hours than adults due to age. Furthermore, there is potential that these findings could 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 (25, 44, 81-83).

Kerr et al. (2017) found that instructional videos significantly improved tackling biomechanics in experienced collegiate players, particularly by increasing knee flexion angles and reducing cervical spine acceleration (73). However, the same intervention paradoxically increased head acceleration in younger, less experienced athletes (73). This contrast may reflect a developmental difference: skilled players are able to integrate video instruction into technically sound movement patterns, including optimal knee flexion, whereas younger athletes appeared to benefit more from physical repetition, suggesting they had not yet internalised key biomechanical cues such as a flexed knee position and spatial tracking of themselves and their opponent (12). 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 (20, 60). Such technical errors frequently co-occurred with ineffective spatial tracking and delayed decision-making, which may reflect underlying developmental constraints in sensorimotor integration (20, 60, 68). Adult players typically adjust their approach and align their heads behind or to the side of the ball-carrier (20, 60). Youth players, however, often fail to do so, exposing themselves to greater impact forces at the neck and head (18, 75). This trend persists even when controlling for tackle height or approach speed, underscoring a gap in execution rather than just physical capacity (18, 75).

Across youth cohorts, the most consistently reported technical error is head-in-front positioning, where the tackler's head enters the ball-carrier's path during contact (20). This pattern is often accompanied by a more upright posture and reduced shoulder-led engagement (18). In contrast, the safer technical model described in the literature places the head up and to the side (or behind the ball-carrier line), maintains visual tracking ("eyes up"), ensures shoulder-first contact, and avoids head-to-knee or head-to-hip contact space (72, 75). In practice, this supports coaching that explicitly targets head-to-the-side placement as a primary technical outcome in youth tackle development.

Considering these findings, targeted coaching interventions should prioritise early and sustained development of safe head placement strategies. It is recommended that tackle training should involve progressive exposure to tackle scenarios that gradually increase in complexity and resemble the demands of competition (84). 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 the requisite sensorimotor control and establish stable, repeatable head alignment habits (84). 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, whole-body context.

2.5.2 Biomechanical Differences Influencing Tackle Effectiveness Between Youth and Adult Players

The included studies highlight 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 upon contact, which are key components of effective technique (72, 75). This likely contributes to the observed lower

tackling proficiency in youth rugby players. 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 (72, 75). During a standardised one-on-one front-on shoulder tackling drill, proficiency scores in junior elite players averaged 65.7%, sub-elite juniors dropped to 54.3%, and adult NRL players averaged 89.3%(72, 75). These differences are associated with acceleration and lower-body power thus reducing tackle success (72, 75). Match context also shapes contact exposure. In rugby league, NRL GPS and video analyses report up to 1.2 collisions per minute, consistent with the 13-a-side format, the six-tackle rule, and a 10 m offside line that encourages repeated one-on-one carries and tackles (85, 86). In rugby union, ruck and maul contests distribute contact across the 15 players, with front and second rows peaking at approximately 0.73 to 0.89 collisions per minute, while backs average about 0.28 to 0.41 collisions per minute (72, 87). These contextual differences suggest that league concentrates contact within ball-carrier to tackler duels more often than union, which diffuses contact through multi-player contests, this could be the reason for higher tackle proficiency scores in rugby league due to the potentially greater tackle exposure in game (72, 87). Maintaining leg drive after contact substantially improved outcomes, yielding a 53% increase in the likelihood of dislodging the ball or forcing a turnover of possession (62). Tacklers who approached contact too slowly or without momentum faced a 43% tackle-break rate (67), emphasising the critical role of movement speed over mere body mass in effective tackle execution (72). Given that rate-of-force development predicts tackle success, the lower force and acceleration capacities typical of younger athletes limit collision momentum and post-contact drive; as a result, they are more often driven upright or backward and default to arm-only or head-in-front contacts, which elevate head accelerations and concussion odds (72, 75, 76).

Adult players generally displayed greater hip and knee flexion during tackles, which lowered their centre of gravity and enabled a forward-leaning, braced trunk posture (75, 80, 88). This position is associated with enhanced stability, more effective force sustenance and reduced cervical spine acceleration, contributing to both better performance and safety (69, 73). Kerr et al. (2017) demonstrated that skilled collegiate players, following instructional video interventions, exhibited significantly greater knee flexion angles and reduced cervical spine acceleration than novice players, who failed to replicate these biomechanical adjustments despite receiving the same instructions (73). This suggests that biomechanical proficiency in tackling, particularly in lower-limb flexion, is both a marker and a mechanism of expertise (73). Moreover, Hendricks et al. (2014) identified leg drive and body positioning (e.g., low stance with forward trunk lean) as critical determinants of tackle success, further reinforcing the importance of these physical and technical attributes in skilled performers (89). These biomechanical advantages, however, appear to emerge with experience and physical maturity, suggesting that youth players may lack the neuromuscular control and lower-limb strength required to adopt and sustain such postures under dynamic conditions, such as those encountered during match play. Training should therefore emphasise the practice of these techniques, with less experienced players requiring more repetition to encourage safer technique, improve hip and knee flexion angles, and develop lower limb power. The goal of this activity is to encourage expertise in tackling across all age groups, which is correlated with improved performance and reduced injury.

Furthermore, in another study, youth players often tackled by using an upright body position with reduced flexion of the lower limbs, leading to lower proficiency scores in injury-causing tackles (7.00 ± 1.95 ; 44%) compared to non-injury tackles (9.35 ± 2.56 ; 58%) (70). This biomechanical inefficiency compromises performance and safety, likely due 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 (90). A cluster-randomised controlled trial in schoolboy rugby found that teams performing a thrice-weekly neuromuscular warm-up reduced overall match injuries by 72% and concussion by 59% compared with control subjects (90). Insufficient preparatory movement, such as fewer approach steps before contact, can hinder spatial setup, leading to suboptimal body alignment at tackle contact (44). Tackles made at the hip level resulted in significantly greater head acceleration (27.7g vs. 23.4g), further illustrating the protective benefits of proficient lower limb positioning during tackle 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, both of which are crucial elements for effective tackling (46). This underscores the need for conditioning programmes to improve acceleration, agility, and reactive strength (72).

Shoulder engagement and upper-body techniques further differentiated the two groups of interest in the current review. Adults more frequently executed 'shoulder-first' tackles while youth players more often relied on arm-style tackles or chest-first contact, leading to lower-impact transfers and a higher risk of missed tackles (76). These tackles can increase overall concussion risk by 2.7 times (45). In side-on tackles, under 18 players frequently employed hazardous head-in-front techniques, which can increase concussion risk by up to 7.81 times (20). Head-in-front meant the tackler's head is placed forward and often sustains the initial contact. When this contact is received from harder areas of the ball-carrier's body, such as the knee, elbow or hip, concussions are more likely to occur (20). Conversely, elite adult players more often utilised safer smother-tackle techniques with the head

positioned to the side and the arms fully wrapped, at rates of 29.7% compared to 21.1% in under-18 players (20). These execution patterns illustrate a potential developmental learning curve in skill acquisition, revealing that youth players often lack the biomechanical sophistication and situational awareness required to consistently apply safe and effective techniques over time. Findings highlight the compounded risk posed by suboptimal tackling form in youth rugby, and poor head placement alone can escalate injury rates from 2.7 to 69.4 per 1,000 tackles (44). The combined injury risk and performance deficits become even more pronounced when coupled with reduced leg drive, poor shoulder contact and an upright body posture during a tackle. Consequently, coaches should implement structured, age-specific training programmes focusing on technical development across the entire body, especially in relation to head positioning, shoulder alignment and explosive leg drive, under both fatigued and non-fatigued conditions.

Overall, 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 area (20, 45). Framing the tackle in this way shifts the aim from forceful collision to anticipating the location of the ball-carrier aiming for accuracy and success (20, 45). In elite match play, smother tackles that target the mid-torso and upper arm can increase gain-line success by approximately three to four times (52), and laboratory work shows the same contact height reduces peak tackler head accelerations by about 23% (18). A smother tackle relies on the tackler controlling angle and speed to set a two-arm wrap around the ball and chest (52). It is most feasible when relative approach speed is moderate or when support is present, and it may require briefly absorbing momentum before clamping (52). This makes it potentially safer in certain scenarios, but it is situation-specific and will not be optimal in every tackle context (55). Consequently, multiple tackle types should be taught at the youth level,

with consistent emphasis on the pre-tackle phase across all engagements (55). Given that youth players are still likely to be developing neuromuscular coordination as they grow, controlled-contact scenarios and decision-making drills can help reinforce positive habits under pressure, improve competency, and encourage autonomy. This could result in better reaction times when responding to the ball-carrier, which could improve pre-tackle set-up positions and encourage correct tackle type selection for a given scenario (76). These strategies may lower injury incidence while improving technical proficiency, facilitating safer transitions into the adult game.

2.5.3 Dominant vs. 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 (78). Across adult cohorts, dominant-shoulder tackles compared to non-dominant tackles show safer and more effective mechanics, yielding lower head accelerations (23.0 ± 13.7 g vs 30.4 ± 21.3 g, $p < 0.01$) (18) and higher peak impact forces (2.84 ± 0.74 vs 2.44 ± 0.64 kN) (16). Non-dominant entries display greater neck flexion and lateral bending, and departures from recommended posture are linked to a higher risk of injury and lower tackle success rate (16). Muscle activation patterns revealed greater anticipatory engagement on the dominant side, thus suggesting better neuromuscular preparation (16). These findings could be due to greater coordination, strength, and proprioceptive feedback associated with the dominant limb, and to reduced familiarity or technical control when using the non-

dominant shoulder (16). Coaches should seek to address these asymmetries in shoulder preference through practice, making sure training focuses on tackle mechanics when using the nondominant shoulder with real-time feedback to enhance proficiency and increase symmetry (16, 72, 75).

Although direct youth-adult comparisons of dominant versus non-dominant shoulder tackles are limited, coordination on the practised or dominant side is typically more anticipatory and refined, consistent with experience-dependent neural adaptation (91). The period from 9 to 12 years in boys and 8 to 11 years in girls is considered a sensitive window for coordination because motor pathways undergo rapid myelination and activity-dependent synaptogenesis in response to practice, followed by synaptic pruning in adolescence (91). Skills that are rehearsed during this phase are more likely to be consolidated into efficient, long-lasting neuromuscular patterns (91). Therefore, coaches should incorporate unilateral neuromuscular training within this stage to develop robust patterns on both shoulders, progressing from closed to open tasks and emphasising lead-leg to same-shoulder alignment (45, 91). Such practice may reduce asymmetry-related risk while improving technical proficiency (45, 91).

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 (77). Under fatiguing conditions, non-dominant shoulder tackles display marked deterioration in control, exacerbating adverse joint kinematics and elevating peak head accelerations (25, 77). This trend may be attributed to diminished neuromuscular control, compromised coordination and impaired decision-making processes as fatigue accumulates throughout gameplay (25, 77). This decline in neuromuscular control under fatigue likely reflects reduced motor unit recruitment and firing frequency, particularly in

high-threshold motor units that are critical in driving explosive movement (92). 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 due to weaker cortical representation and less rehearsed movement patterns (92). Consequently, fatigue can significantly amplify the risks associated with non-dominant shoulder tackles, highlighting the necessity for conditioning protocols designed to maintain technical integrity under fatigued conditions (25, 77). Supporting this assertion, the review identified fatigue, performance anxiety, and inexperience as key factors that impair young players' technical execution, especially in open-field play and high-pressure conditions (73). 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. Two studies in youth rugby players observed increased head and neck injury incidence in the latter stages of youth tournaments which they attributed to technical deterioration under fatigue and stress (70, 71). This supports the interpretation that head placement errors in younger players may be partly cognitively linked to their ability to sustain attention during play, particularly later in a game, and that this deficit appears to affect their ability to respond to a stimulus, such as a ball-carrier changing direction. Fatigue appears to increase reaction time and affect biomechanical factors, such as knee and hip flexion, as less time is available to assume these positions and generate the necessary leg drive during the tackle (77).

From a coaching perspective, these findings suggest the need for interventions that explicitly promote proficiency on both dominant and non-dominant sides, bridging the asymmetry gap. Coaches should programme drills that balance shoulder engagement and reinforce correct head placement, with extra repetitions from the non-dominant side and clear success criteria for wrap quality and body alignment. Because fatigue degrades tackle

mechanics, conditioning should reproduce match-like fatigue while protecting technique, for example, constrained small-sided games with tackle quotas, repeated tackle intervals interleaved with short sprints, and controlled contact circuits that keep technical error rates low. A traditional compound lower-body exercise, such as the back squat, emphasising coordinated hip and knee flexion, can be programmed to build strength endurance that supports sustained leg drive: 3–5 sets of 8–12 repetitions at ~60–75% 1RM, with a controlled tempo and 60–90 s rest. This prescription targets local muscular endurance without claiming direct improvement in tackle outcomes and should be paired with contact-specific conditioning that links running demand, entry speed, and tackle execution. Addressing bilateral skill and fatigue-specific constraints in this way is likely to enhance player safety and reduce concussion and cervical injury risk associated with asymmetric or fatigued tackle execution (60, 77).

2.5.4 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. From the 28 studies that met the inclusion criteria, 22 studies were conducted in adult participants (5, 16, 18, 19, 44, 54-69) and only five studies in youth (46, 51, 70-73). One study included both youths and adults (20), and two studies used female participants (54, 73). These trends demonstrate the disparity between the number of studies examining youth and female tackling and those examining adult male tackling. 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.

Despite these constraints, this systematic review offers a robust evaluation of rugby tackling techniques, contributing valuable insights into performance, safety considerations, and coaching strategies for injury prevention. It must be highlighted that the Downs and Black (D&B) tool used for quality assessment may not fully account for domain-specific nuances of cross-sectional or biomechanical studies. In particular, the tool offers limited resolution regarding confounding variables and blinding in experimental biomechanics. Therefore, downs and black scores in this context should be interpreted as broad indicators of methodological soundness rather than as precise measures of risk of bias or internal validity. In conducting this review, every effort was made to synthesise the available data in an unbiased and systematic manner. Nonetheless, as with any review, interpretive bias may still be present, particularly given the limited number of youth-specific studies and the heterogeneity of study designs. Future reviews may benefit from using design-specific quality appraisal tools, such as the Joanna Briggs Institute (JBI) Critical Appraisal Checklists, to provide more tailored quality assessments for biomechanical and observational studies.

2.6 Conclusion

This systematic review evaluated biomechanical differences in rugby tackle technique across age groups, with particular emphasis on youth versus adult performance. Across 28 included studies, adult players consistently displayed better tackle mechanics including greater hip and knee flexion, braced trunk posture, and improved head positioning. These characteristics were associated with reduced head impact accelerations and lower injury risk, reflecting superior neuromuscular control and technical proficiency. In contrast, youth players frequently exhibited elevated cervical spine acceleration, less flexed limb positioning, and

higher rates of head-in-front contact, highlighting developmental and technical vulnerabilities. A particularly key finding was the pronounced asymmetry in tackle technique between dominant and non-dominant shoulders. Dominant-side tackles consistently exhibited safer biomechanical profiles, with lower head accelerations, improved posture, and increased leg drive. These differences were amplified under fatigue, where technical deterioration was more apparent on the non-dominant side. This suggests a need for unilateral technical development and neuromuscular training, especially during sensitive motor learning periods, to prevent any asymmetries in technical execution. Instructional interventions such as video modelling showed promise in improving tackle biomechanics, particularly in skilled or older players. However, younger and less experienced players may respond better to physical repetition than to visual instruction alone, indicating that the developmental stage mediates the effectiveness of coaching methods. Findings also suggest that physical maturity, neuromuscular control, and repeated exposure play key roles in technical acquisition, but few studies directly assessed these factors longitudinally.

Despite the robust synthesis presented, this review was limited by the relatively small number of youth-specific studies, a lack of female representation and heterogeneous study designs. In summary, this review highlights clear biomechanical disparities in tackle technique between youth and adults, and between dominant and non-dominant shoulders. These findings underscore the need for targeted, developmentally appropriate interventions to improve tackle safety and efficacy in young athletes. Future research should prioritise longitudinal studies examining the effects of neuromuscular training, bilateral skill acquisition, and coaching interventions across key developmental stages to reduce injury risk and optimise technical performance throughout the rugby development pathway.

3 Investigating Tackle Kinematics of Amateur Youth Rugby Players Using Theia3D

3.1 Abstract

Introduction: Tackling accounts for over 70% of head impacts in rugby, with improper technique increasing the risk of concussions and cervical injuries. While adult tackle biomechanics are well studied, limited evidence exists on how tackle height and laterality affect posture and safety in adolescent players. This study examines how tackle height and contact shoulder influence trunk, neck, and lower-limb kinematics in youth rugby, with implications for safe and effective skill development.

Methods: Fifteen male amateur rugby players aged 14.86 (0.77) performed tackles under four separate conditions: regular dominant (Reg), low dominant (L), regular non-dominant (RegND), and low non-dominant (LowND) against a tackle bag. Two trials per condition were analysed using eight high-speed cameras and Theia3D markerless motion capture. Linear mixed-effects models assessed differences in joint angles and centre-of-mass velocity across conditions, with post hoc pairwise comparisons and effect sizes reported.

Results: Tackle height and shoulder used significantly altered joint angles at contact. Low tackles increased axial trunk flexion ($\Delta = 16.4^\circ$, $d > 1.5$) and neck flexion ($\Delta = 7.1^\circ$), while LowND produced the largest deviations, increasing trunk segment angle by 29.1° and neck flexion by 10.2° compared to Reg. Hip flexion increased by $\sim 20^\circ$ in low tackles, whereas knee flexion changes were smaller. Approach velocity did not differ meaningfully between conditions. These findings suggest that low and non-dominant tackles shift players into a head-down, flexed body position, which may elevate head impact risk against the knee.

Conclusion: Adolescent rugby players adopt distinct biomechanical strategies when tackling low and on their non-dominant side, producing more flexed trunk and neck angles

without compensatory changes in speed. Coaching should emphasise achieving level change through hip and knee flexion while maintaining trunk control and head-up positioning, alongside bilateral practice to reduce non-dominant collapse. These results provide evidence for refining youth tackle training to balance safety and skill acquisition.

Keywords: rugby tackling; adolescent; kinematics; markerless motion capture

3.2 Introduction

Tackling is the predominant action in rugby that exposes adolescent players to concussion and cervical injuries (5). Chapter 2 of this work synthesised evidence indicating that technique, rather than mere exposure, is the controllable factor for coaches, with three technical features showing the strongest correlations to safer outcomes: head to the side of contact, reduced trunk inclination toward the ball carrier, and sufficient hip flexion angle at the point of contact (72, 75). Tackling accounts for 72% of head impacts in rugby, and the majority of those impacts are sustained by the tackler, which places significant importance on controllable posture at contact (5). Incorrect head placement is a key driver of harm to the tackler, with one study (44) demonstrating that concussions occurred in 31.5 per 1,000 tackles when the head was placed in front versus 1.1 per 1,000 tackles when the correct head position was adopted (44). What is still unclear from the current literature is how these features of tackling execution interact with two typical coaching constraints in youth settings: tackle height and shoulder placement to the side. Additionally, it is unclear whether adolescents exhibit the same kinematic solutions as adults in so-called “real-world” tackling conditions. Differences in loading suggest they may not, since peak linear head accelerations for adolescents in front-on tackles are about 60.3 to 75.1 m/s², equivalent to 6.1 to 7.7 g, whereas semi-professional adult tacklers typically record roughly 4.6 to 6.6 g, depending on tackle instruction (55, 73).

Adolescence brings rapid and non-linear gains in stature and mass, together with potential temporary reductions in coordination and reaction time, with the most acute effects occurring between the ages of ~12 years for girls and ~14 years for boys (31, 93). During this time, 76% of girls and 90% of boys experiencing these large growth spurts have noticeable impairments in coordination, with the most pronounced deficits observed in balance,

proprioceptive control, and reaction time (31). These maturational changes could alter how players organise posture and head position under time pressure (31). Most biomechanical descriptions of tackles come from adult cohorts or from drills that simplify contact scenarios (19). Adult players demonstrate greater trunk flexion angle with low tackles compared with torso height tackles, which can lead to a partial loss of sight of the ball-carrier and increase concussion risk (19). Children may be less constrained by pre-learned tackling habits and could be more likely to achieve level change through greater hip and knee flexion rather than relying primarily on trunk flexion (90). This strategy may support safer low-tackle mechanics by preserving trunk control and visual tracking, although it remains unclear whether children adopt this distal strategy during tackling (90).

Very few studies report 3D kinematics of tackling in rugby, and none presently exist in adolescent players during front-on tackles while manipulating the common constraints that coaches cue in practice. This creates a practical knowledge gap, as coaches often set a lower target to reduce missed tackles and head-to-head collisions (4). However, a lower tackle can increase trunk inclination and bring the head closer to the opponent's knee unless head-to-the-side and torso orientation are well controlled (19). A preference for the dominant shoulder may build confidence and proficiency in execution on the dominant side, yet it can also conceal side-specific deficits that degrade head and trunk posture when task constraints become more demanding (60, 77). Traditionally, a lower incidence of asymmetries when tackling is linked to a lower injury risk, and therefore, these factors may be important to consider in terms of making tackling a safer activity to execute for youth players (60, 77).

In collision tasks, marker-based motion capture can suffer from practical tracking issues because limbs or the opponent can obscure reflective markers and can detach during contact, leading to missing trajectories and trial exclusion (19, 73). For example, two previous

studies examining both youth and adult tackles excluded trials with missing data due to marker obscuration or marker detachment during contact, thereby reducing the usable sample size and potentially biasing laboratory datasets towards “cleaner” impacts, because higher-contact or more chaotic tackle events are more likely to produce occlusion or marker loss (19, 73). Markerless motion capture and AI-based video analytics address key limitations of marker-based systems in collision tasks by estimating 3D pose directly from video (19, 40, 73). This eliminates the need for skin-mounted reflective markers and reduces data loss from marker occlusion or detachment during contact (19, 40, 73). Theia3D is one such markerless motion capture system and has demonstrated close agreement with marker-based systems across tasks such as gait, squatting, and landing, with sagittal-plane joint angles differing by approximately $\sim 3^\circ$ and intraclass correlations exceeding 0.80 in most cases (41). Agreement tends to be highest for hip and knee flexion–extension, with lower reliability observed in transverse-plane variables and ankle joint motions (41).

This chapter addresses the gap in adolescent rugby tackling literature by using markerless motion capture to quantify joint and segmental kinematics in adolescent tacklers across two controlled constraints: target height (regular versus low) and shoulder side (dominant versus non-dominant). The focus is on technique variables that are coachable and observable: hip and knee flexion, trunk inclination and axial rotation at contact, axial neck angle and neck flexion relative to the point of contact and approach velocity. By testing the height and shoulder-side used at contact, it may be possible to determine whether common coaching cues drive the intended postural changes and whether those changes are likely to reduce head-in-danger positions.

3.2.1.1 *Aim*

To determine how tackle height and shoulder side influence key neck, trunk, hip, knee and ankle angles and velocity at the point of tackle contact in adolescent rugby players, and to identify the movement solutions that achieve a lower target without compromising head safety.

3.2.1.2 *Research questions*

RQ1: How do neck, trunk, hip, knee and ankle angles and centre of mass (COM) velocity differ between regular- and low-height tackles at contact? (H1)

RQ2: How does using the non-dominant versus the dominant shoulder alter neck, trunk, hip, knee and ankle angles and COM velocity at contact? (H2)

RQ3: Does shoulder contact above or below the hip and dominant or non-dominant side interact, and if so, which combination produces the most favourable head and trunk angles? (H2)

3.2.1.3 *Hypotheses*

H1: Low-height tackles will result in greater hip flexion and increased trunk segment flexion angles at contact, with small or no change in knee flexion angle, and without a meaningful change in approach velocity, compared to regular height tackles.

H2: Using the dominant shoulder will increase axial trunk rotation angle away from the point of contact and axial neck angle away from the point of contact, compared to non-dominant tackles. The largest trunk and neck angle change will occur when a low height is combined with the non-dominant shoulder, compared to a regular height with the dominant shoulder.

3.3 Methodology

3.3.1 Participants

A total of 15 male amateur rugby players aged 12 to 18 years were recruited from rugby clubs local to the University of Essex in Colchester, England, between December 2024 to March 2025. This study was approved by the University of Essex's Human Research Committee (ETH2425-0702). Although a sensitive coordination window is often described as ~12 years for males, this study focused on ages 12 to 18 years because adolescence combines rapid maturation-related changes in size and strength with a step-up in contact exposure and intensity, which may alter tackle mechanics and increase the consequences of poor posture (91). This age band encompasses the key period when tackle technique is coached and consolidated in age-grade rugby, making it the most relevant group for translating biomechanical findings into practice.

The sample size was based on a previous study that examined tackle kinematics and reported significant differences in trunk inclination between normal and low tackles (19). An *a priori* power analysis was conducted in G*Power 3.1 for a within-participant 2 × 2 design (tackle height and contact side), using an effect size of $f = 0.81$ reported from previous adult rugby tackle trunk flexion change from a low to a regular tackle (19). This indicated a minimum of 8 participants to achieve a power of 0.8 at an alpha of 0.05. To account for two trials per condition and an assumed intraclass correlation coefficient (ICC) of 0.30, plus 10% potential attrition, the target sample was increased to 15 participants. All participants were playing for an amateur or semi-professional rugby academy at the time of testing. Characteristics recorded included age, height, weight, playing frequency, player age, and dominant shoulder for tackling, as detailed in Table 5.

The inclusion criteria required participants to be male rugby players aged ≤ 18 years who actively participated in at least one rugby training session per week. Exclusion criteria included any current musculoskeletal injuries, a history of concussion or head trauma within the six months prior to testing, neurological disorders affecting motor control or balance, cardiovascular conditions that contraindicate moderate physical exertion, diagnosed psychological conditions that may be exacerbated by participation, or prior musculoskeletal or neurological surgery (within the previous six months).

Table 5. Participant Characteristics (n=15)

Characteristics	Mean (SD)
Age (years)	14.86 (0.77)
Height (cm)	171.87 (9.23)
Weight (kg)	72.20 (12.41)
Playing Frequency (hr/week)	3.55 (1.57)
Player Age (years)	5.58 (2.44)
Dominant Side	Left = 2, Right = 13

Dominant side = preferred shoulder to tackle with

3.3.2 Study Design

This study employed a field-based, cross-sectional design. Participants performed four types of tackles: Regular Dominant Shoulder (Reg), Low Dominant Shoulder (Low), Regular Non-Dominant Shoulder (RegND), Low Non-Dominant Shoulder (LowND). Each participant completed two trials of each tackle type, totalling eight tackles per participant. Tackle types were randomised for each participant. Participants performed one practice tackle before each condition to ensure safety and adherence to instructions.

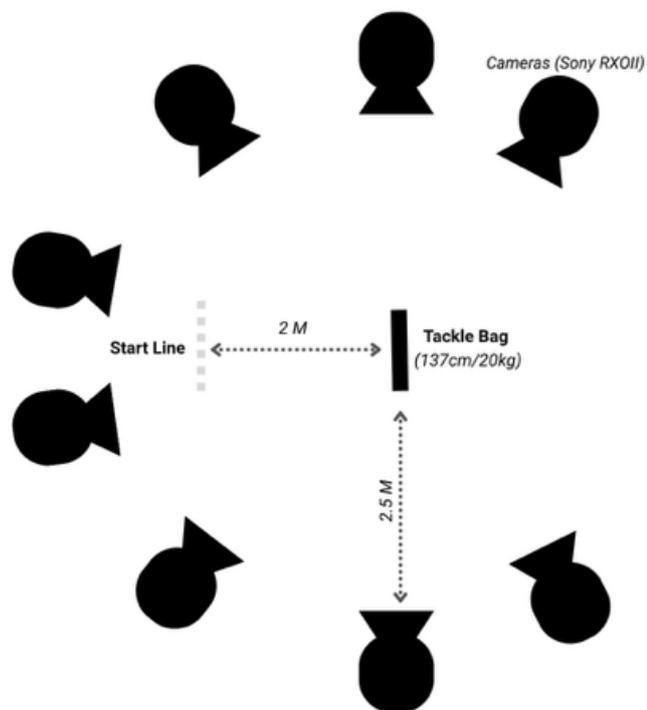


Figure 3. Camera Configuration for Tackle Assessment Protocol

3.3.3 Equipment

Before each recording session, the researcher (H.E.) prepared and calibrated the experimental setup. The hardware configuration employed for data acquisition in each session was standardised and consisted of the following components:

1. Video Capture: Eight Sony RX0 II video cameras (Model: DSC-RX0M2G), powered by sixteen Sony NP-BJ1 rechargeable Li-ion batteries.
2. Camera Control: Eight corresponding Sony CCB-WD1 Wired Control Boxes.
3. Mounting: Eight Libec TH-X Tripod Systems to ensure stable camera positioning.
4. Cabling: Eight rolls of Matrix CAT6 shielded twisted pair (SF/UTP) cable (4PR/23AWG, dual sheath LSOH/PVC) for signal transmission.
5. Networking: One NETGEAR MS510TXPP Smart Switch to interconnect all hardware components.
6. Calibration Target: One rectangular chessboard, supplied by the Theia manufacturer, used for extrinsic camera calibration procedures.
7. Control & Monitoring: One laptop computer that served as the central control interface for the system (ASUS ROG Strix G18, RTX 5070.)
8. Tackling Trial: Tackle Bag and Crash Mat

Each camera was connected to its corresponding control box (Sony CCB-WD1 Wired Control Boxes.), which was mounted on a tripod at a height of approximately 1.65 m above the ground surface (Figure 3) (94). To ensure synchronisation, all eight control boxes were then connected to the switch via network cables. The switch was linked to the laptop, which functioned as the primary control unit. The entire data capture session was managed through a browser-based interface, accessed on the laptop using the Google Chrome browser via a

manufacturer-provided IP address. Video data were acquired at 1280×720 pixels and 120 frames per second (fps).

The first procedural step was the extrinsic calibration of the multi-camera system using the manufacturer-supplied chessboard. The Theia software's algorithm identified the blue squares on the chessboard to automatically establish the origin and orientation of the global coordinate system. Following a successful calibration, the tackle assessment protocol would begin.

3.3.4 Tackle Assessment Protocol

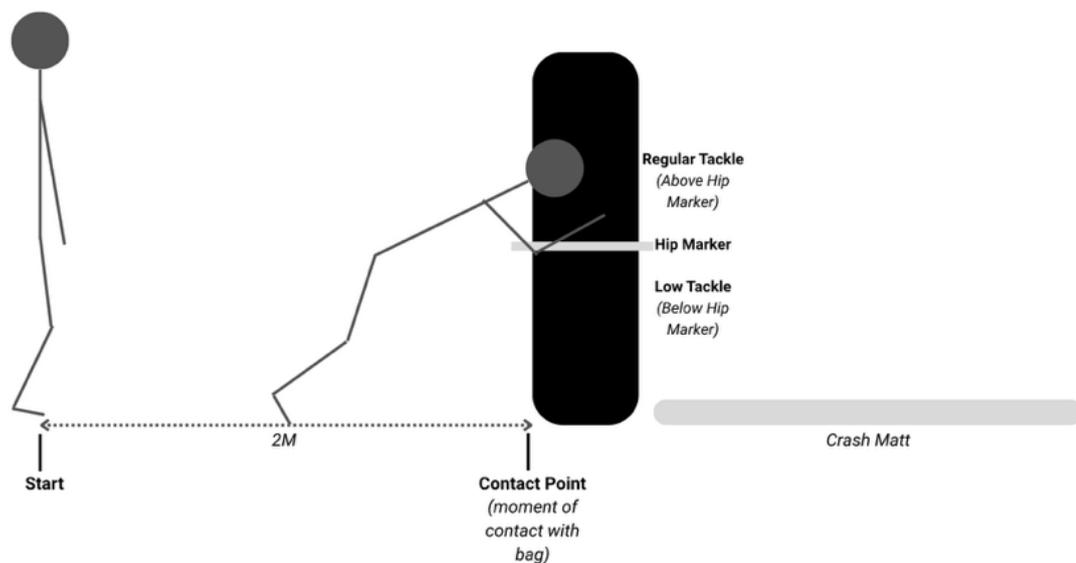


Figure 4. Tackle Assessment Protocol Set-Up

Participants' height (cm) and body mass (kg) were recorded before testing. The participant then stood next to the bag whilst the researcher attached a marker to the bag at the participant's hip height, which was clearly visible. For each tackling trial, the participant had a 2 m run-up for four tackle conditions with two repetitions of each (Figure 4). The

condition order was randomly assigned by the researcher using a randomiser (OpenAI. (2025). ChatGPT [GPT3o]). Each tackle type was repeated twice for a total of eight tackles per participant. The dominant shoulder was defined as that which the participant identified as being their preferred one to tackle with. After each trial, participants rested until they felt recovered, then repeated the same tackle type for a second attempt. Immediately before each attempt, the investigator delivered standardised verbal instructions. For the regular condition (Reg), participants were told: “Approach the bag with a low, stable posture; lead with your dominant shoulder; wrap both arms around the bag while driving forward with the legs; make contact above the hip marker; keep the head positioned to the side of the contact.” For RegND, the script was identical except “lead with your non-dominant shoulder.” For Low, the script was identical to Reg except “make contact below the hip marker.” For LowND, both modifications were applied, that is, non-dominant shoulder and below-hip contact, with all other cues unchanged.

3.3.5 Biomechanical data processing

Video data were processed using Theia3D (Theia Markerless Inc., Kingston, ON, Canada; v2022.1.0.2309) to generate each participant’s full-body model, which was exported as C3D files and imported into Visual3D (v5.02.30; C-Motion, Germantown, MD, USA) for kinematic processing and variable extraction. Segment angles were used to describe the orientation of a segment relative to the global laboratory frame, whereas joint angles described the orientation of a distal segment relative to a proximal segment. Time-series angles were calculated using Cardan/Euler angles with a sagittal (flexion–extension), then frontal (lateral flexion), then transverse (axial rotation) rotation sequence, and a single value for each variable was extracted at the moment of initial contact with the tackle bag. In total, 13

dependent variables were extracted: trunk segment flexion, trunk segment lateral flexion, trunk segment axial rotation; trunk joint flexion, trunk joint lateral flexion, trunk joint axial rotation; neck joint flexion, neck joint lateral flexion, neck joint axial rotation; hip flexion; knee flexion; ankle dorsiflexion and COM forward velocity. For all flexion variables, flexion was positive and extension negative, dorsiflexion was positive and plantarflexion negative; for frontal- and transverse-plane trunk and neck variables, values were side-normalised so that motion towards the contact side was coded as positive and motion away from the contact side as negative, to allow pooled interpretation across tackle sides. COM velocity was positive in the anterior (forward) direction and negative in the posterior (backward) direction.

3.3.6 Statistical analysis

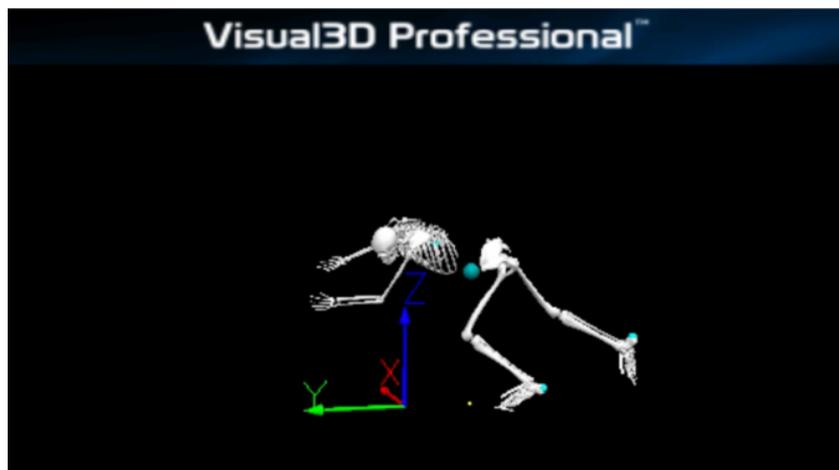


Figure 5. Visual 3D Kinematic Model of the Rugby Tackle

Descriptive data are reported as mean \pm one standard deviation (SD). In total, there were 13 dependent variables as mentioned in the previous section. The independent variable was tackling type with four levels (Reg, Low, RegND, LowND). For each dependent

variable, a linear mixed-effects model with tackle type as a fixed effect and a subject-specific intercept as a random effect to account for repeated measures within participants. Residuals were inspected visually to verify approximate normality and homoscedasticity. When the fixed effect was significant, we performed pairwise comparisons between tackle types with a Bonferroni adjustment to control the familywise error rate. For each contrast, t , degrees of freedom, P , and F computed were reported from the mixed model. Effect sizes for post-hoc contrasts were expressed as Cohen's d with 95% confidence intervals, interpreted using conventional thresholds of 0.2 (small), 0.5 (medium), and 0.8 (large) (95). All analyses were conducted in R (v4.3.3) within RStudio (2025.05.1+513) using lme4 (v1.1-35.1)(96), lmerTest (v3.1-3)(97), emmeans (v1.8.8)(98), and the easystats (99) ecosystem for estimation, diagnostics, and reporting.

3.4 Results

3.4.1.1 Trunk Segment and Joint

Figure 6 illustrates the 3D trunk segment angles across dominance and tackle height. Tackling type had a significant effect on trunk segment flexion angle ($F(3, 103.39) = 108.90, P < .001$). Trunk segment flexion was greatest in the LowND condition, which was significantly greater than Reg ($t(106.36) = 14.39, P < .001, d = 3.76, 95\% \text{ CI } [3.03, 4.49]$) and RegND ($t(106.36) = 13.05, P < .001, d = 3.41, 95\% \text{ CI } [2.71, 4.11]$). The Low condition also produced significantly more trunk segment flexion angle than Reg ($t(106.56) = 11.56, P < .001, d = 3.14, 95\% \text{ CI } [2.45, 3.83]$) and RegND ($t(106.56) = 10.27, P < .001, d = 2.79, 95\% \text{ CI } [2.12, 3.45]$). These results show that low-tackle instructions prompted greater trunk segment flexion angle, regardless of shoulder dominance. Tackling type had no significant effect on trunk segment lateral flexion angle ($F(3, 103.37) = 2.30, P = 0.081$). However, tackling type did

have a significant effect on trunk segment axial rotation angle ($F(3, 105.31) = 3.76, P = 0.013$), driven by greater rotation in Reg compared with Low ($t(108.25) = 3.10, P = 0.015, d = 0.84, 95\% \text{ CI } [0.29, 1.39]$).

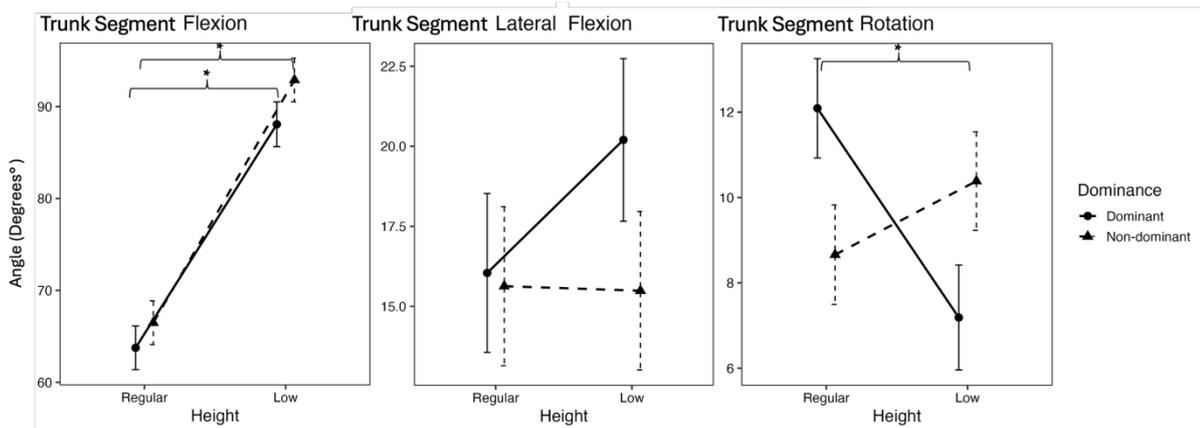


Figure 6. Average Trunk Segment Angles with Standard Error Bars in Degrees ($^{\circ}$) for Rugby Tackle contact in Flexion, Lateral Flexion and Axial Rotation

* = Statistically significant differences ($P < 0.05$)

Abbreviation: LND; Low Non-Dominant, L: Low, RND: Regular Non-Dominant, R: Regular

Tackling type had a significant effect on trunk joint flexion angle ($F(3, 100.03) = 37.91, P < .001$). LowND produced significantly greater trunk joint flexion than Reg ($t(100.36) = 8.75, P < .001, d = 2.25, 95\% \text{ CI } [1.56, 2.94]$) and RegND ($t(100.36) = 7.93, P < .001, d = 2.04, 95\% \text{ CI } [1.35, 2.73]$), while the Low condition was also greater than Reg ($t(100.59) = 6.73, P < .001, d = 1.80, 95\% \text{ CI } [1.08, 2.52]$) and RegND ($t(100.59) = 5.94, P < .001, d = 1.59, 95\% \text{ CI } [0.87, 2.31]$). Trunk joint axial rotation showed no significant effect ($F(3, 100.04) = 1.95, P = 0.127$). However, trunk joint lateral flexion angle was significantly affected ($F(3, 100.04) = 7.88, P < .001$), with RegND greater than Low ($t(100.74) = -4.53, P < .001, d = -1.21, 95\% \text{ CI } [-1.93, -0.49]$) and LowND ($t(100.45) = -3.58, P = 0.003, d = -0.92, 95\% \text{ CI } [-1.61, -0.23]$), indicating more lateral lean when tackling upright from the non-dominant side.

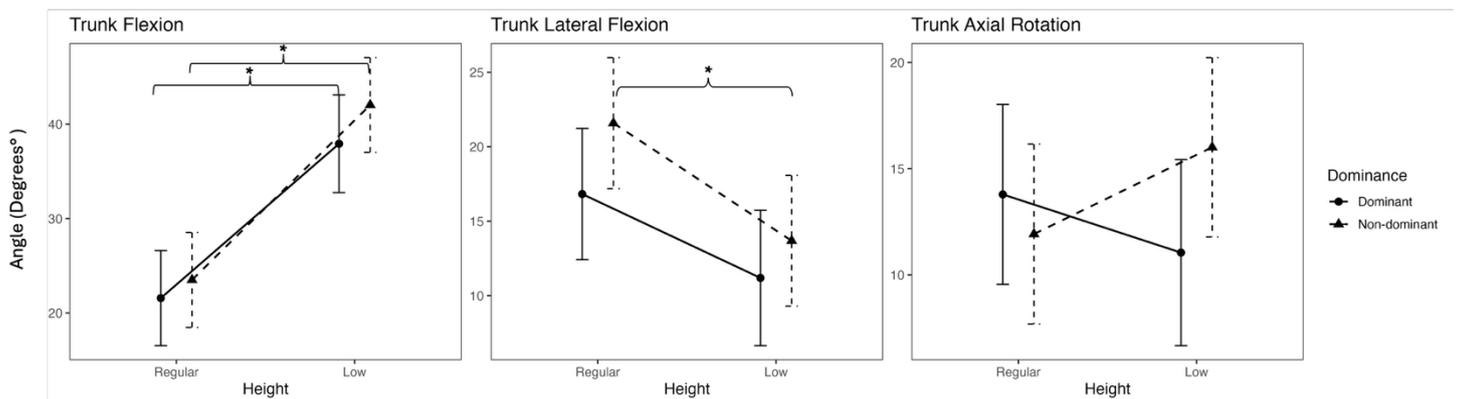


Figure 7. Average Trunk Angles with Standard Error Bars in Degrees (°) for Rugby Tackle Contact in Flexion, Lateral Flexion, and Axial Rotation

* = Statistically significant differences ($P < 0.05$)

Abbreviations: LND; Low Non-Dominant, L; Low, RND; Regular Non-Dominant, R; Regular

3.4.1.2 Neck Joint

Tackling type had a significant effect on neck joint flexion angle ($F(3, 100.02) = 12.05$, $P < .001$). LowND produced significantly greater neck flexion than RegND ($t(100.23) = 5.06$, $P < .001$, $d = 1.30$, 95% CI [0.61, 2.00]) and Reg ($t(100.23) = 4.61$, $P < .001$, $d = 1.18$, 95% CI [0.49, 1.88]); Low also exceeded RegND ($t(100.39) = 3.53$, $P = 0.004$, $d = 0.94$, 95% CI [0.22, 1.66]) and Reg ($t(100.39) = 3.09$, $P = 0.015$, $d = 0.83$, 95% CI [0.11, 1.55]). Neck joint axial rotation angle showed no significant effect of tackling type ($F(3, 100.06) = 0.30$, $P = 0.827$). However, neck joint lateral flexion angle was significantly affected ($F(3, 100.09) = 9.11$, $P < .001$). Reg produced greater side bending than Low ($t(101.66) = -4.53$, $P < .001$, $d = -1.21$, 95% CI [-1.93, -0.49]) and LowND ($t(101.02) = -3.97$, $P < .001$, $d = -1.02$, 95% CI [-1.71,

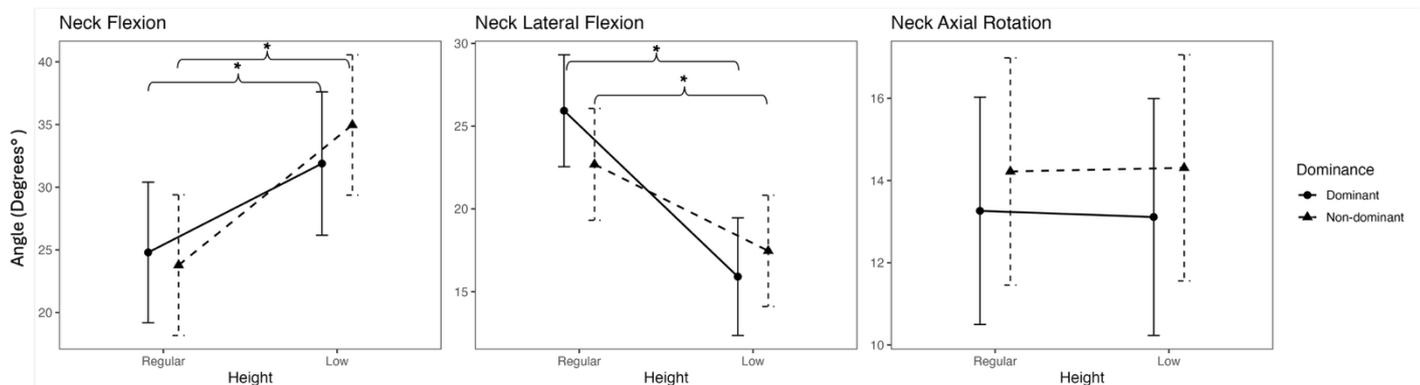


Figure 8. Average Neck Angles with Standard Error Bars in Degrees ($^{\circ}$) for Rugby Tackle Contact in Flexion, Lateral Flexion and Axial Rotation

* = Statistically significant differences ($P < 0.05$)

Abbreviation: LND; Low Non-Dominant, L: Low, RND: Regular Non-Dominant, R: Regular

-0.33]), while RegND was also greater than Low ($t(101.66) = -3.07, P = 0.017, d = -0.82, 95\% \text{ CI } [-1.54, -0.10]$).

3.4.1.3 Ankle, Knee and Hip Joint Angles

Tackling type had a significant effect on non-dominant (ND) hip angle ($F(3, 100.05) = 2.72, P = 0.049$) and dominant (D) hip angle ($F(3, 100.03) = 3.96, P = 0.010$), although no adjusted pairwise differences were statistically significant. Tackling type had no significant effect on ND knee angle ($F(3, 100.04) = 2.69, P = 0.050$), D knee angle ($F(3, 100.04) = 2.48, P = 0.066$), ND ankle angle ($F(3, 100.09) = 1.35, P = 0.261$), or D ankle angle ($F(3, 100.06) = 0.96, P = 0.416$), suggesting no consistent changes in joint angle patterns across conditions for these segments.)

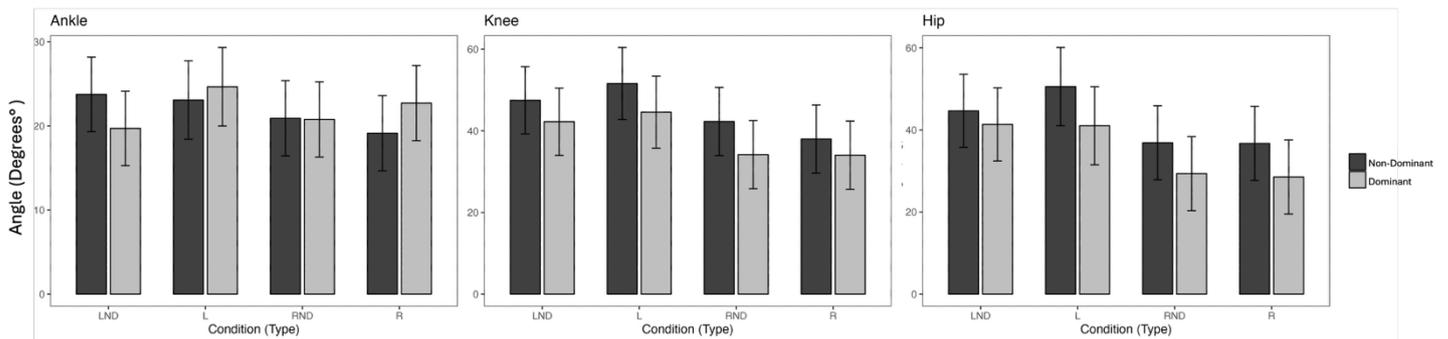


Figure 9. Average Flexion Angles with Standard Error Bars in Degrees ($^{\circ}$) for Rugby Tackle Contact in non-dominant and dominant Ankle, Knee and Hip.

Abbreviation: LND; Low Non-Dominant, L: Low, RND: Regular Non-Dominant, R: Regular

3.4.1.4 Centre-of-Mass Velocity

Tackling type had no significant effect on COM velocity ($F(3, 100.07) = 0.98, P = 0.406$), and no pairwise differences were significant, indicating approach speed remained constant across all tackle types.

3.5 Discussion

The present study examined how two common practice constraints, target height and shoulder dominance, influence 3D tackling kinematics in adolescent rugby players. In partial support of our hypothesis, lowering the target shifted adolescents toward more flexed trunk and neck joint angles at contact, while any additional effects of using the non-dominant shoulder were small, with the largest deviations observed when both constraints were combined. Trunk segment/joint flexion angle increased most in the LowND condition, which aligns with the biomechanical goal of achieving a lower contact point by bending through the hips and trunk. Approach speed did not differ significantly between conditions, providing no evidence that players changed speed to achieve the posture changes. Bilateral differences between Reg and RegND, and between Low and LowND, were small ($d = 0.08$ – 0.12), suggesting minimal asymmetry at this developmental stage. This may reflect an undeveloped lateral bias, offering a coachable window to promote bilateral tackle proficiency before long-term habits form through accumulated repetitions and unilateral cueing.

Adolescents performed the low tackle primarily by increasing trunk segment flexion, trunk joint flexion, neck joint flexion, and hip flexion at contact, particularly when approaching from the non-dominant side. Neck flexion increased when the target height was lowered. This may be due to adolescents adopting a more proximal movement solution at the instant of

contact. Rather than consistently increasing lower-limb-driven level change at contact, some players met the low target by flexing through the trunk, which often couples with increased cervical flexion as the head follows the trunk. This interpretation is also sensitive to event timing, as lower-limb lowering may occur earlier in the approach and may not be fully reflected at the contact frame. This partly aligns with adult tackle-bag studies reporting that low tackles are characterised by greater trunk joint flexion at contact (19, 58). A more flexed trunk and neck posture may make it harder to sustain an eyes-up, head-up position under live-contact demands, increasing the likelihood that the head enters hazardous space (contact with the knee or boot), which has been associated with higher head-injury risk during tackle events (80). However, laboratory evidence also indicates that more distal mechanics can support low contact and that the relationship between technique change and head loading may differ by cohort (73). A previous laboratory study using marker-based optical motion capture examined whether coaching information or repetition changes tackle mechanics and head loading during front-on, tackle-bag contacts (73). Participants first completed three baseline tackles, then viewed the World Rugby Rugby Ready instructional video, which cues contact below the hip (towards the thigh), before completing three further tackles; fixed-effects modelling was used to separate the effect of video instruction from attempt-to-attempt repetition (73). In skilled collegiate players, video instruction was associated with increased knee flexion (40.4°) and a mean reduction in peak head linear acceleration (51.8 m/s^2), whereas repetition was associated with a mean increase in linear acceleration (11.2 m/s^2). In less experienced high school players, the video was associated with a mean increase in peak head linear acceleration (15.4 m/s^2), while repetition was associated with a mean decrease (5.2 m/s^2) (73). Relative to that evidence, the present adolescents showed a more proximal strategy at the contact instant, with no clear increase in

knee flexion at contact, or change of COM velocity from reg to low tackles, which suggests that the mechanics underpinning level change, and their links to head loading, may not transfer uniformly across populations and contexts.

Interpretation is also sensitive to the timing of kinematic sampling within the tackle sequence. One previous lab study using optical motion capture, in adult rugby players, demonstrated that pre-contact posture can meaningfully shape contact posture in tackle-bag trials (19). Greater contralateral trunk axial rotation and greater hip abduction measured pre-contact were associated with a more downward trunk posture at contact, which is biomechanically consistent with greater trunk joint flexion at contact (19). Applied to the present study, this supports a measurement-based explanation for the absence of a knee-flexion effect at the contact instant: adolescents may adopt a lower-limb-level change strategy earlier in the approach, which is not captured when only contact-instant angles are analysed. Future youth work should therefore quantify a pre-contact window alongside contact-instant kinematics, and cohort-based explanations should remain cautious because maturation status, strength, and coordination were not assessed (100, 101). Collectively, these findings indicate that the relationship between knee flexion and head loading may be context- and cohort-dependent; coaching should therefore avoid assuming that increased knee flexion at contact will always reduce head acceleration, and instead prioritise achieving level change through the lower limbs while checking that trunk control and head position are maintained in the specific population being trained.

A previous instrumented-mouthguard cohort study in community rugby reported that U13 players accrued a larger proportion of their weekly head-acceleration events during training, whereas U19 players were more likely to experience higher-magnitude events during matches, where higher-magnitude refers to events above 30 g peak linear acceleration (102).

This context is relevant to the present tackle-bag findings because lowering the target height increased trunk joint flexion and cervical flexion at contact, a configuration that may make it harder to sustain an eyes-up, head-up posture as contact intensity increases in later age grades (102). Technique selection and contact location provide additional context for how head loading can change at a similar tackle height. A controlled laboratory study in adults simulating one-on-one tackle scenarios using 3D motion capture showed that a shoulder-led smother tackle executed with a more upright trunk and a vertical thrust reduced peak head acceleration compared with a traditional upper-torso hit, and that contacting the mid-torso resulted in lower tackler head acceleration than contacting the lower torso (18). Taken together, these findings support coaching progressions that first consolidate a consistent tackle shape, defined here as level change through hip and knee flexion with stable trunk control and head-to-the-side, eyes-up positioning, before increasing approach speed and introducing higher-magnitude contact exposures (18, 102).

At regular and low tackle height, the non-dominant side produced similar trunk, neck, in flexion and lateral flexion and lower limb in flexion, indicating no effect of limb dominance. The primary driver of posture in these trials was target height rather than shoulder dominance. Adult studies typically report a preference for one shoulder, as reflected in success rates and contact characteristics, rather than a consistent change in trunk flexion between sides (7). The contrast between adult and youth nondominant/dominant tackles suggests that strong lateralisation develops with age and exposure, although the present data cannot identify the mechanism. Taken together, the results indicate that adolescents show limited side-to-side kinematic bias at both regular and low heights. However, minor dominance effects cannot be ruled out, given the sample size and the variability typical of adolescent movement. Overall, this interpretation aligns with developmental research

showing that during adolescence, coordination and balance skills continue to improve, and many young athletes display mixed-laterality profiles in complex movements rather than fixed one-sided dominance (103). This lack of asymmetry is favourable because it suggests a coachable window to consolidate bilateral tackling proficiency before the stronger shoulder preference and lateralisation typically observed in adults becomes entrenched (7, 103).

The near symmetry between the shoulders is potentially an important coaching opportunity to help retain this kinematic characteristic into adulthood. Coaches could use this window to build bilateral proficiency before one-sided habits emerge, and may consider training it during early adolescence, given the likely sensitive period for the development of coordination between the ages of 8 and 12 years (26). From ~14 years, most boys experience rapid growth leading to substantial size and ability mismatches within rugby squads (31, 93). During this phase, full-speed collisions could be reduced in favour of prioritising bilateral tackle practice that preserves technique shape under low-target conditions, especially on the non-dominant side. This prioritises motor competency during periods when athletes may be more vulnerable due to their developmental stage. Only once biomechanical shape is consistently maintained can acceleration and contact intensity be built, which is likely to yield durable gains in both tackle success and safety as players advance (102).

3.6 Limitations

The present study used tackle-bag trials at fixed target heights, which improves experimental control but limits ecological validity. In the present models, target height explained posture far more than shoulder side, with only a small side effect at low targets; this may partly reflect the absence of evasive ball-carrier behaviour and the simplified interaction constraints of bag-based tackles. In live contact, ball carriers can adapt their movement in

response to the tackler, which may in turn alter the tackler's positioning at contact (58). A further limitation is that angles were extracted at the contact instant, which may not capture pre-contact strategies, such as peak knee or hip flexion occurring earlier in the approach. Future research should therefore examine a pre-contact window (for example, two steps before contact and the final step) in addition to contact and use a live-opponent design with objective speed measurement (for example, timing gates) and wearable sensors (for example, IMUs) to quantify approach speed and lower-limb actions under more representative conditions.

Additionally, only two trials per condition were analysed, which may reduce sensitivity to small dominance-related effects and increase the influence of trial-to-trial variability. Finally, the sample comprised adolescent males (14.86 ± 0.77 years) from a single pathway, limiting generalisability across earlier developmental stages, including the proposed sensitive period for coordination development around 8 to 12 years and periods of rapid growth and potential "adolescent awkwardness" (26, 31). Future studies should recruit younger and more diverse cohorts and include functional dominance profiling (for example, bilateral strength and skill assessments) to clarify whether critical periods exist for acquiring robust tackle mechanics across both shoulders.

3.7 Practical Application

In this adolescent cohort, target height was the primary determinant of posture at contact, with lower targets increasing trunk and neck flexion, while shoulder side showed only small effects. Coaching should therefore prioritise *how* players achieve a low contact height, emphasising level change through the hips and knees while maintaining trunk control and an eyes-up, head-to-the-side position as the target lowers. This recommendation follows directly from the present kinematic pattern, where adolescents tended to increase trunk and neck

flexion under low targets, which may be undesirable if it compromises visual tracking or head positioning in live contact.

Physical qualities may also support these technical goals. In junior rugby league, faster sprint acceleration has been associated with higher tackle-technique scores, with 10 m acceleration showing a moderate-to-large relationship ($r \approx 0.60$) in one cohort (72). While this does not demonstrate causality, it suggests that developing acceleration and lower-limb force production may help some adolescents achieve level change and maintain a stable base for contact without relying on excessive trunk and neck flexion. Practically, this can be integrated through age-appropriate lower-limb strength and power development alongside technical tackle practice. Finally, because side-to-side kinematic differences were small in this sample, coaches may have a useful window to develop bilateral proficiency by practising tackle technique on both shoulders before strong lateralisation emerges with accumulated exposure, as has been reported in adult populations (7).

3.8 Conclusion

Adolescent players demonstrated greater trunk and neck flexion when tackling towards a low target, with the largest deviations occurring when a low target was combined with the non-dominant shoulder. Approach speed remained consistent across conditions, suggesting that any differences are likely due to coordination choices rather than differences in speed. At regular height, side-to-side differences were minimal, indicating potential for developing symmetry. Coaching should focus on cueing depth through the hips and knees while maintaining trunk control and a head-to-the-side, eyes-up position. It should also involve training both shoulders so that dropping height or switching sides does not compromise technique. These findings are based on controlled bag trials and should be cautiously extended to live training and match play; future research should incorporate live ball-carriers

and a larger, more diverse adolescent population to determine if these postural differences lead to safer and more effective tackles across a broader youth group. Overall, the kinematic patterns identified here provide clear targets for technical coaching and the development of progressive contact training in adolescent rugby.

4 Discussion

This research examined tackle ability and tackling kinematics in youth rugby players aged 12 to 18 years, addressing four objectives through a systematic review (Chapter 2) and an experimental kinematic study (Chapter 3). Chapter 2 addressed Objectives 1 and 3 by synthesising evidence comparing youth and adult tackling, identifying the technique characteristics most consistently linked with safer and more effective execution across age groups, and highlighting where age-related differences in posture and mechanics may influence performance indicators. Chapter 3 addressed Objective 2 by quantifying adolescent kinematics across four coached tackle executions in tackle-bag trials, showing that target height was the primary determinant of contact posture, with lower targets increasing trunk and neck flexion angles. In contrast, tackle side showed no meaningful influence on trunk, neck, or lower-limb joint angles at regular height, and only small differences were observed when combined with a low target. Approach speed was similar across conditions, indicating that the observed postural differences were not explained by participants slowing down, but more likely reflect coordination adjustments prior to contact. Together, Chapters 2 and 3 address Objective 4 by outlining actionable coaching recommendations in Table 6.

Table 6. Key Findings from Chapters with Practical Applications

Source	Finding	Practical Implication
Chapter 3: Effect of low height tackles on posture.	Low target tackles increased trunk flexion (~20°), neck flexion (~10°), and hip flexion (~20°). Knee changes were smaller. Approach speed differences trivial to small.	Coach level change via hips and knees while preserving head up and neutral trunk, especially when tackling low.

Chapter 2 & 3: Dominant vs non-dominant side tackling.	At regular and low, dominant and non-dominant tackles were very similar (Chapter 3). Overall imbalance was smaller than reported in adults (Chapter 2).	The present adolescent cohort show low dominant–non-dominant imbalance compared to adults, justifying coaching practice that maintains bilateral proficiency through matched exposure across shoulders.
Chapter 2: Incorrect head placement significantly increases concussion risk.	Head-in-front is a primary mechanism of concussion in youth.	Priority coaching target: eliminate head-in-front across all contexts through head-to-the-side positioning and tracking.
Chapter 2: Smother tackles reduce tackle breaks and improve performance.	Mid-torso, shoulder-first contact with wrap is both effective and safer.	Coach a smother style at youth level to balance efficacy and lower head acceleration exposure.
Chapter 2: Dominant-shoulder tackles show lower head acceleration than non-dominant (in older/adult cohorts).	Laterality is a factor in adults, with greater head acceleration risk on the non-dominant side.	In later years, tackling practice on both shoulders remains essential to prevent adult-like asymmetries from emerging.
Chapter 2: Youth front-on peak head acceleration higher than adults in comparable tackles.	For a given event class, youth can experience greater head loading, especially with poor technique.	Technique quality and exposure management are central for youth safety.

4.1 Research Question 1: How do tackle kinematics vary by age in adolescent to adult rugby players?

Chapter 2 found that, compared with adults, adolescents more often perform regular-height tackles with a more flexed trunk, greater reliance on the arms, and more frequent head-in-front positioning, whereas adults more commonly demonstrate greater hip and knee flexion, shoulder-led contact, and a stronger two-arm wrap (20, 72, 73, 75). This has been linked to improved tackle success and lower head acceleration, although these relationships vary by context and measurement approach (72, 73, 75). Inversely, the head-in-front position, more frequently seen in youths, can increase concussion risk by 5 to 8 fold when compared

with head-to-the-side tackles (20). In low tackles, adults show mixed movement solutions. Some evidence suggests that coaching can increase knee flexion at contact in skilled players, indicating that some adults adopt a more distal lowering strategy at contact, meaning they achieve level change through the lower-limb joints, namely the knee and ankle, rather than through trunk and hip flexion alone (73), while other laboratory studies link lower-target contact with increased trunk joint flexion and hip flexion at contact without a significant change in knee flexion (19). The present adolescent data in Chapter 3 indicate that lowering the target mainly increased trunk and neck flexion at contact, with no significant increase in knee or ankle angles. In adult tackle-bag and match literature, to achieve a lower tackle level change at the knees and hips, increasing flexion with controlled trunk posture is linked to higher tackle success, increased leg drive, and better visibility of the ball-carrier, reducing the risk of contact with the ball-carrier's boot or knee, thus making it safer for the tackler (19, 20, 72, 75). Although these patterns are not observed in all adult tackle studies, they provide a framework for safer mechanics during tackling at low points in both adults and adolescents (20, 72, 75).

In Chapter 3, the tackle side showed a smaller influence than target height at regular height. Dominant and non-dominant trials exhibited similar contact kinematics, whereas the largest postural deviations occurred when a low target was combined with the non-dominant shoulder. Chapter 2 found in adults, non-dominant shoulder tackles often exhibited greater head acceleration, improper alignment, decreased stability and greater shoulder abduction, which has been suggested to explain the increased injury risk on the non-dominant side in adult studies (54, 55). This may indicate that differences between the dominant and non-dominant shoulders were not pronounced in this cohort, suggesting a potential window for coaching to maintain symmetry (72, 75). However, whether such asymmetries strengthen with age or can be altered through coaching requires longitudinal or intervention evidence

(72, 75). Because maturation status and pre-contact kinematics were not assessed in Chapter 3, within-youth age-related explanations remain largely derived from the literature therefore, interpretations of developmental mechanisms should be cautious (25, 26, 73, 77).

Conclusion for RQ1: Evidence across Chapters 2 and 3 indicates that adolescent tackle mechanics differ from those of adults, with youth potentially more likely to rely on a trunk-and-arm dominant strategy and to show less consistent lower-limb-level change at contact, particularly when tackling low (19). In the present study, lowering the target primarily increased trunk and neck flexion, and the largest postural deviations occurred when low targets were combined with the non-dominant shoulder. In contrast, adult literature more frequently associates safer, more effective low-tackling with level changes driven by hip and knee flexion and with controlled trunk posture, although such positions are not documented in all adult studies (19, 20, 72, 75). Therefore, coaches of adolescents should encourage players to adopt lower body positions (lower-limb driven level change while maintaining head position and trunk control) and should develop these patterns bilaterally before a potential favouritism for one side, or another begins to emerge (73, 77).

4.2 Research Question 2: What characterises the biomechanical execution of a tackle in adolescents and what are the coaching implications for improving safety and performance?

One characteristic of adolescent biomechanical execution in tackles, highlighted in Chapter 3, was that it varied most with target height. At regular height, adolescents tended to maintain a more upright contact posture with comparatively less lower-limb level change. However, lowering the target increased trunk and neck flexion at contact, with the greatest postural drift when low targets were combined with the non-dominant shoulder. Chapter 2 provides the benchmark for interpreting these patterns: safer and more effective tackles are

typically characterised by level change driven primarily by hip and knee flexion, head up with the head placed to the side, shoulder-first contact to the mid-torso or hip region, a firm two-arm wrap and continued leg drive (72, 75). Considering that template, the low-target posture used by some adolescents in the study detailed in Chapter 3, characterised by increased trunk and neck flexion without significantly changing knee or ankle angles, might be a less effective approach during low tackles. This position could potentially compromise head stability and trunk control during live contact, even though head impact was not directly measured in the utilised tackle bag task. In line with this interpretation, Chapter 2 explains that head-in-front and arm-only contact actions carry a significantly greater risk of concussion compared to head-to-the-side and shoulder-led contacts with a wrap (20, 45, 54, 62). It also notes that more upright or hip-level entries are associated with higher head accelerations for tacklers than smother-style contacts at mid-torso (20, 45, 54, 62). Chapter 3 found that the largest postural drift during tackling was when a low target was combined with the non-dominant shoulder while switching shoulders at regular height produced minimal change. Approach speed was similar across conditions, indicating that these posture changes reflected coordination adjustments to meet a lower target rather than participants slowing down to adjust to a lower position. Because the task involved a tackle bag, head-to-knee exposure and injury outcomes could not be measured directly. Therefore, any mechanism linking increased flexion to hazardous headspace should be interpreted using match-based evidence rather than inferred from the present data (5).

Practically, the findings of Chapters 2 and 3 are that coaching should focus on how players adopt low body positions, cueing hip and knee flexion to achieve a level change, while monitoring trunk control and head-to-the-side, eyes-up positioning, and then checking that this tackle shape is retained when the target is lowered, and when tackling on the non-

dominant shoulder. Given the minimal side-to-side differences at regular height, training can use matched exposure across shoulders, and task difficulty can be progressed once athletes demonstrate a stable tackle shape, consistent with the principle that practice challenge should be scaled to the current skill level (104). These coaching priorities are underpinned by athletic development (89, 90, 105). The ability to maintain a low, stable tackle shape under increasing collision demands likely depends on lower-limb strength and power, trunk capacity, and neck strength and control (72). Physical preparation can support this technical goal by developing lower-limb strength and unilateral plant-and-drive capacity, alongside trunk and neck isometric strength to support head–torso stability during contact, with load (number, intensity and density of tackles) progressed only once tackle shape is consistently retained at lower targets (89, 90, 105).

Conclusion for RQ2: In adolescents, the biomechanical features most consistently associated with safer tackle execution in the literature include head-to-the-side placement with the head up, level change driven primarily by hip and knee flexion to create a low but controlled posture, shoulder-first contact to the mid-torso or hip region, a firm wrap, and continued leg drive (72, 75). The present experimental findings indicate that lowering target height, particularly when combined with non-dominant shoulder entries, is the constraint most likely to increase trunk and neck flexion at contact. This identifies where tackle shape in youth is most vulnerable to postural breakdown, toward a flexed trunk and neck position that could compromise head-up, head-to-the-side alignment during contact (5). Coaching should therefore prioritise eliminating head-in-front and arm-only contact behaviours, emphasise lower-limb driven level change while maintaining trunk control and head position, and consolidate this tackle shape bilaterally before progressing task demands such as lower targets, higher approach speeds, or greater contact intensity (72, 75, 104).

4.2.1 Limitations

Chapter 2, the systematic review, was constrained by heterogeneity in study designs, populations, and outcome measures, with several included studies relying on video-derived proxies to address technique. Furthermore, both studies focused on front-on, one-on-one tackles, which limits generalisability to the full spectrum of tackle scenarios encountered in match play, such as side-on or multi-player contacts. Neither study assessed fatigue directly, despite its established role in degrading tackle technique late in games. Chapter 3 was also restricted to acute laboratory assessments, rather than capturing in-game or longitudinal adaptations. Finally, both studies were conducted in amateur cohorts, which aligns with the target age group but limits the generalisability of the findings to elite development pathways, where physical and technical profiles may differ substantially.

Chapter 3 employed a controlled tackle bag target rather than a live, moving ball carrier, which limits ecological validity and restricts conclusions about dynamic decision-making and realistic game situations. The absence of a true opponent also precludes potential injury outcomes meaning that safety inferences rely on more well-established correlates, such as head and trunk posture, tackle height, and head acceleration patterns, as identified in the review. The experimental sample was modest in size, consisted only of male players, and was cross-sectional in design, which reduces statistical power and limits the sensitivity to detect finer age-group differences or longitudinal changes over time.

Chapter 3 utilised markerless motion capture, which can have inaccuracies in recording contact scenarios because the pose is estimated from video (106). At contact, self-occlusion and occlusion by the tackle bag, as well as rapid segment reorientation at impact, can reduce tracking accuracy of joints and increase the likelihood of brief tracking dropout or

subtle drift in joint and segment angle estimates.-(106). This is particularly relevant when interpreting small between-condition differences or transverse-plane measures where errors can be proportionally larger (107). While the current dataset was processed successfully, the possibility of an undetected contact-phase tracking error remains which could have affected the actual observed events (106, 107). Future research should enhance camera redundancy and angular coverage around the contact zone by incorporating more viewpoints and decreasing reliance on a single camera. Additionally, it is recommended to use image settings that reduce motion blur and to report trial-level quality control criteria or sensitivity analyses. This will help quantify the robustness of key kinematic outcomes against potential tracking uncertainties during impact.

4.2.2 Future Directions

Future research should prioritise longitudinal designs that follow the same players across adolescence to better capture developmental trajectories in relation to tackle technique. Such work, undertaken in larger samples than the current study, would help to identify precisely when coordination improves, stabilises or temporarily deteriorates during puberty, providing clearer guidance on the optimal windows for targeted coaching. High-fidelity simulations or in-game analyses with live, moving ball carriers are needed to validate the kinematic patterns observed under controlled conditions, particularly the posture breakdowns observed in low- and non-dominant tackles in Chapter 3. Incorporating fatigue protocols would also be valuable, given the review evidence that technical errors increase late in games.

Advancing the measurement of risk is another priority. Instrumented mouthguards and wearable inertial devices should be integrated with motion capture to link tackle

kinematics to head accelerations and injury proxies directly. Training intervention studies are also required to test whether targeted approaches such as bilateral tackling drills, head-placement training, and combined lower-limb and neck conditioning can improve both technique and injury outcomes. Broadening the scope of participants is equally important: the current work focused on adolescent males, but future studies should include female athletes, younger cohorts (i.e., pre-12 years), and elite development pathways to assess generalisability. Taken together, these directions support the development of a progressive, developmentally informed coaching pathway that narrows the youth–adult mechanics gap while prioritising safety.

4.2.3 *Implications for Governing Bodies*

The findings support the need for youth-specific contact guidance that focuses on how tackle height is achieved, rather than generic messaging to “tackle lower”. At an age-grade level, coach education and training frameworks could emphasise observable technical outcomes (head-to-the-side positioning, shoulder-first contact, two-arm wrap, and lower-limb driven level change) and recommend progressive task constraints that scale difficulty (target height, approach speed, and shoulder side) according to competence. While this thesis does not directly quantify injury reduction, it provides mechanistic evidence to inform the design of age-specific tackle coaching resources, certification standards, and staged contact exposure within junior pathways.

4.3 Conclusion

This research aimed to investigate the effect of age on tackle ability and kinematics in amateur rugby players aged 12 to 18, using three-dimensional motion analysis. This was achieved by first synthesising age-related differences in tackle mechanics, technical injury,

and performance risk factors when tackling (Chapter 2) and by quantifying constraint effects in adolescents using three-dimensional motion analysis (Chapter 3). The result of the review appears to demonstrate that, compared with adults, adolescents more often adopt upright posture, arm-only contact, and head-in-front positioning, whereas adults more commonly exhibit deeper hip and knee flexion, shoulder-first contact, and stronger wrap. Target height was the primary determinant of posture, with shoulder dominance being a secondary factor. Lowering the target increased trunk and neck flexion, and side effects were small at regular height but more evident when low targets were combined with the non-dominant shoulder. Together, these findings meet the objectives by identifying coachable features for adolescents and by clarifying that tackle height, rather than the tackle's side alone, challenges posture. The practical message is to coach players on how to get low to secure trunk control and head-to-side placement as the target height is lowered, and to build bilateral proficiency while limiting lateral bias in adolescence. Claims about injury reduction or match outcomes are beyond the scope of the present study but these data provide the scientific foundation to extend the research into longitudinal training and injury monitoring studies. Within this scope, the thesis provides a coherent evidence base for age-appropriate coaching priorities and a clear pathway for validating transfer to training and competition.

5 Appendices

Systematic Review Extracted Data

Table 7. All extracted data from the 28 studies included in the systematic review

Study	Quantitative	Qualitative
Ogata et al(54)	<p>Peak Head Acceleration (PhA): High tackle: 27.4g Middle tackle: 27.7g Low tackle: 23.4g</p> <p>Peak Trunk Acceleration (PtA): High tackle: 12.8g Middle tackle: 10.7g Low tackle: 12.3g</p> <p>Dominant shoulder Tackles resulted in lower PhA (23.0 ± 13.7 g) compared to non-dominant tackles (30.4 ± 21.3 g).</p>	<p>High and middle - head acceleration than low tackles*</p> <p>Non-dominant shoulder= - head acceleration due to potential neck instability and improper alignment.</p> <p>Dominant shoulder showed - trunk acceleration, suggesting -stability.</p>
Edwards et al(55)	<p>Shoulder Abduction: DNRL: $-44.4 \pm 8.8^\circ$ SNRL: $-36.2 \pm 11.0^\circ$ SPL: $-28.7 \pm 11.1^\circ$</p> <p>Shoulder Flexion: DNRL: $52.6 \pm 32.2^\circ$ SNRL: $39.2 \pm 26.7^\circ$ SPL: $26.6 \pm 19.0^\circ$</p> <p>Head-Up Trunk Extension: SPL: $23.9 \pm 15.8^\circ$ DNRL: $16.4 \pm 22.2^\circ$</p> <p>Dominant vs. Non-Dominant Shoulder: Dominant: 3.3–8.4 lower abduction* - head-up trunk extension with dominant</p> <p>Tackle Speed: No differences across tackle types.</p>	<p>Coaching instructions can alter shoulder kinematics significantly, potentially reducing injury risks*</p> <p>SPL and DTS techniques are suggested for safer tackle execution.</p> <p>Non-dominant side engagement is associated with - injury risk.</p> <p>DNRL showed the greatest shoulder abduction, flexion, and internal rotation at contact.</p> <p>SPL demonstrated - shoulder abduction and flexion, potentially - injury risk.</p> <p>Dominant shoulder side resulted in - shoulder abduction compared to the non-dominant side.</p>
Edwards et al(56)	<p>Dominant NRL (DNRL): Adhered: 99%, Not Adhered = <1%</p> <p>Peak Head Accelerations: Tackler (Linear): 5.5 ± 2.6g (not adhered), 4.6 ± 1.7g (adhered). Tackler (Angular): 397 ± 178 deg/s² (not adhered), 321 ± 122 deg/s² (adhered).</p> <p>Player Speed (m/s): Tackler Speed at Contact: 1.8 ± 0.5 (both adhered and not adhered).</p> <p>Smother NRL (SNRL): Adhered= 74%, Not Adhered= 26%</p> <p>Peak Head Accelerations: Tackler (Linear): 5.0 ± 2.2g (not adhered), 4.8 ± 2.3g (adhered). Tackler (Angular): 400 ± 259 deg/s² (not adhered), 352 ± 202 deg/s² (adhered).</p> <p>Dominant Torso & Stick (DTS) Adhered: 65%, Not Adhered= 35%</p> <p>Peak Head Accelerations:</p>	<p>Adherence to instructions = ball carrier's inertial head kinematics - DNRL and SNRL / - DTS and SPL*</p> <p>SPL= - tackle effectiveness but posed - kinematic risks to the ball carrier.</p> <p>DTS showed inconsistent execution, indicating a steep learning curve.</p> <p>Inconsistent adherence to the smother techniques highlights a need for more focused coaching.</p>

	<p>Tackler (Linear): 6.6±2g (not adhered), 4.6±1.7g (adhered). Tackler (Angular): 325±175deg/s² (not adhered), 344±185deg/s² (adhered). Joint Angles (Degrees-): Pelvis Flexion: -49.2±18.0 (not adhered), -26.5±12.1 (adhered). Trunk Flexion: -43.3±12.8 (not adhered), -42.1±16.2 (adhered). Smother Pop & Lock (SPL) Adhered: 68%, Not Adhered= 32% Peak Head Accelerations: Tackler (Linear): 6.0±2.2g (not adhered), 4.4±1.4g (adhered). Tackler (Angular): 415±174 deg/s² (not adhered), 344±185 deg/s² (adhered). Joint Angles (Degrees-): Ankle Dorsiflexion: 12.2±10.9 (not adhered), 10.7±15.3 (adhered). Pelvis Flexion: -21.4±22.9 (not adhered), -7.3±15.3 (adhered).</p>	
Parmley et al(57)	<p>Speed(m/s): Ball-carriers: 4.73 ± 1.12 Tacklers: 2.82 ± 1.07 Ball-carriers maintained -speed into 88% of tackles. Acceleration(m/s²): Ball-carriers: 0.67 ± 1.01(acceleration into contact). Tacklers: -1.26 ± 1.36(deceleration into contact).</p>	<p>Ball-carriers accelerate into contact, whereas tacklers decelerate. Positional comparisons showed backs had higher speeds than forwards during tackles. Differences in speed and acceleration are influenced by positional roles and game context (e.g., backs often encounter more open-field scenarios).</p>
Kawasaki et al (20)	<p>Concussion Key Risk Factors Identified: Head-in-front tackles significantly increased concussion risk: Front-on tackles: 3.93x higher risk Side-on tackles: 7.81x higher risk Tackling below the hip (side-on tackles) had 1.13x higher risk than torso or chest-level tackles. Elite- concussion risk than U18/U22 in side-on tackles (1.78x higher risk).</p>	<p>Head-in-front tackles were the most critical risk factor for concussions. Lowering tackle height does not necessarily reduce concussion risk side-on tackles below the hip had higher risk. U18 players used more head-in-front tackles than Elite players, despite Elite players having higher concussion incidence. Smother tackles were more common in Elite players (29.7%) than U18 (21.1%), suggesting that better technique may reduce concussion risk. Coaching should focus on eliminating head-in-front tackles and promoting safer tackle techniques.</p>
Edwards et al (18)	<p>Tackler Head Accelerations: DNRL (Hip contact): 6.2 ± 2.3 g (linear), 420 ± 180 rad/s² (angular). DTS (Midtorso contact): 4.5 ± 1.6 g (linear), 321 ± 110 rad/s² (angular). SNRL (Upper torso contact): 5.1 ± 1.9 g (linear), 365 ± 189 rad/s² (angular). SPL (Mid/upper torso contact): (linear), 331 ± 134 rad/s² (angular).</p>	<p>Targeting the hip (DNRL)= - tackler head acceleration but = ball carrier head acceleration. Midtorso tackles (DTS, SPL) = = head accelerations for the tackler, making them safer. SPL technique (mid/upper torso with pop-up) = lowest tackler head acceleration but increased ball carrier acceleration. Midtorso tackles may be safer than DNRL for reducing concussion risk in tacklers.</p>
Edwards et al(58)	<p>Tackler Speed Approach Speed: 2.77–3.12 m/s Speed at Contact: 2.27–2.60 m/s Lower Limb Angles at Contact Knee Flexion: UpperNRL ≈ 49° (dominant), LowerNRL ≈ 42° (dominant) Hip Flexion: UpperNRL ≈ 56° (dominant), LowerNRL ≈ 48° (dominant) Trunk Flexion at Contact UpperNRL: 15.3° (dominant) LowerNRL: 8.6° (dominant) Dominant vs. Non-Dominant Side No significant kinematic differences (<2°)</p>	<p>Ball carriers adopted two movement strategies based on tackle height: - stability by lowering their centre of gravity during mid/high torso tackles. Positioned themselves upright to enable offloading or evasion in lower torso tackles. Coaching can benefit by recognising and training players to modify their techniques for safety and performance.</p>

Gardner et al(59)	<p>General HIA Propensity Tacklers: 0.99 HIAs per 1,000 tackles Body Position (HIA Propensity) Upright tackler: 1.38 HIAs/1,000 Bent tackler: 0.71 HIAs/1,000 Head Contact with Opponent Highest risk: Head-to-elbow (99.50 HIAs/1,000), Head-to-knee (56.38 HIAs/1,000) Lowest risk: Head-to-torso (0.03 HIAs/1,000) Interaction Between Body Positions Upright tackler and upright ball carrier: 2.64 HIAs/1,000 Bent tackler and bent ball carrier: 0.05 HIAs/1,000 Upright tackler and bent ball carrier: HIA every 4.96 matches Upright tackler and falling/diving ball carrier: HIA every 14.36 matches Incidence HIAs from upright tackles: Every 1.36 matches HIAs from bent tackles: Every 4.14 matches</p>	<p>Tacklers are more likely to sustain head injuries compared to ball carriers. Upright tackles pose the highest risk for HIAs due to head-to-head and head-to-elbow contacts. Lowering tackle height (bent position) reduces HIA risk* Excessively low tackles (diving)= - head-to-knee and head-to-boot impacts. Injury prevention strategies should focus on coaching bent-at-the-waist techniques and avoiding upright tackles.</p>
Suzuki et al(60)	<p>Injury Incidence Rate 12.0 injuries per 1,000 player-hours (95% CI: 9.1–15.6) Risk Factors for Injury Lack of forward-facing: OR = 3.27 * Incorrect head position: OR = 4.85 * Non-use of arms after contact: OR = 5.03 *</p>	<p>Tacklers with poor positioning before contact (not facing forward) = - risk of mild cervical injuries. Incorrect head position and failure to engage arms post-contact were key contributors to injury. Coaching should emphasise pre-contact positioning and post-contact arm engagement.</p>
Suzuki et al(61)	<p>Concussion Incidence 11.7 concussions per 1,000 player-hours (95% CI: 9.4–14.5) Pre-Contact Phase Tackler head position down increased concussion risk by 4.67 times * Contact Phase Tackler head/neck contact with the ball carrier increased concussion risk by 18.62 times * Tackles from the side increased concussion risk by 3.67 times * Post-Contact Phase Tacklers who did not grip, pull, or wrap were 4.38 times more likely to sustain concussions *</p>	<p>Concussion risk is influenced by a combination of tackler and ball-carrier actions. Incorrect head positioning (e.g., in front of or to the side of the ball-carrier) and lack of proper arm wrapping contribute to concussions*</p>
Hendricks et al(62)	<p>Tackling Outcomes Offloads Jersey tackles increased offload likelihood by 58% * Smother tackles reduced offload likelihood by 30% * Contacting ball-carrier legs increased offload likelihood by 34% * Tackle Breaks Smother tackling reduced break likelihood by 60% * Possession Lost Tackler moderate leg drive increased possession loss by 53% *</p>	<p>Smother tackles and strong leg driving post-contact = effective in preventing tackle breaks and reducing possession retention by the attacking team. Ball-carriers using jersey tackles or strong leg drives = - offload and tackle break opportunities. Efficient transitions from tackle to ruck with active ball placement and minimal players committed were key to maintaining possession.</p>

Kawasaki et al(19)	<p>Trunk Orientation Low tackles resulted in greater trunk inclination (15° lower than normal tackles) * Opposite-leg tackles showed greater trunk bending and rotation contralateral to the impacted shoulder Combined low and opposite-leg tackles exaggerated these effects Shoulder Kinematics External rotation and abduction were significantly lower in opposite-leg tackles * Impact Metrics Shoulder impact height in low tackles: ~33.7% of player height, significantly lower than in normal tackles (43.7%)* Multivariate Analysis Trunk rotation (OR: 7.5, CI: 1.5–37.7) * Hip abduction (OR: 5.8, CI: 1.5–22.9) *</p>	<p>Low Tackles: Increased forward trunk inclination correlates with a slouched posture = - injury risk to the head, neck, and shoulders. Opposite-Leg Tackles: Higher trunk bending and rotation = force transmission efficiency and - risk of imbalance post-contact. Technical Recommendations: Players should maintain a straight back and head-up posture during low tackles to mitigate injury risks. Emphasis on pre-tackle positioning to optimise alignment and reduce improper trunk orientation.</p>
Suzuki et al (63)	<p>Risk Factors for Concussion Collision tackle: OR = 84.00 * Tackler head/neck as first contact point: OR = 23.47 * No arm usage: OR = 3.54 * Tackle break by ball-carrier: OR = 5.76 * Protective Factors Tackler using arms: OR = 0.11 *</p>	<p>Tacklers are at a - risk of concussion when: Performing collision tackles (without binding). Making initial contact with their head/neck. Failing to bind arms during and after contact. Ball-carrier evasive manoeuvres like side steps can reduce tackle impact speed, lowering concussion risk for tacklers. Coaching should emphasise proper tackling techniques, including shoulder-first contact and effective use of arms for binding.</p>
Tanabe et al(64)	<p>Shoulder Kinematics Shoulder abduction: Shoulder tackle = 75°, Arm tackle = 95° *, Head-in-front tackle = 97° Shoulder external rotation: Shoulder tackle = 54°, Arm tackle = 61°, Head-in-front tackle = 33° * Neck Kinematics Neck extension: Shoulder tackle = 28°, Arm tackle = 28°, Head-in-front tackle = 13.2° *</p>	<p>Arm Tackles: - shoulder abduction and external rotation at impact = -risk for shoulder dislocation. Frequently occurred when ball-carrier changed direction. Head-in-Front Tackles: neck extension + external shoulder rotation = -potential for instability. - risk of shoulder dislocation compared to normal shoulder tackles. Technical Recommendations: Tackling techniques (e.g., shoulder-first contact) reduce risks of shoulder dislocation. Coaches should emphasise maintaining proper head and neck positions and reducing reliance on arm tackles.</p>
Hendricks et al (65)	<p>Offloads: Jersey tackles increased offload likelihood by 58%* Smother tackles reduced offload likelihood by 30%* Contacting ball-carrier legs increased offload likelihood by 34%* Tackle Breaks: Smother tackling reduced break likelihood by 60%* Possession Lost: Tackler moderate leg drive increased possession loss by 53%*</p>	<p>Ball-Carriers: Fending and strong leg drive = critical to tackle breaks and offloads. Falling sideward post-tackle = - retained possession during ruck contests. Tacklers: Front-on shoulder tackles with strong leg drive = ball-carrier offloads and breaks. Technical deficiencies (e.g., upright posture) = - risk of conceding gainline success. Training Recommendations: Emphasise technical aspects like front-on shoulder tackles and post-contact leg drive during drills. Include ruck techniques in tackle drills to improve transition skills.</p>
Sobue et al (44)	<p>Injury Incidence: Incorrect head positioning: 69.4 injuries/1,000 tackles Correct head positioning: 2.7 injuries/1,000 tackles Injury Types: Concussions: 31.5 vs. 1.1 injuries/1,000 tackles Neck injuries: 9.5 vs. 0.3 injuries/1,000 tackles Stingers: 37.9 vs. 1.1 injuries/1,000 tackles Pre-Contact Phase: Shorter pre-contact phase in injury cases (0.43s vs. 0.85s) Fewer steps before contact in injury cases (3 vs. 4)*</p>	<p>Tacklers with correct head positioning = head and neck injuries* Incorrect head positioning was attributed to habit, injured shoulders, or ball-carrier's movement. 61% of players believed they could have prevented incorrect head positioning.</p>

Seminati et al(16)	<p>Impact Forces: Stationary dominant shoulder: 2.84 ± 0.74 kN Stationary non-dominant shoulder: 2.44 ± 0.64 kN (13% lower) Dynamic dominant shoulder: 3.40 ± 0.86 kN (20% higher than stationary dominant) Contact Duration: Stationary dominant shoulder: 0.102 ± 0.012 s Stationary non-dominant shoulder: 0.111 ± 0.021 s (8.8% longer) Dynamic dominant shoulder: 0.095 ± 0.020 s (6.9% shorter) Impulse: Stationary dominant shoulder: 0.170 ± 0.030 kN-s Stationary non-dominant shoulder: 0.163 ± 0.028 kN-s Dynamic dominant shoulder: 0.178 ± 0.033 kN-s Neck Motion at Impact: Neck flexion: Stationary dominant: $22 \pm 15^\circ$ Stationary non-dominant: $27 \pm 19^\circ$ (22.7% higher) Dynamic dominant: $27 \pm 15^\circ$ (22.7% higher than stationary dominant) Neck lateral bending: Stationary dominant: $12 \pm 9^\circ$ Stationary non-dominant: $18 \pm 10^\circ$ (50% higher)</p>	<p>Technique Variations: Dominant-side tackles adhered more closely to recommended technique = - head positioning and - lateral neck bending. Non-dominant tackles= - cervical instability - biomechanical control. Coaching Implications: Training should focus on improving non-dominant-side tackling techniques. Emphasise maintaining proper head positioning to reduce injury risk. Dynamic tackles require more attention to cervical stability and controlled head motion.</p>
Burger et al(70)	<p>Injury Incidence: 50% of all injuries occurred during tackles (27 ± 6 injuries per 1,000 hours) Tackle-related time-loss injuries: 11 ± 4 per 1,000 hours Proficiency Scores: Front-On Tackles: Tackler proficiency (16-point scale): Injury: 7.00 ± 1.95 (44%) Non-injury: 9.35 ± 2.56 (58%)* Side/Behind Tackles: Tackler proficiency (12-point scale): Injury: 5.47 ± 1.60 (46%) Non-injury: 8.14 ± 1.75 (68%)* Phase-Specific Proficiency: Pre-Contact Phase: Shortening steps reduced injury risk for tacklers* Contact Phase: Correct head placement was higher in non-injury events* Post-Contact Phase: Shoulder drive after contact increased likelihood of non-injury outcomes*</p>	<p>Tackler Technique: - proficiency in head placement and shoulder usage associated with non-injury outcomes. Shortening steps before contact= -positioning and - injury risk. Ball-Carrier Technique: - awareness of tacklers and evasive movements= - injury likelihood. Coaching Implications: Focus on pre-contact positioning and post-contact techniques to minimise injury risk. Incorporate training that emphasises both offensive and defensive technique execution during tackles.</p>
Burger et al(71)	<p>Injury Incidence: Tackle-related injuries: 27 per 1,000 player-hours Time-loss injuries: 11 per 1,000 player-hours Match Situational Variables: Tacklers more likely injured in the 4th quarter* Contact Variables: Tacklers less likely injured using same-shoulder tackles as leading leg compared to arm tackles* Tacklers more likely injured during collision tackles Post-Contact Variables: Tacklers less likely injured when the ball carrier's legs were the first body region to touch the ground*</p>	<p>Injury Mechanisms: Tacklers most frequently injured at the head/neck (73% of cases). Technique Observations: Shoulder tackles on the same side as the leading leg are safer than arm tackles. Coaching Recommendations: Emphasise active shoulder tackles over collision tackles. Train players to maintain awareness of the playing environment to reduce injury risk.</p>

Hendricks et al(51)	<p>Concussion Incidence: 5.78 concussions per 1,000 player-hours Proficiency Scores (16-point scale for tackler) Tackler: Injury: Mean = 7.25±2.06, 45% Non-injury: Mean = 6.67± 3.24, 41%* Technique Differences: Head placement on correct side of ball carrier: Injury = 25%, Non-injury = 60%* Shoulder usage (drive into contact): Injury = 25%, Non-injury = 60%* Leg drive upon contact: Injury = 0%, Non-injury = 25%* Aerial Contact Proficiency: Injury: 2.00 (22%) Non-injury: 5.00 (56%)*</p>	<p>Injury Mechanisms: Concussions primarily occurred due to improper head placement and lack of leg drive upon contact. - technical execution in contact phases= -concussions. Coaching Recommendations: Focus on improving head placement, shoulder usage, and leg drive in tackles. Emphasise technical skill development in tackling and contact situations from a young age to reduce injury risk.</p>
Burger et al(46)	<p>Injury Incidence: Tackle-related injury rate: 23.8 to 50.0 per 1,000 player-hours Time-loss injuries: 8.9 to 22.2 per 1,000 player-hours Injury Distribution (Tacklers): Overall injuries: 61% (158/260); Head/neck injuries: 40% Time-loss injuries: 55% (57/104); Head/neck injuries: 44% Match Timing: Injury rates increased in the final quarter of matches: Overall injuries: 35% Time-loss injuries: 37% Tournament Comparisons: Higher tackle-related injury rates at Under-13 Craven Week than Under-18 tournaments*</p>	<p>Tackler Injuries: Predominantly head/neck injuries due to improper technique or fatigue. Coaching Recommendations: Emphasise correct tackling techniques (e.g., head and shoulder placement). Train players to maintain technique under fatigue. Implement recovery protocols during high match-load tournaments.</p>
Hendrick et al (66)	<p>Velocity Before Contact: Front-On Tackles: Tackler average velocity: Super 14: 5.0 ± 1.8 m/s Varsity Cup: 6.4 ± 2.6 m/s Under-19: 5.7 ± 1.9 m/s Side-On Tackles: Tackler average velocity: Super 14: 5.4 ± 2.2 m/s Varsity Cup: 5.5 ± 2.1 m/s Under-19: 3.9 ± 1.1 m/s Acceleration Before Contact: Tacklers in Varsity Cup front-on tackles decelerated more than ball-carriers (-6.49 ± 10.64 m/s² vs. 1.98 ± 4.95 m/s²)* Time to Contact: Significant differences in tackler vs. ball-carrier velocity at: 0.5s before contact in Varsity Cup front-on tackles (7.1 m/s vs. 4.6 m/s)* 0.4s before contact in Under-19 side-on tackles (3.1 m/s vs. 4.6 m/s)*</p>	<p>Tacklers adjusted velocity in the pre-tackle phase to match the ball-carrier's velocity, achieving suitable relative velocity for effective contact. Differences in velocity dynamics varied by competition level, with professional players demonstrating better control and stability. Coaching Recommendations: Train players to manage velocity and acceleration during the pre-tackle phase. Emphasise tackle timing and approach angles for effective contact while minimising injury risk.</p>

King et al (67)	<p>Total Tackles: 3,019 tackles analyzed (625 ± 60 per match) Tackle Heights: Hip/Thigh: 36.1% (most frequent contact area)* Mid-Torso: 34.2% Lower Legs: 13.8% Shoulder: 11.2% Head/Neck: 4.7% (least frequent but highest injury risk)* Tackle Direction: Blind vision tackles (060°-300° approach) were the most common* Front-on tackles (000° approach): 10.8% Side-on tackles (300°-060° approach): 37.2% Tackle Success Rates: Tacklers succeeded in 57% of tackles Ball-carriers broke tackles in 43% of cases Field Position Analysis: More tackles occurred in the defensive 30-40m zone than in the attacking half*</p>	<p>Most tackles occurred at the hip/thigh level, but head/neck tackles had the highest injury risk. Blind vision tackles (from outside the ball carrier's peripheral vision) were common and may contribute to injury risk. Forwards were more frequently involved in tackles than backs. The hooker was the most involved in tackles. Coaches should emphasise safe tackling technique, especially in blind vision tackles and head-high contacts.</p>
Gabbett et al(72)	<p>Tackling Proficiency Scores: Junior Elite: 65.7 ± 12.5% Junior Sub-Elite: 54.3 ± 16.8% (significantly lower)* Acceleration (10m Sprint): Junior Elite: 1.81 ± 0.08 sec Junior Sub-Elite: 1.94 ± 0.13 sec* Muscular Power (Vertical Jump): Junior Elite: 51.6 ± 7.7 cm Junior Sub-Elite: 46.7 ± 7.0 cm* Statistical Correlations with Tackling Ability: Acceleration was the strongest predictor (r = 0.60)* Lower body power was a moderate predictor (r = 0.38)* Multiple Regression: Acceleration explained 24% of variance in tackling ability*</p>	<p>Junior Elite players - tackling technique compared to Sub-Elite players* Acceleration = most important physical quality linked to better tackling performance. Lower body power also contributed to effective tackling, but to a lesser extent. No significant correlation between tackling ability and body mass or skinfold thickness. Strength and conditioning programs should emphasise acceleration and lower body power development.</p>
Quarrie et al(68)	<p>Total Injuries: 1348 injuries required on-field treatment 211 injuries required player replacement 281 injuries matched to medical records Injury Risk Factors: Tacklers at highest risk when making low tackles Tackles from behind had a higher injury rate than front-on or side-on tackles Injury Rate per 1,000 Tackles: Ball carriers: 1.1 replacements* Tacklers: 0.8 replacements* Tackle Direction and Injury Risk: Tackles from behind: 2.2x greater risk* Side-on tackles: 1.5x greater risk than front-on* Speed and Injury Risk: Tacklers sprinting: 5.0x higher risk*</p>	<p>Tackle height, direction, and player speed affect injury risk* Head-to-head collisions were a common cause of injury in both ball carriers and tacklers. Loading injuries (bodyweight impact) were common in lower limb injuries. Coaching strategies should focus on reducing high-risk tackle types, particularly tackles from behind and improper head positioning.</p>

Hendricks et al(69)	<p>Mass (kg): Ball-carriers: 100.1 ± 13.7 kg Tacklers: 93.4 ± 10.9 kg* Velocity Before Contact (m/s): Ball-carriers: 5.1 ± 1.8 m/s Tacklers: 4.9 ± 2.0 m/s Momentum Before Contact (kg·m/s): Forwards: 563 ± 226 kg·m/s Backs: 438 ± 135 kg·m/s* Tackle Outcome: Tacklers dominated 57% of tackles Ball-carriers dominated 43% of tackles Kinetic Energy Before Contact (Joules): Ball-carriers: 1463 ± 1030 J Tacklers: 1389 ± 1055 J Magnitude of Impact (Energy Transferred on Contact): 2705 ± 1462 J</p>	<p>Ball-carriers were heavier than tacklers but did not always dominate tackles* Momentum advantage and tackle dominance were proportionally similar, indicating that factors other than size contribute to success. Tacklers often entered the tackle with - velocity, neutralising the ball-carrier's mass advantage. Coaches should emphasise acceleration and timing in tackling, as momentum alone does not predict tackle success.</p>
Kerr et al (73)	<p>P1 Preliminary Investigation: Tackle ROM: Cervical spine: 129.7°–163.5° Hips: 81.0°–120.7° Knees: 82.0°–141.0° Mean joint angles at impact: Cervical spine: 147° ± 25.8 Left hip: 98.5° ± 21.7 Right hip: 97.7° ± 21.5 Left knee: 122.5° ± 25.8 Right knee: 108.0° ± 28.8 Peak linear accelerations: Head: 29.9G ± 11.3 Shoulder (Left): 37.7G ± 11.1 Shoulder (Right): 36.2G ± 12.1</p> <p>P2 Novice vs Experienced, Before/After Video Intervention: Knee flexion angle (right knee): Skilled players: 77.2° pre → 117.6° post* Skilled female players: 64.2° pre → 142.9° post* Hip flexion angle: No significant change Shoulder acceleration: Skilled female players: 458.2 m/s² pre → 332.6 m/s² post (p=0.055) Head acceleration: ~28% reduction post-instruction (not significant) Cervical spine acceleration (fixed effects model): Educational intervention effect: -51.8 m/s² (p=0.27) Repetition effect: +11.2 m/s² (p=0.42)</p> <p>P3 Before/After Video Intervention: Linear head accelerations: Highest accelerations: First tackle pre (75.1 m/s²) and post-intervention (70.0 m/s²) Significant reduction pre-intervention tackle 1 → 3 (75.1 → 60.3 m/s²)* No significant immediate change pre/post-intervention (p=0.09) Angular head acceleration: No significant differences Head acceleration (fixed effects model): Educational intervention effect: +15.4 m/s²* Repetition effect: -5.24 m/s² *</p>	<p>Video instruction improved tackle technique in experienced collegiate players, particularly increasing knee flexion. Improved technique (lower center of gravity, increased knee flexion, bent waist) linked to reduced injury risk. Skilled players effectively integrated video instruction, showing measurable biomechanical improvements. Novice players showed less consistent improvement; some increased acceleration, suggesting alternative training methods might be needed. High school players benefited more from repetition rather than video instruction, indicating developmental differences in learning strategies. Instructional videos may vary in effectiveness by skill level, experience, and developmental stage. Repetitive physical practice could be essential at younger ages; older, experienced players are better able to translate observational learning into improved tackling.</p>

Tucker et al (5)	<p>HIA events: Total HIA events analysed: 464 (335 tacklers, 129 ball carriers) Tackle-related HIA propensity: 1.94 per 1000 tackles</p> <p>Specific Tackle Characteristics: Tackle Type HIA/tackle: Active shoulder tackles: 2.98 per 1000 tackles Passive shoulder tackles: 1.44 per 1000 tackles Smother tackles: 1.40 per 1000 tackles Illegal tackles: 65.9 per 1000 tackles High tackles (illegal): 237.5 per 1000 tackles</p> <p>Tackle Direction: Front-on tackles: 2.67 per 1000 tackles Angled tackles: 1.62 per 1000 tackles Side-on tackles: 1.32 per 1000 tackles Tackles from behind: 1.54 per 1000 tackles</p> <p>Acceleration into Contact: Tackler accelerating: 4.47 per 1000 tackles Ball carrier accelerating: 1.56 per 1000 tackles Both players accelerating: 1.91 per 1000 tackles</p> <p>Player Speed: High-speed tackler: IRR = 3.05 compared to static tackler Higher ball-carrier speed: increases risk for static/slow tacklers, reduces risk for high-speed tacklers</p> <p>Body Position: Upright tacklers: 1.5 times higher injury risk (2.69 per 1000 tackles) than bent-at-waist (1.87 per 1000 tackles) Upright ball carriers: 2.13 times higher risk compared to bent-at-waist ball carriers</p>	<p>Energy transfer during tackles (high speed, front-on, active shoulder, acceleration) significantly increases head injury risk. Head-to-head and high-contact tackles above the shoulder line greatly elevate injury likelihood. Player body position is critical; upright positions substantially increase head injury risk. Lowering tackle height and encouraging bent-at-waist positions could significantly decrease injury risks for both tacklers and ball carriers. Propose targeted interventions, such as law changes and education, aimed specifically at improving tackle safety through body position adjustments. Challenges exist in balancing injury reduction with maintaining effective tackle performance. Possible unintended consequences of interventions, including increasing risk of other injury types, should be closely monitored.</p>
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*= significance $p < 0.05$

5.1 Ethics & Data Collection Forms

5.2 Research Proposal

long Title

Investigating Age and Maturation-Related Differences in Tackle Ability and Kinematics of Amateur Rugby Players Using Theia3D

Short title

Maturation and Tackle Performance in Amateur Rugby Players Using Theia3D

Team

Chief Investigator: Mr Henry Edgington (University of Essex)

Co-Investigators: Dr Bernard Liew, Dr Jason Moran, Mr Matthew Barrett (University of Essex)

Project funder

N/A

Sponsor

N/A

PROTOCOL VERSION NUMBER AND DATE

Version 3.1 & 9th October 2024

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

5.2.1 KEY CONTACTS

Insert full details of the key trial contacts including the following

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Co-investigators	<p>Bernard Liew– School of Sport, Rehabilitation and Exercise Science, University of Essex, bl19622@essex.ac.uk</p> <p>Jason Moran - School of Sport, Rehabilitation and Exercise Science, University of Essex, jmorana@essex.ac.uk</p> <p>Matthew Barrett - School of Sport, Rehabilitation and Exercise Science, University of Essex, mb21229@essex.ac.uk</p>

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 115 of 181

5.2.2 Summary

Trial Title	Investigating Age and Maturation-Related Differences in Tackle Ability and Kinematics of Amateur Rugby Players Using Theia3D
Trial Design	Laboratory, cross-sectional
Trial Participants	Male amateur rugby players aged ≤ 18
Planned Sample Size	30 participants from local rugby clubs, including at least five age groups for example: 12,13,14,15,16 years old

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 116 of 181

Planned Research Period	1 st December 2024 for 2 months	
	Objectives	Outcome Measures
Primary	<ol style="list-style-type: none"> 1. To assess the differences in tackle success rates, defined by the accuracy and safety of technique as determined by World Rugby guidelines, between younger rugby players (≤ 13 years) and older players (14-18 years) during standardized tackling drills. 2. To analyse the kinematic variables (e.g., body posture, head position, and shoulder alignment) during tackles across different age groups using motion capture technology. 	Biomechanical outcomes of joint motion using Theia 3D
Secondary	<ul style="list-style-type: none"> - To determine whether there is an optimal developmental window for 	Biomechanical outcomes

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 117 of 181



	<p>acquiring and refining safe and effective tackling skills in amateur rugby players, by comparing kinematic efficiency and technical performance between age groups.</p>	
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Background

Rugby union is one of the most popular team sports in the world, with figures from the International Rugby Board showing its increasing popularity among teenagers, who represent 22% to 39% of registered players in the top five rugby-playing nations(48). Tackling is one of the most important yet high-risk skills in rugby, responsible for a significant proportion of injuries, including concussions, shoulder dislocations, and fractures(48). The rugby tackle is an open and unpredictable event in which the tackler engages with the ball carrier, attempting to bring the carrier to the ground or hold up play(16, 88). The most common cause of head injury with either the tackler or ball carrier is when the head contacts a hard segment of the body. The most common locations are the head, elbow or knee of the ball carrier(5). This study will focus on the risk to the tackler, as improper tackling technique is the leading cause of head impacts, with 72% of these impacts occurring to the tackler(5). In the study by Tucker et al., (2017) the highest risk areas for head injury assessments (HIA) are addressed, the highest tackler HIA area is head-to-head collisions making up 18%(5). Head-to-head collision is most caused by a high tackle, this is when the tackler contacts the ball carrier above the shoulder(5). The second and third highest risk sights to the tackler are head to elbow (2% of all HIAs) and head to knee (4% of all HIAs)(5). This study shows the importance of drilling effective tackling technique, encouraging players to aim for sights such as the mid-thigh or the torso to avoid hard segments of the body(5).

Contact Tackling involves complex biomechanical processes, making it difficult to assess reliably due to the numerous combinations of movements between the ball carrier and tackler(16). This complexity is exacerbated by the fact that forces are transmitted through multiple loading points and impacting structures, each with different elastic properties(16). To fully understand the biomechanics of a tackle, the event must be divided into different phases: pre-impact, impact, and post-impact. Before impact, the tackling player recruits' muscles in a

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 119 of 181

bottom up-pattern, starting with muscles of the lower limbs to the torso during pre-impact phase, as the tackler reaches the impact and post impact phase the musculature of the upper limbs and upper torso is recruited(16). During impact, forces deform the bodies and propagate through the tackler's body, from the contact point (typically shoulder or neck) down to the ground.(16) After the impact, the force produced by the tackler to resist the ball carrier is transmitted through the kinetic chain from the legs to the point of impact, with the player continuing forward motion(16, 50). Additionally, muscles around the cervical spine activate through anticipatory co-contraction and stiffening to maintain head stability during the tackle(16, 50). Peak impact forces are experienced during a dominant side tackle, which is the most commonly used side for a tackling, therefore the present study will measure the dominant side(16).

Current literature states that a safe and effective shoulder tackle involves approaching the ball carrier with a low, stable body position, head up, and eyes on the target(108). The tackler contacts the leading shoulder, aiming for the midsection or lower, and wraps both arms around the ball carrier while driving through the legs(108). The head should be positioned to the side of the contact to avoid injury, and the neck and shoulder muscles should be engaged to absorb impact and maintain stability(16, 108). This technique helps minimise the risk of concussions, neck injuries, and shoulder dislocations(108). The study by Kawasaki et al., (2018) found the normal shoulder tackle, which is aimed towards the average player's pelvis, is seen as safer compared with a low tackle aiming towards the thigh of the player contradicting the notion a lower tackle is safer potentially being safer(19). The main reason for this being the low tackle involves significantly greater trunk inclination in the horizontal plane which causes a slouched posture, leading to a downward head position, improper trunk orientation and visual impediment which induces positional error of the extremities which may be responsible for improper tackling technique. This could partially explain the epidemiologic findings that low tackles lead to a higher risk for contact injuries such as concussions. The breakdown of technique and a downwards head position during the low tackle may also

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 120 of 181

prevent the tackler from seeing the knee which is a high risk area for head collision(5, 19). These findings were found in adult rugby players and therefore may not affect youth rugby players due to less mobility constraints and greater motor learning capacity during youth, therefore if lower is safer for the receiving player could youth rugby players learn to safely and effectively use a low tackle without improper trunk orientation thus leading to an overall safer tackling scenario for both the tackler and receiving player.

Despite the importance of tackling safety, there is a lack of comprehensive data on the forces, muscle activations, and stresses involved during these high-impact events, which has hindered the development of effective injury prevention strategies, especially for youth players. As participation in youth rugby continues to grow, understanding how age and biomechanics affect tackling ability is crucial for developing training protocols that both improve skill acquisition and reduce injury risk. Research indicates that motor skills are best developed during childhood and early adolescence, when neuroplasticity—the brain’s ability to reorganize and form new neural connections—is at its peak. This period is ideal for learning complex motor tasks like tackling, yet the optimal age for introducing tackling techniques remains unclear. While younger players (12-13 years) may have a lower overall risk of injury compared to older players (14-18 years), the biomechanical differences in tackle execution between these age groups are not well understood(23, 28-30). The period of puberty, marked by rapid physical and cognitive changes, can impair coordination and influence how players learn and perform tackling techniques(31). Therefore, identifying the right time to teach and refine tackling skills is essential for balancing skill development with injury prevention during these critical years(31).

This study will employ advanced motion capture technology, Theia3D, to analyse the tackle kinematics of amateur rugby players aged ≤ 16 yrs. By gathering data on body posture, head position, and shoulder alignment, the study aims to identify biomechanical and skill-based differences between younger and older players. Understanding these differences will enable

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 121 of 181

coaches to tailor training protocols to the developmental stages of their players, ensuring that tackling is taught in a way that promotes safety while optimizing skill acquisition. Additionally, the study seeks to determine whether there is an optimal developmental window for acquiring and refining safe and effective tackling skills, which could significantly inform future coaching practices and injury prevention strategies.

Summary & Importance:

With the increasing emphasis on reducing concussion rates in world rugby, the need for evidence-based training strategies is more urgent than ever. This study is both timely and essential for understanding injury risk in youth rugby, as it will be the first to use Theia3D technology to analyse the kinematics of a youth rugby tackle. By gaining a deeper understanding of tackle mechanics, this research will inform the development of coaching techniques that encourage safer tackling practices. A secondary objective of the study is to determine the optimal developmental window for acquiring safe tackling skills. Identifying this window could lead to further exploration of why certain age groups are better suited for learning these techniques. The outcomes of this study will contribute to improved coaching practices, reducing the risk of concussions and other injuries in youth rugby. Furthermore, the findings will provide critical data for creating age-appropriate training protocols that enhance both performance and long-term player safety, shaping the future of youth rugby training programmes and injury prevention strategies.

Methods

This study proposes a single comprehensive work package using Theia3D motion capture technology to address one primary objective and one secondary objective.

The **primary objective** is to assess and compare tackle success rates, defined by the accuracy and safety of technique, and to analyse the kinematic variables (e.g., body posture,

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 122 of 181

head position, and shoulder alignment) across at least five age groups (≤ 18 years) during standardized tackling drills. Theia3D, an AI-powered motion capture system, will be used to capture detailed biomechanical data, allowing for a thorough analysis of performance and movement patterns in each age group.

The dependent variables in this study, include the following:

1. **Trunk inclination:** The angle of inclination during different tackles (normal tackle vs. low tackle).
2. **Trunk bending:** The degree to which the trunk bends during the tackle, particularly toward the impacted shoulder.
3. **Trunk rotation:** The rotation of the trunk during the tackle, particularly to the side of the impacted shoulder.
4. **Tackle height:** Inferred by adding all the joint angles together

These variables will be compared across the two different tackles (normal vs. low) to assess the kinematic differences and their influence on tackle performance and injury risk.

The **secondary objective** is to determine whether there is an optimal developmental window for acquiring and refining safe and effective tackling skills in amateur rugby players by comparing the kinematic efficiency and technical performance of players across these age groups. Insights gained will guide the development of age-appropriate training protocols to enhance player safety and performance.

Hypothesis

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 123 of 181

We hypothesise that younger players (≤ 13 years) will have lower tackle success rates, defined by accuracy and safety of technique, compared to older players (14-18 years), due to less physical development and experience. This can be inferred by seeing a greater variance between tackles along with trunk inclination increasing which will indicate a less safe tackle. Furthermore, we expect kinematic variables, such as body posture, head position, and shoulder alignment, to be more biomechanically efficient in older players (14-18 years) than in younger players (≤ 13).

The secondary hypothesis will be the optimal developmental window for learning and refining safe and effective tackling skills will occur between the ages of 14 and 18, as players in this age range are more likely to show better integration of physical and cognitive demands during tackles. Learning can be inferred through greater consistency in measures for example during the low tackle age groups consistently hitting the bag at the same height.

Design:

This is a cross-sectional, field-based study designed to evaluate the differences in tackle success rates and biomechanical efficiency across at least five age groups of amateur rugby players (≤ 18 years). The study will use Theia3D motion capture technology to record and analyse kinematic variables (e.g., body posture, head position, and shoulder alignment) during standardized tackling drills. All data will be collected during a single testing session for each participant, and comparisons between age groups will be made based on the recorded metrics.

Eligibility Criteria:

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 124 of 181

Inclusion Criteria:

- Male rugby players aged ≤ 18 years.
- Regularly active in amateur rugby, participating in at least one rugby training sessions per week.

Exclusion Criteria:

- Any current musculoskeletal injuries or conditions that could be aggravated by physical activity, particularly in the lower limbs, shoulders, or back.
- History of concussions or other significant head or neck injuries within the last 6 months.
- Known neurological disorders that could affect motor control or balance.
- Cardiovascular conditions that contraindicate moderate physical exertion.
- Diagnosed anxiety or other psychological conditions that may be exacerbated by participation in a monitored physical activity setting.
- Previous surgery related to the musculoskeletal or nervous system within the past six months.

Sample Size:

Based on a difference in trunk inclination between normal and low tackles of 12.3° (normal tackle: $3.9^\circ \pm 2.9^\circ$; low tackle: $-8.4^\circ \pm 3.5^\circ$) with a pooled standard deviation of 3.214, an effect size (Cohen's d) of 3.827 was calculated(19). To detect this effect size with a power of 0.8 and an alpha value of 0.05, a total sample size of 3 participants per group is required. However, to ensure more robust results, we aim to recruit a larger sample of 6 participants per group in the study. Therefore, our sample size will be 30.

Recruitment:

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 125 of 181

Method (via Rugby Clubs): Participants will be recruited through local amateur rugby clubs. Coaches and club representatives will be provided with recruitment flyers and the study's Participant Information Sheet (PIS) to distribute among eligible players and their parents/guardians. Interested participants will contact the research team to arrange their participation.

Procedure

The height and body mass of the participants will first be assessed. Tackle kinematic will be measured using Theia3D, eight cameras will be placed surrounding the test area ensuring adequate clearance from the cameras to the participants to ensure safety. Cameras will all be positioned so that they can clearly see the centre of the tackle area providing an unobstructed 360° view of the athlete's movements (figure.1). This setup allows for precise capture of the kinematic variables associated with the tackle performance.

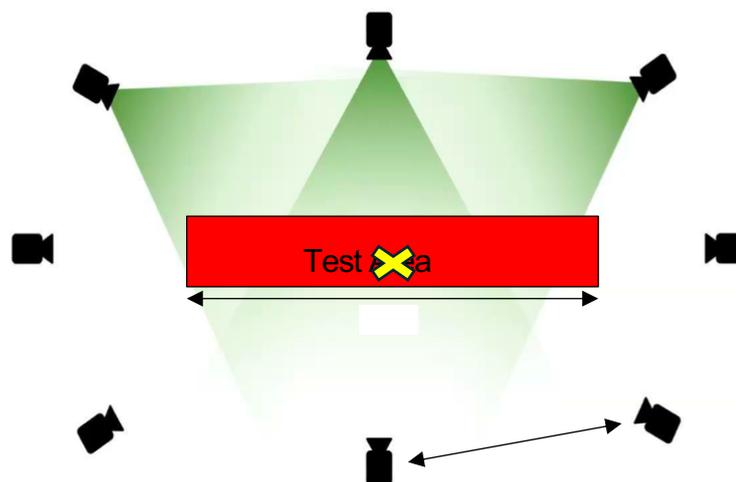


Figure 7. Theia3D Camera locations



Tackle Procedure Protocol:

Each participant will begin the drill in a standing position, positioned 2.5 meters away from the tackle bag. This distance is standard in rugby training drills and allows for the natural build-up of acceleration and body positioning prior to executing the tackle(19) (figure 2.). The starting distance ensures consistent approach speed and tackle force. Upon receiving the researcher's verbal cue, "Go," the participant will perform a shoulder tackle or low tackle on the tackle bag. The tackle bag that the children will be using is typical of those used in rugby training and is a soft bag that doesn't exert any pain on the individual who undergoes the tackle. The objective is to replicate the movement mechanics typical in a training session, focusing on correct body alignment, shoulder impact, and driving the bag into a crash mat placed behind it. Proper form will be emphasized to ensure that the tackle is safe and effective, as would be expected during live gameplay. Each participant will complete both tackles three times. This repetition scheme is based on previous research on tackle kinematics, which suggests that 2-3 tackles per technique are sufficient to generate consistent and reliable data(19). Repeating the tackle ensures that natural variability in technique is accounted for, allowing for more accurate measurement of kinematic variables. The only instructions given to the participants are as follows.

Normal Shoulder Tackle:

1. Run straight towards the tackle bag, keeping your head up and eyes on the target.
2. Lead with the foot that is on the same side as your dominant shoulder.

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

3. Make contact with the tackle bag using your dominant shoulder.
4. Drive through the tackle by pushing with your legs.
5. Wrap both arms around the tackle bag and hold on.
6. The point of impact should be around the height of the tackle bag that matches a player's pelvis.

Low Tackle:

1. Run towards the tackle bag, keeping your head up and facing the target.
2. Lead with the foot that is on the same side as your dominant shoulder.
3. Lower your body and make contact with the tackle bag at a point below the player's thigh.
4. Drive through the tackle by pushing with your legs.
5. Wrap both arms around the tackle bag and hold on at the lower level.

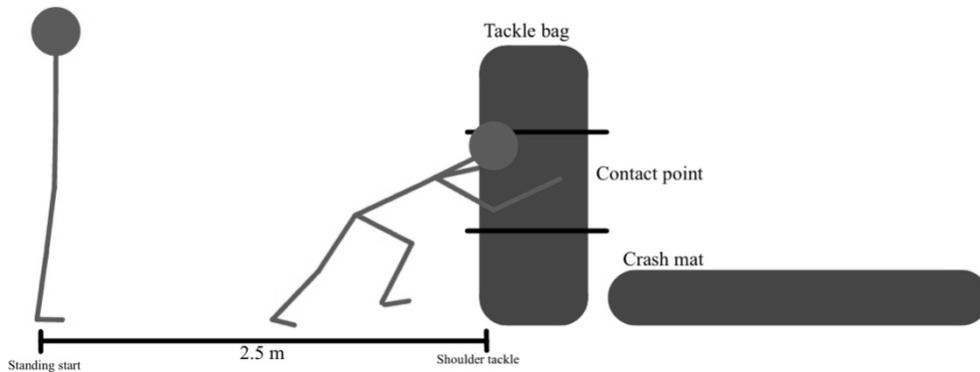


Figure 2. Shoulder tackle with standing start performed on a tackle bag

5.2.2.1 *Statistical Inference*

The primary dependent variables for this study are the maximal joint moments and powers of the hip, knee, and ankle. The independent variables will be the different tasks assessed (Table 2). Linear mixed models will be used for inference to account for repeated measurements per individual. Point estimates together with 95%CI will be created. Post-hoc pairwise contrast will be performed. Statistical assumptions of linearity, normality of residuals

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 129 of 181

and homogeneity of variance will be checked. If the statistical assumptions are violated, other statistical approaches will be considered, such as using a different distribution.

5.2.2.2 *Assessment and management of risk*

Low Risk of Injury During Tackling Drills

The risk of injury during the tackling drills is low. The study focuses on performing a standardized tackling motion on a stationary tackle bag, which is a routine part of rugby training. There are several reasons the risk is minimized:

- Participants will be performing familiar actions they already experience in regular training sessions.
- The drills are short, with adequate rest provided between each trial to prevent fatigue-related errors.
- A thorough warm-up and cool-down will be conducted before and after the trials to prepare the participants' muscles and joints for physical exertion.

Management Strategy: Only participants without any recent injuries or musculoskeletal conditions will be recruited, based on the inclusion and exclusion criteria. A qualified coach will supervise all sessions to ensure proper technique and minimize injury risk.

End of Project

The end of the data collection process for WP1 is when we have collected the biomechanics data, of our 30 participants

5.2.3 Data management

5.2.4 Participant involvement and engagement

In planning this project, we actively engaged with rugby coaches and players to ensure the study design aligns with the safety and practical considerations of young athletes. These discussions helped us refine the number of tasks, the intensity of the tackling drills, and the overall structure of the sessions to ensure that the procedures are safe, feasible, and appropriate for the target age groups (≤ 18 years).

5.2.5

5.2.6 How will the data be analysed and by whom

For work packages one and two, the data will be analysed by the primary researcher based at the University of Essex, UK. The researcher will develop the codes required to clean the raw data, develop the computer models required to answer our research questions. The research fwll be trained in some of the analytic techniques required in work package two, by Dr Bernard Liew and Dr Jason Moran from University of Essex, UK. All raw and processed data will be stored on our University's Box system. The data set will be anonymised as soon as possible using a participant ID/pseudonym, and kept always separate from personally identifiable data. The anonymised data will be shared with the research team, who will already have access to the Box data folder

ERAMS ID: ETH2425-0315

Tackle Kinematics and Maturation

Version 3.1, 9th October 2024

Page 131 of 181

5.2.7 Data Protection and Confidentiality

The legal basis for using the data is obtained by the signed informed consent to the study. The Data Controller is the University of Essex, and the specific contact is the University Information Assurance Manager (dpo@essex.ac.uk).

The only identifiable data we will collect about the participant is their name, date of birth, and video images. We will immediately delete their name changing to participant number, date of birth will be kept so that we can use this in age related analysis. Parents data collected will include their name, height and gender, this will be gathered for maturation related analysis using the Khamis-Roche method(109). When processing this information identifiable information such as name will be removed and the parents data will be saved in the same data collection form which correlates with their child's participant number. All videos will be processed and changed into biomechanical markers for analysis therefore the original video will be deleted, and non-identifiable 3D motion video will be kept.

All data will be kept confidential and unique participant numbers (e.g. "subj_01") will be allocated instead of using their name on any electronic and hardcopy files. All anonymised data and video images collected will be stored until data is processed on our secure Box system. In addition, we will be putting all anonymised data (i.e. no names, date of birth, and video images) into public scientific papers and conference material.

The participant's rights to access, change, or move your information are limited, as we need to manage their information in specific ways for the research to be reliable and accurate. If the participants withdraw from the study, we will keep their information that we have already obtained. To safeguard their rights, we will use the minimum personally identifiable information possible.

5.2.8 How will data be used and stored?

We will be using information from the participants to undertake this research. The only hardcopy (paper) data that will be collected are the signed informed consent sheet. This hardcopy data will be safely stored in a locked cupboard within a locked room in the Chief Investigator's office. The cupboard can only be accessed by the research fellow and Chief Investigator.

All human motion capture sensor data, activity volume data, and subsequent results, will be safely stored on the University of Essex cloud service (Box). Box is password-protected and accessible only to the research fellow and Investigators mentioned in this information sheet. The hardcopy data will be digitised and stored on Box within a month from the participant's testing. The hardcopy data will be destroyed at the School of Sport, Rehabilitation and Exercise Sciences (University of Essex) upon the completion of the project (6 months).

5.2.9 Dissemination of results of this research

The results from this project will be used for scientific conference presentations, published scientific journal articles, and as part of teaching materials. No individual subject will be identified in any report or presentation arising from the research. In addition, we will publish the entire fully anonymised (i.e. no names, date of birth, email, phone numbers, and video images) data onto the University of Essex's Research Data Repository (<https://researchdata.essex.ac.uk/>).

PIS for Parents of Child Participating in Study 2

Age and Maturation-Related Differences in Kinematics of Amateur Rugby Players

Using Theia3D



Invitation paragraph

My name is Henry Edgington, and I am a MsD student in the Department of sports rehabilitation and exercise science at the University of Essex. would like to invite your child to take part in a research study. Before your child decides whether they wish to take part, it is important to understand why the research is being conducted and what it will involve. Please take the time to read the following information carefully and discuss it with others if you and your child wish. There is information at the end of the leaflet on how to contact us if you and your child have any questions or concerns.

What is the purpose of the study?

This study aims to investigate the development of tackle ability and the movement efficiency in young rugby players aged 12-18 years using a submaximal tackle simulation (Figure 1.). The purpose is to analyse whether there is an optimal age for acquiring and refining tackling skills in youth rugby, which can help inform coaching practices and reduce injury risks.

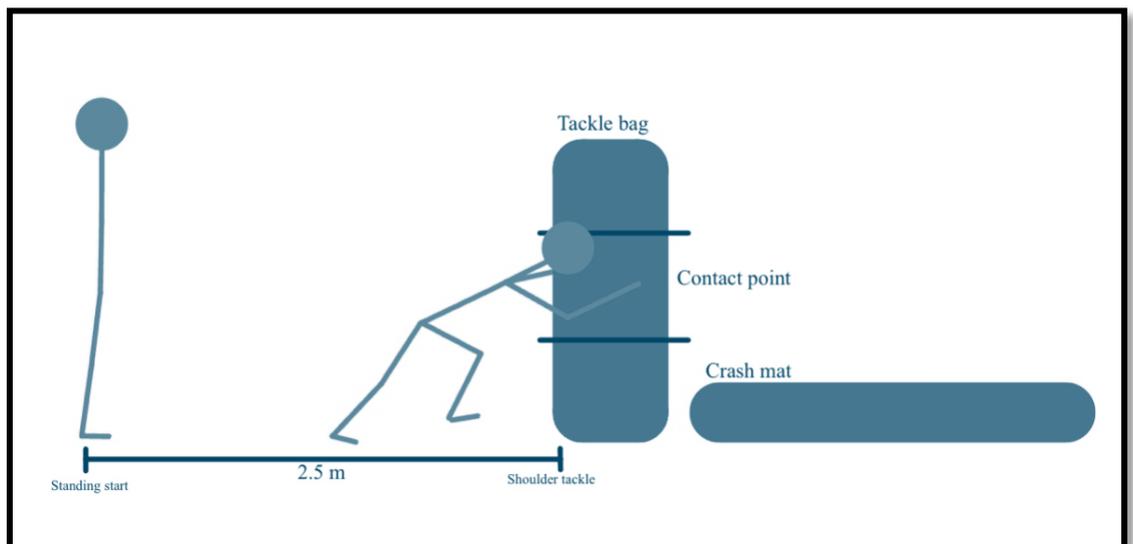


Figure 8. Study design

Why has my child been invited to participate?

Your child has been invited to participate because they are an amateur rugby player aged 12-18 years. We aim to recruit up to 30 participants from local rugby clubs for this study.

Your child will be able to take part if:

- They are aged 12-18years
- They are regularly active in amateur rugby, participating in at least one rugby training session per week.

They will not be suitable to take part if they have:

- Any current musculoskeletal injuries or conditions that could be aggravated by physical activity, particularly in the lower limbs, shoulders, or back.
- A history of concussions or other significant head or neck injuries within the last 6 months.
- Any known neurological disorders that could affect motor control or balance.
- Cardiovascular conditions that contraindicate moderate physical exertion.
- Diagnosed anxiety or other psychological conditions that may be exacerbated by participation in a monitored physical activity setting.
- Previous surgery related to the musculoskeletal or nervous system within the past six months.

Does your child have to take part?

No. Participation in this study is entirely voluntary. If your child decides to take part, you will be asked to sign a consent form, and your child will be asked to provide verbal assent which will be collected by the primary researcher on the day of data collection. Your child is free to withdraw from the study at any time without giving a reason. If they withdraw, the decision will not affect relationships with the rugby club or any future participation in rugby activities. Any data that has already been collected will continue to be used. However, no

more data will be collected from your child after they withdraw. Their records will be kept strictly confidential.

What will happen to your child if they take part?

If your child is interested in taking part in this study, we will check that they are eligible to participate. This will happen during one of the sessions at the lab. Once eligibility is confirmed, we will schedule suitable dates for your child to come down to the lab for testing.

If your child chooses to take part, they will be asked to visit our designated testing area once. During the visit, they will be asked to perform a series of simulated submaximal tackling drills on a tackle bag under controlled conditions. Tackling motions will be recorded using eight high-speed video cameras placed around the testing area to capture movements from all angles.

The tackle drill will involve starting 2.5 metres away from a tackle bag and, upon the researcher's signal, performing either a normal shoulder tackle or a low tackle on the bag three times per tackle, with adequate rest in between trials to ensure safety and mitigate the effect of fatigue. These were defined as:

Tackle 1. Normal shoulder tackle

Participant is instructed to run straight at the tackle bag facing the target with their head up. The dominant shoulder first makes contact with the tackle bag on the same side as



the leading leg. The legs continue to drive through on contact. Using both arms to wrap around the tackle bag, and the level of the impact should be around the height of an average player's pelvis.

Tackle 2. Low tackle



This tackle is similar to the normal shoulder tackle except that it is at a lower height (below the thigh of the player).

The entire session should take approximately 30 minutes.

All films taken will be processed using Theia3D which produces skeleton animated image of the participant to use for subsequent analysis.

What information will be collected?

We will collect data on height, weight, body measurements, activity levels and rugby experience as well as detailed video capture data during the tackling drills. All data will be anonymised, and each name will be replaced with a unique code to ensure confidentiality. If

possible, both parents will be asked to provide their height, as this information will assist in maturation analysis using the Khamis-Roche method. This method predicts biological maturation by considering both the parents' height and the child's height.

What are the possible benefits of taking part?

By participating in this study, your child will be contributing to the understanding of tackle technique development in youth rugby. This knowledge may help improve coaching practices and reduce injury risks for young rugby players in the future.

What are the possible disadvantages and risks of taking part?

While the tackle drill is similar to regular rugby training and is a submaximal simulation, there are some minor risks associated with physical activity. These include:

- **Muscle Strains or Sprains:** Due to the physical exertion required for the drills.
- **Impact Injuries:** Potential bruising or discomfort from contact with the tackle bag.
- **Fatigue-Related Risks:** Multiple repetitions may lead to fatigue, increasing the risk of improper technique or injury.

However, these risks are considered minimal and are no greater than those encountered in regular rugby practice. All drills will be supervised by qualified coaches and researchers to ensure safety.

To support participants during the study, the research team will provide guidance and advice on what to expect during the exercise and what they should do if they experience any symptoms or discomfort. Participants will be instructed to communicate with the research team if they experience any pain or discomfort during and following the visits and to seek medical attention if necessary.

After any visit to the University to participate in the study, participants are advised to report any side effects or adverse reactions related to their participation to the principal investigator, Mr Henry Edgington, who can be reached by email at he20113@essex.ac.uk. Non-medical emergencies should be reported by calling NHS 111 to seek guidance. NHS 111 is a free, non-emergency service available for urgent health care assessment. The NHS 111 service will signpost you to the most appropriate care for your child's condition, which could be your GP, local pharmacy, or walk-in centre.

Overall, the research team is committed to ensuring the safety and well-being of all participants throughout the study. Participants will be fully informed about the potential risks and benefits of the study and will be provided with the necessary support and guidance to participate safely and effectively.

How will my child's data be stored and who will have access to it?

Your child can stop being part of the study at any time, without giving a reason, but we will keep information about your child that we already have. We need to manage your records in specific ways for the research to be reliable. This means that we won't be able to let you see or change the data we hold about you and your child. If you agree to take part in this study, your child will have the option to take part in future research using your data saved from this study, this data will be stored on a password protected Excel file and only accessible by the investigators.

All participant data, and subsequent results, will be safely stored on the University of Essex cloud service (Box). Box is password-protected and accessible only to the

investigators. The hardcopy data (Consent forms, Par-Q) will be digitised and stored on Box within a month from the participant's testing. Identifiable data including your name, date of birth, phone number, and email address will be transferred onto a password protected Excel spreadsheet within a month from testing, that is stored online on Box, this spread sheet will also include the participants unique ID (subj_01).

Videos captured will be stored on a password protected box account only accessible by the investigators. During the analysis, captured videos will be processed on Theia3D which will create an anatomical video of the movement performed, this will be fully anonymised and saved as the unique subject ID (subj_01). The anonymised human motion data will be used during our analysis, and in future research studies. You and your child will have the option to give us permission to share their video data with other researchers deposit them in a public scientific data repository. The anonymised human motion data will be securely transferred to the investigators, by sending them a secure Box URL link to the data. Any new results created will be securely uploaded into our Box storage via the same URL link.

Once we have finished the project, we will keep the data so we can check the results and use in future research. We will write our reports in a way that no-one can work out that your child took part in the study. The results from this project will be used for scientific conference presentations, published scientific journal articles, and as part of teaching materials. In addition, we will publish the entire fully anonymised (i.e. no names, date of birth, email, phone numbers, and video images) data onto the University of Essex's Research Data Repository (<https://researchdata.essex.ac.uk/>) and also the public reposition, Figshare (<https://figshare.com/>).

How long will my child's data be stored for?

The hardcopy data will be destroyed at the School of Sport, Rehabilitation and Exercise Sciences (University of Essex) upon the completion of the project (1 year). In addition, we will back up all data on a university encrypted external hard disk for 3 years. After 3 years, all data will be stored on Box, and the data from the hard disk will be securely deleted.

Will my child's participation be kept confidential?

The legal basis for using the data is informed consent to the study. The Data Controller is the University of Essex, and the specific contact is the University Information Assurance Manager (dpo@essex.ac.uk). We will be using information from your child to undertake this research. This means that we are responsible for looking after their information and using it properly. All information and data you and your child give us will be kept safe and secure.

The identifiable data we will collect about your child is their name, date of birth, and video images. We will also be collecting your (parent) name, phone number, and email address. All data will be kept confidential and unique participant numbers (e.g. "subj_01") will be allocated instead of using your child's name on any electronic and hardcopy files. All video images will be fully processed into skeletal animation images for all subsequent analysis - please see the figure below (figure 2.). All anonymised data and video images collected from your child will be stored indefinitely on our secure Box system, as we will be using it for future research.

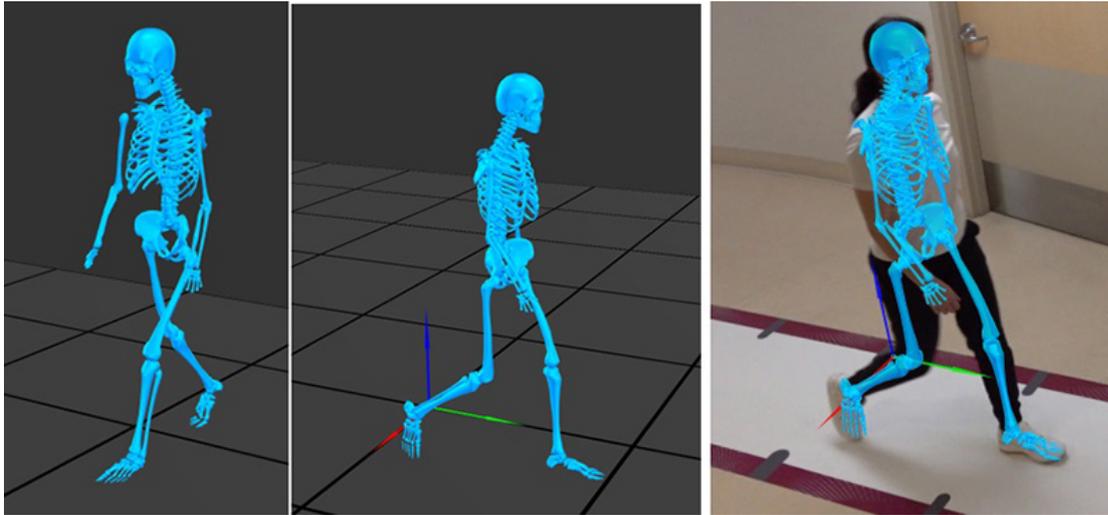


Figure 9. Theia3D capture transferred to non-identifiable video

Rights to access, change, or move your child's information are limited, as we need to manage information in specific ways for the research to be reliable and accurate. If they withdraw from the study, we will keep the information about them that we have already obtained. To safeguard their rights, we will use the minimum amount of personally identifiable information. You can find out more about how we use information by contacting the Information Assurance Manager (dpo@essex.ac.uk).

Certain individuals from the University of Essex and regulatory organisations may look at research records to check the accuracy of the research study. The University of Essex will only receive information without any identifying information. The people who analyse the information will not be able to identify your child and will not be able to find out their name or contact details.

Withdrawing your child's data

Participants can request access to the information they provide and may ask for the destruction of that information at any time prior to anonymisation. After the data have been anonymised, it will not be possible to withdraw it from the study. If your child wishes to withdraw, please contact the principal investigator, Mr. Henry Edgington, at he20113@essex.ac.uk.

Please note that if your child's data is withdrawn before anonymisation, it may still be used if you are happy for us to retain it. However, if you prefer, you can request that all collected data be destroyed, and no further use will be made of it. If anonymisation has already occurred, withdrawal is no longer possible as the data will no longer be linked to your child.

What is the legal basis for using personal data and who is the Data Controller?

The legal basis for processing my child's data is informed consent. Their data will be processed in accordance with the General Data Protection Regulations (GDPR), with the University of Essex acting as the Data Controller for this study. The University processes personal data for the primary purpose of research under the lawful basis set out in Article 6 (1)(e) of the UK GDPR: 'processing is necessary for the performance of a task carried out in the public interest or in the exercise of official authority vested in the controller.' For Special Category data, the lawful basis is Article 9 (2)(j), 'processing is necessary for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes in accordance with Article 89(1).' This requires the University to meet a substantial public interest condition under Schedule 1, Part 1 of the Data Protection Act 2018, specifically Condition 4: Research. For more information on data protection legislation and you and your

child's rights, you can visit the University's Data Protection and Research Activity webpage or contact the University's Data Protection Officer at dpo@essex.ac.uk.

Who has reviewed the study?

This study has been reviewed by the Ethics Sub-Committee 2 at the University of Essex. IRAS ID ETH2425-0315

Concerns and Complaints

If you or your child have any concerns or complaints about the study, please contact Henry Edgington at he20113@essex.ac.uk. If you are still concerned, you think your complaint has not been addressed to your satisfaction, or you feel that you cannot approach the principal investigator, please contact the departmental Director of Research responsible for this project [Dr Jamie Tallent; jamie.tallent@essex.ac.uk]. If you are still not satisfied, please contact the University of Essex REO Research Integrity Manager (reo-integrity@essex.ac.uk). Please include the ERAMS reference which can be found at the footer of this page so that the study can be identified, details of the name or description of the study, the researcher(s) involved, and the details of the complaint you wish to make.

Contact details

Mr Henry Edgington School of Sports, Rehabilitation & Exercise Sciences, University of Essex, Wivenhoe Park, CO4 3SQ, Colchester (he20113@essex.ac.uk)

Dr Bernard Liew School of Sports, Rehabilitation & Exercise Sciences, University of Essex, Wivenhoe Park, CO4 3SQ, Colchester (bl19622@essex.ac.uk)

Dr Jason Moran School of Sports, Rehabilitation & Exercise Sciences, University of Essex, Wivenhoe Park, CO4 3SQ, Colchester (jmorana@essex.ac.uk)

Matthew Barrett School of Sports, Rehabilitation & Exercise Sciences, University of
Essex, Wivenhoe Park, CO4 3SQ, Colchester (mb21229@essex.ac.uk)

Participant for Child

Project Title

Age and Maturation-Related Differences in Kinematics of Amateur Rugby Players

Using Theia3D

ETH2425-0315

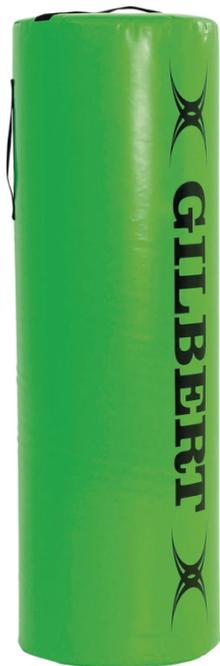


Invitation Paragraph

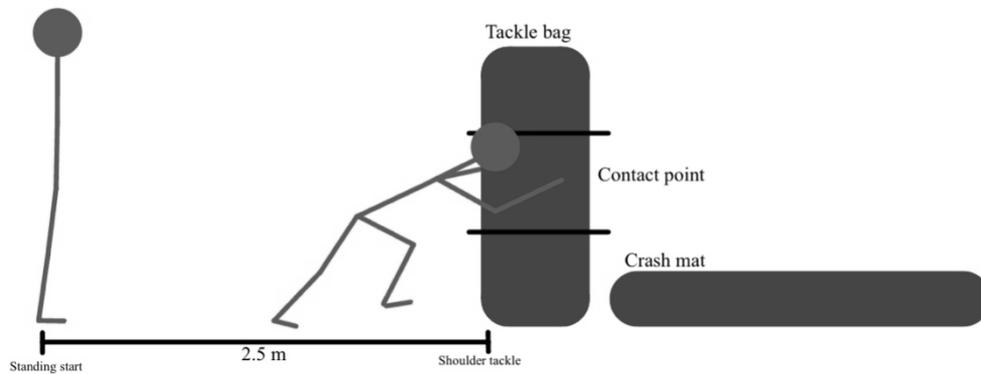
My name is Henry Edgington, and I am an MsD student at the University of Essex. I would like to invite you to take part in a research study. Before deciding whether to take part, it is important that you understand why the research is being conducted and what it will involve. Please take the time to understand the information.

What is the test?

You will complete two tackling simulations using a tackle bag



The testing will be laid out like the image below



The tackle drills will be similar to the ones you do during training.

The first will be a Normal shoulder tackle



For this tackle, you will run straight toward a tackle bag with your head up. As you get close, your shoulder on the same side as your front leg will hit the bag first. After that, you'll drive your legs and wrap both arms around the bag. The goal is to tackle the bag at about the same height as someone's hips.

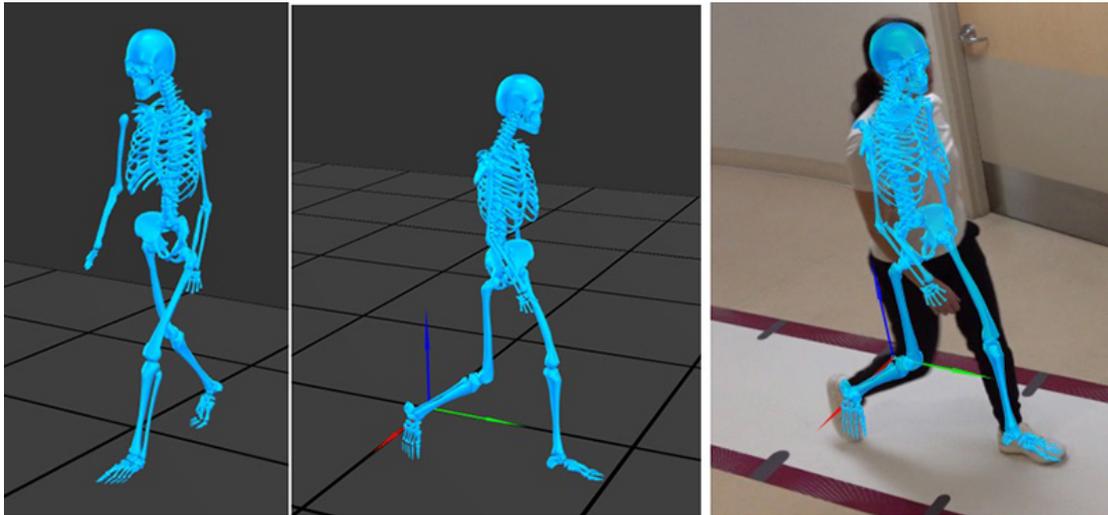
The second will be a low tackle



This tackle is similar to the normal shoulder tackle, but you'll aim lower. Instead of hitting the bag at hip height, you'll aim below the thighs. Again, you'll run straight at the bag, lead with your shoulder, and wrap both arms around it.

You'll do both tackles three times. The whole session will take around 30 minutes.

Once all the tackles have been complete, we will process your videos in an analysis software called Theia3D this will look similar to the images below



Concerns or complaints

If you have any concerns or questions, please tell your parent/guardian. Or feel free to speak to any of the research team during the session

Names of the principal research team

Mr Henry Edgington

Dr Bernard Liew

Dr Jason Moran

Mr Matthew Barrett



Physical Data Collection Form

Subject ID:

Date of collection:

Time of collection:

DOB(Day/Month/Year)

Age(yrs):

Height (cm):

Body mass (kg):

Dominant Side (R/L):

How long have you played rugby for (yrs):

How often do you train per week (Sessions):

5.2.9.1 <i>Tackle type</i>	5.2.9.2 <i>Repetition</i>	5.2.9.3 <i>Repetition</i>
	1	2

5.2.9.4 <i>Regular shoulder tackle</i>	5.2.9.5	5.2.9.6
5.2.9.7 <i>Low tackle</i>	5.2.9.8	5.2.9.9
5.2.9.10 <i>Low ND</i>	5.2.9.11	5.2.9.12
5.2.9.13 <i>Regular ND</i>	5.2.9.14	5.2.9.15

Tackle Assessments (do not fill out)

Khamis-Roche Assessment

Mothers height(cm):

Fathers Height(cm):

Parental Consent Form

**Investigating Age and Maturation-Related Differences in Tackle Ability and Kinematics
of Amateur Rugby Players Using Theia3D**

ERAMS number: ETH2425-0315

Research Team: Mr Henry Edgington, Dr Bernard Liew, Dr Jason Moran, Mr Matthew
Barrett

Please initial box

I can confirm that I have read the participant information sheet and my child has read the child participant information sheet for the above study. My child and I have had an opportunity to consider the information, ask questions, and have had these questions answered satisfactorily.

I can confirm that my child and I understand participation is voluntary and that are free to withdraw from the project at any time without giving any reason and without penalty.

I can confirm that my child does not have any of the following:

- Any current musculoskeletal injuries or conditions that could be aggravated by physical activity, particularly in the lower limbs, shoulders, or back.
- A history of concussions or other significant head or neck injuries.

- Known neurological disorders that could affect motor control or balance.
- Cardiovascular conditions that contraindicate moderate physical exertion.
- A current diagnosis or history of chronic pain conditions, such as fibromyalgia.
- Any condition or injury that limits physical activity or participation in contact sports, including recent sprains, fractures, or dislocations.
- Previous surgery related to the musculoskeletal or nervous system within the past six months.
- Diagnosed anxiety or other psychological conditions that may be exacerbated by participation in a monitored physical activity setting.
- A history of significant joint instability, such as recurrent dislocations or severe ligament tears, particularly in the shoulders, knees, or ankles.

I understand my child's anonymised (no names, emails, phone numbers, video images) data will be hosted on publicly accessible scientific data repositories, such as the University of Essex's Research Data Repository (<https://researchdata.essex.ac.uk/>) and Figshare (<https://figshare.com/>).



I can confirm that my child and I agree for the videos captured may be shared with other researchers in the future at the discretion of the research team, to advance research in this field. **This is optional and will not affect eligibility to participate in this study.** The information collected about me and my child will be used to support other research in the future and may be shared anonymously with other researchers.

I agree for the research team listed on this project to contact me of any future research projects that may arise from the results of this project for my child. **This is optional and will not affect my child's eligibility to participate in this study.**

I can confirm that my child and I agree to take part in the above study.

Parent/guardian declaration

I, the undersigned, confirm that the information provided is accurate and complete to the best of my knowledge on behalf of my child. I understand that the purpose of this questionnaire is to ensure the safety of my child during their participation in this study. My child acknowledges that participation involves physical activity and has been informed of the potential risks associated with this study.

Participant Name

Participant ID

Parent/ Guardian Name

Date

Parent/ Guardian Signature

Researcher Name

Date

Researcher Signature

Physical Activity Readiness Questionnaire for parent/guardian (PARQ)

Dear Parent/Guardian,

We are excited to invite your child to participate in our research study on tackling techniques in youth rugby players. This study involves physical activity that includes performing rugby tackles under controlled conditions. To ensure the safety and well-being of your child, we need to assess their readiness for physical activity by gathering important information about their health and fitness.

This **Physical Activity Readiness Questionnaire (PAR-Q)** is designed to identify any potential health risks that could affect your child's ability to safely participate in the study. Please answer the following questions as accurately as possible. Your responses will help us make sure that your child can engage in the study activities without unnecessary risks.

If you have any concerns or are unsure about any of the questions, please feel free to discuss them with us or consult your child's healthcare provider.

Thank you for your time and support in ensuring your child's safety during this research.

Sincerely,

Mr Henry Edgington

University of Essex

He20113@essex.ac.uk

ERAMS number: ETH2425-0315

General Information

Name	
Date of birth	
Parent/ guardian name	
Telephone number	

Medical History

Condition	Yes	No	Details
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Have you ever been diagnosed with a heart condition or experienced any cardiovascular issues?			
Have you ever experienced chest pain, dizziness, or fainting during physical activity?			
Do you have high blood pressure?			
Have you been diagnosed with any chronic conditions (e.g., asthma, diabetes, epilepsy)?			
Do you have any known allergies, particularly to exercise-induced asthma or anaphylaxis during physical exertion?			

Injury and Musculoskeletal Health

Condition	Yes	No	Details
-----------	-----	----	---------

<p>Do you have any current injuries or pain, especially in your lower limbs, back, or shoulders?</p> <p>- If yes, please describe the injury and when it occurred.</p>			
<p>Have you had any musculoskeletal injuries in the last 6 months (e.g., sprains, fractures, dislocations)?</p>			
<p>Have you ever experienced any joint instability, such as recurring dislocations or ligament injuries?</p>			
<p>Have you had any surgeries related to bones, joints, or muscles in the past 12 months?</p>			

Neurological and Concussion History

Condition	Yes	No	Details
<p>Have you ever been diagnosed with a concussion or any other head or neck injury?</p>			

- If yes, how many concussions have you had, and when was the last one?			
Have you ever experienced balance issues, dizziness, or coordination problems?			
Do you have any known neurological disorders that might affect motor control, balance, or coordination?			

Psychological and Emotional Well-being

Condition	Yes	No	Details
Do you experience anxiety or any psychological conditions that may be affected by participation in physical activities, such as rugby?			
Have you ever felt overly anxious, stressed, or scared while playing sports?			

Physical Activity and Exercise History

Condition	Yes	No	Details
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<p>Do you regularly participate in physical activity or sports?</p> <p>- If yes, please list the sports/activities and the frequency.</p>			
<p>Have you ever experienced any discomfort, shortness of breath, or excessive fatigue while engaging in physical activity?</p>			
<p>Have you participated in any intensive physical training in the last 48 hours?</p>			

Please note that if you have answered 'yes' to any of the questions, there may be some restrictions to the type of exercise programme your child can participate in. If you are unsure about any of the questions we would strongly advise that you contact your doctor before allowing your child to start the exercise programme.

Any additional question or information please write below

Parent/guardian declaration

I, the undersigned, confirm that the information provided in this questionnaire is accurate and complete to the best of my knowledge. I understand that the purpose of this questionnaire is to ensure the safety of my child during their participation in this study. I acknowledge that my child's participation involves physical activity, and I have been informed of the potential risks associated with this study.

I confirm that:

- I have provided accurate information regarding my child's medical history, physical condition, and any relevant injuries or conditions.
- I understand that if any health conditions arise, I should inform the research team immediately.
- I am aware that my child can withdraw from the study at any time without penalty.
- I understand the purpose and potential risks of the study, and I give my consent for my child to participate.

Parent/Guardian Name (Printed): _____

Parent/Guardian Signature: _____

Date: ____/____/____

Child's Name (Printed): _____

Child's Signature (If appropriate): _____

Date: ____/____/____

Researchers Name (Printed): _____

Researchers Signature: _____

Date: ____/____/____

**Investigating Age and Maturation-Related Differences in Tackle Ability and Kinematics of Amateur Rugby Players Using Theia3D –
Verbal Assent Form**

ERAMS number: ETH2425-0315

Research Team:

Henry Edgington – School of Sport, Rehabilitation and Exercise Science, University of
Essex, he20113@essex.ac.uk

Bernard Liew– School of Sport, Rehabilitation and Exercise Science, University of Essex, bl19622@essex.ac.uk

Jason Moran - School of Sport, Rehabilitation and Exercise Science, University of Essex,
jmorana@essex.ac.uk

Matthew Barrett - School of Sport, Rehabilitation and Exercise Science, University of Essex, mb21229@essex.ac.uk

Script

Hi, my name is *Henry Edgington*. If you have any questions about what I am telling you, you can ask me at any time.

I want to tell you about a research study we are doing. In this study, we want to learn more about how young rugby players tackle and how we can make it safer for everyone who plays.

You are being asked to take part because you are aged 16 or younger, and we've already spoken to your parent or guardian, who said it's okay for you to take part in this research.

If you're happy to join, I will ask you to do some tackling drills, like the ones you might already do in training. We'll look at how you tackle and use special cameras to study how your body moves when you do it.

Some of the drills might feel challenging, but if you get too tired or feel uncomfortable, just let me know. You can stop anytime you like, and it's totally fine. Just tell me and we will stop.

You don't have to be part of the study if you don't want to. It's completely up to you. Even if you say yes now, you can still change your mind later, and no one will be upset.

Your parent or guardian has already said it's okay for you to join. If you have any questions, you can ask me, your parents, or your guardians now or later.

Do you have any questions?

Are you willing to take part in this research study?

To be completed by person taking assent only

Subject ID: _____

Child's response (circle the answer) Yes No

Child's name: _____

Researcher name, signature and
date: _____

PARTICIPANTS NEEDED

(PARTICIPATION WILL TAKE APPROXIMATELY 30 MINUTES)



REGISTER YOUR INTEREST



University
of Essex



TACKLE ABILITY IN YOUTH RUGBY PLAYERS USING THEIA3D

THIS STUDY AIMS TO INVESTIGATE THE DEVELOPMENT OF TACKLE ABILITY AND THE KINEMATIC EFFICIENCY IN YOUNG RUGBY PLAYERS TO DETERMINE THE OPTIMAL AGE FOR LEARNING AND REFINING TACKLING SKILLS

WHO DO WE NEED?

WHAT DOES IT INVOLVE?

THEIA 
Markerless

18-12 YEARS OLD AMATEUR

- RUGBY PLAYERS
- HEALTHY INDIVIDUALS

- ATTEND ONE SESSION AT OUR TESTING AREA
- PERFORM A SERIES OF TACKLE DRILLS ON A TACKLE BAG
- HAVE YOUR TACKLING MOTION RECORDED AND ANALYSED USING MOTION CAPTURE TECHNOLOGY

CONTRIBUTE TO VALUABLE RESEARCH IN YOUTH RUGBY TRAINING

PRINCIPLE INVESTIGATOR:
HENRY EDGINGTON
HE20113@ESSEX.AC.UK

6 Reference List

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