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Rugby tackle kinematics in adolescent players: effects of tackle height and shoulder side

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ABSTRACT

Tackling is a major injury event in rugby, yet little is known about how adolescents adjust their body position when tackle height and shoulder side are manipulated. This cross-sectional study determined how tackle height and shoulder side influenced neck, trunk, hip, knee, and ankle positions, and centre-of-mass velocity in adolescent rugby players. Fifteen male amateur players (14.86 ± 0.77 years) completed tackles against a tackle bag under four conditions: regular-height dominant shoulder, low-height dominant shoulder, regular-height non-dominant shoulder, and low-height non-dominant shoulder. Two trials per condition were analysed using eight cameras and the Theia3D motion capture system. Linear mixed-effects models were used to test differences in joint angles and centre-of-mass velocity, with effect sizes reported. Tackle height and shoulder side altered joint positions. Low tackles increased trunk flexion by 16.4° and neck flexion by 7.1°, with the largest deviations when a low target was combined with the non-dominant shoulder, increasing trunk flexion by 29.1° and neck flexion by 10.2° versus regular-height dominant tackles. Hip flexion increased by about 20°, knee flexion changed less, and approach speed was similar between conditions. Coaches should emphasise lowering through the hips and knees, trunk control, head-up positioning, and regular tackle practice on both shoulders.

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KEYWORDS
Rugby tackle; tackle height; shoulder dominance; kinematics; markerless motion capture

Introduction

Tackling is the predominant action in rugby that exposes adolescent players to concussion and cervical injuries (Tucker et al., 2017). Previous research indicates that technique, rather than exposure alone, is a potentially controllable factor for coaches with three technical features showing the strongest correlations with safer outcomes: head to the side of contact, reduced trunk inclination towards the ball carrier and sufficient hip flexion angle at the point of contact (Gabbett & Ryan, 2009; Gabbett et al., 2010). Tackling accounts for 72% of head impacts in rugby, with the majority sustained by the tackler, emphasising the importance of a controllable

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posture at contact (Tucker et al., 2017). Incorrect head placement compounds this risk: concussions occur in 31.5 per 1,000 tackles when the head is placed in front of the ball carrier, compared with 1.1 per 1,000 when it is placed correctly to the side (Sobue et al., 2018). What remains unclear is how these technical features interact with two common youth-coaching constraints, tackle height and shoulder side, and whether adolescent tacklers adopt the same kinematic strategies as adults. Differences in head-impact loading between cohorts, approximately 6.1 to 7.7 g in adolescents compared with 4.6 to 6.6 g in semi-professional adults during front-on tackles, suggest that the underlying kinematic strategies may also differ (Edwards et al., 2024; Kerr et al., 2018).

Adolescence brings rapid, nonlinear gains in stature and mass alongside temporary reductions in coordination and reaction time, with the most acute effects occurring around the ages of ~12 years in girls and ~14 years in boys, most maturational changes being largely complete by ~16–17 years in the latter (Hirtz & Starosta, 2002; Malina et al., 2004). These changes could alter how young players organise posture and head position under time pressure (Hirtz & Starosta, 2002; Malina et al., 2004).

Despite these developmental considerations, most biomechanical descriptions of tackles come from adult cohorts or from drills that simplify contact scenarios (Kawasaki et al., 2018). Adult players demonstrate greater trunk flexion angle with low tackles compared with torso height tackles and this can lead to a partial loss of sight of the ball-carrier, increasing concussion risk in the process (Kawasaki et al., 2018). On this, children could be less constrained by pre-learned habits and more likely to achieve level changes through greater hip and knee flexion, which could preserve trunk control and visual tracking during low tackles (Hislop et al., 2017). However, whether adolescents actually adopt this distal strategy during tackling remains unclear (Hislop et al., 2017).

Very few research studies report 3D kinematics of tackling, and none have examined adolescent front-on tackles while manipulating the constraints that coaches can cue their players in practice. Coaches often cue a lower target to reduce missed tackles and head-to-head collisions, yet 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 (Kawasaki et al., 2018; Rugby, 2014). A dominant-shoulder preference can build proficiency on one side while concealing side-specific deficits that degrade posture under more demanding constraints, and lower tackling asymmetry has been associated with reduced injury risk (Davidow et al., 2020; Suzuki et al., 2020). Therefore, these factors may be important to consider when addressing safety in youth tackling (Davidow et al., 2020; Suzuki et al., 2020).

Based on the above, the aim of the current study was to determine how tackle height (regular versus low) and shoulder side (dominant versus non-dominant) influence trunk, neck, hip, knee and ankle angles and centre-of-mass velocity at the instant of contact in adolescent rugby players. It was hypothesised that low-height tackles would produce greater hip flexion and increased trunk segment flexion at contact, with small or no change in knee flexion angle and no meaningful change in approach velocity compared with regular-height tackles. It was additionally hypothesised that using the dominant shoulder would increase axial trunk and neck rotation away from the point of contact relative to non-dominant tackles and that the largest trunk and neck angle changes would occur when low target height is combined with the non-dominant shoulder compared with regular height using the dominant shoulder.

Materials and methods

A total of 15 male amateur rugby players aged 14.86 (0.77) years were recruited from rugby clubs between December 2024 and March 2025. This study was approved by the University of Essex's Human Research Committee (ETH2425-0702).

The sample size was based on a previous study examining tackle kinematics, which reported significant differences in trunk inclination between normal and low tackles (Kawasaki et al., 2018). 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 (Kawasaki et al., 2018). 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 1.

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 include any current musculoskeletal injuries, a history of concussion or head trauma within the 6-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 6 months).

This study employed a field-based, cross-sectional design. Participants performed four types of tackles: Regular Dominant Shoulder (R), Low Dominant Shoulder (L), Regular Non-Dominant Shoulder (RND), and Low Non-Dominant Shoulder (LND). 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. A marker was placed on the tackle bag at each participant's greater-trochanter height to divide the bag into two contact zones: a regular zone, extending from the marker up to the shoulders of the height-matched tackle bag, and a low zone, extending from the marker down to the mid-thigh. Tacklers were instructed to make contact within the regular zone

Table 1. 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.

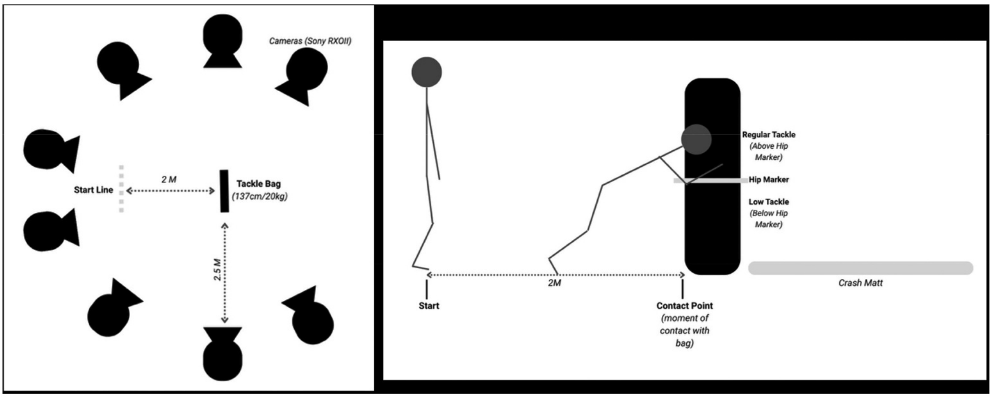

Figure 1. Camera configuration and tackle assessment protocol. Eight synchronised Sony RX0 II video cameras (Model DSC-RX0M2G; 1280 × 720 pixels, 120 Hz) were mounted on tripods at ~1.65 m and networked to a central laptop. Participants completed a 2 m run-up into a tackle bag on a crash mat. The marker on the bag was positioned at each participant's greater trochanter height, demarcating the boundary between the regular and low-contact zones.

using the dominant shoulder (R) or non-dominant shoulder (RND), and within the low zone using the dominant shoulder (L) or non-dominant shoulder (LND).

Before each session, the multi-camera system was prepared and calibrated. Eight synchronised high-speed video cameras (Sony RX0 II video cameras (Model: DSC-RX0M2G)) were mounted on tripods at approximately 1.65 m (Figure 1) and networked via wired control units to a central laptop for control and monitoring. Video was recorded at 1280 × 720 pixels and 120 Hz using the manufacturer's browser-based interface. Extrinsic calibration was performed at the start of each session using the manufacturer-supplied rectangular chessboard to define the global coordinate system. Following successful calibration, tackling trials were completed using a tackle bag and crash mat.

Participants' stature (cm) was measured using a wall-mounted stadiometer (Seca 213, Seca GmbH & Co. KG, Hamburg, Germany) and body mass (kg) using a calibrated digital floor scale (Seca 803, Seca GmbH & Co. KG, Hamburg, Germany), in light athletic clothing and without footwear. The dominant shoulder was defined as the one the participant identified as their preferred tackling side. Participants rested between attempts until they felt fully recovered (~2 minutes). Immediately before each attempt, the investigator delivered the following standardised verbal instructions: 'Tackle the bag as you would in a match. Approach at match-intensity speed and make firm contact in the [regular/low] zone using your [dominant/non-dominant] shoulder. Keep your head up and place it to the side of the bag at contact'. The zone and shoulder were substituted according to the randomised condition.

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. The Theia3D full-body model is a single pelvis-rooted kinematic chain of 19 segments comprising the pelvis, abdomen, thorax, neck, head, upper limbs, and lower limbs, with each segment defined by a parent segment, an origin, a joint type with associated degrees of freedom, and proximal and distal anatomical limits (Theia Markerless Inc., 2026a). For example, the thorax has the abdomen as its parent, originates at the base of the neck, and is bounded proximally by the abdomen and distally by the neck via three rotational and one translational degrees of freedom; the right thigh has the pelvis as its parent, originates at the right hip, and is bounded proximally by the right hip and distally by the right knee via three rotational degrees of freedom (Theia Markerless Inc., 2026a). The full segment specification is provided as Supplementary Table S1. Theia3D tracks 124 key points using deep learning and inverse kinematics, with reported precision of <1 cm and 3° and has shown joint-centre differences of <2.5 cm (hip 3.6 cm) and lower-limb segment-angle RMSD values of <5.5° versus marker-based capture, with mean sagittal-plane differences of approximately 3° and ICCs > 0.80, highest for hip and knee flexion—extension (Kanko et al., 2021; Theia Markerless Inc., 2026b; Yoma et al., 2025).

Segment angles described 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 was extracted at the moment of initial contact with the tackle bag. In total, 13 dependent variables were extracted: trunk segment flexion, lateral flexion and axial rotation; trunk joint flexion, lateral flexion and axial rotation; neck joint flexion, lateral flexion and axial rotation; hip flexion; knee flexion; ankle dorsiflexion; and centre-of-mass (COM) forward velocity. Flexion and dorsiflexion were positive (extension and plantarflexion negative). For frontal- and transverse-plane trunk and neck variables, values were side-normalised such that motion towards the contact side was positive and away from the contact side was negative, enabling pooled interpretation across tackle sides. COM velocity was positive in the anterior direction and negative in the posterior direction.

Descriptive data are reported as mean ± 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 (R, L, RND, LND). 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-statistics, degrees of freedom, p-values and F-statistics were computed and reported from the mixed model. Statistical significance was set a priori at $\alpha = 0.05$, with Bonferroni-adjusted thresholds applied to pairwise comparisons. 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) (Sawilowsky, 2009). All analyses were conducted in R (v4.3.3) within RStudio (2025.05.1 + 513) using lme4 (v1.1–35.1) (Bates et al., 2015), lmerTest (v3.1–3) (Kuznetsova et al., 2017), emmeans (v1.8.8) (Searle et al., 1980), and the easystats (Lüdecke et al., 2019) ecosystem for estimation, diagnostics, and reporting.

Results

Trunk segment and joint angles

Figure 2 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, $p < 0.001$). Trunk segment flexion was greatest in the LND condition, which was significantly greater than R(t(106.36) = 14.39, $p < 0.001$, d = 3.76, 95% CI [3.03, 4.49]) and RND (t(106.36) = 13.05, $p < 0.001$, d = 3.41, 95% CI [2.71, 4.11]). The L condition also produced significantly more trunk segment flexion angle than R(t (106.56) = 11.56, $p < 0.001$, d = 3.14, 95% CI [2.45, 3.83]) and RND (t(106.56) = 10.27, $p < 0.001$, d = 2.79, 95% 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 R compared with L (t(108.25) = 3.10, $p = 0.015$, d = 0.84, 95% CI [0.29, 1.39]).

Figure 3 illustrates the 3D trunk joint angles across dominance and tackle height. Tackling type had a significant effect on trunk joint flexion angle (F(3, 100.03) = 37.91, $p < 0.001$). LND produced significantly greater trunk joint flexion than R (t(100.36) = 8.75, $p < 0.001$, d = 2.25, 95% CI [1.56, 2.94]) and RND (t(100.36) = 7.93, $p < 0.001$, d = 2.04, 95% CI [1.35, 2.73]), while the L condition was also greater than R (t(100.59) = 6.73, $p < 0.001$, d = 1.80, 95% CI [1.08, 2.52]) and RND (t(100.59) = 5.94, $p < 0.001$, d = 1.59, 95% 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, $p < 0.001$), with RND greater than L (t(100.74) = −4.53, $p < 0.001$, d = −1.21, 95% CI [−1.93, −0.49]) and LND (t(100.45) = −3.58, $p = 0.003$, d = −0.92, 95% CI [−1.61, −0.23]), indicating more lateral lean when tackling upright from the non-dominant side.

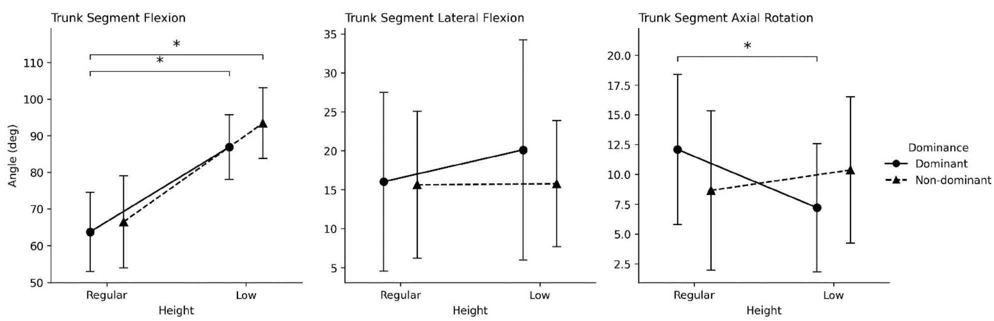

Figure 2. Mean (± SD) trunk segment angles (°; trunk relative to the global laboratory frame) at the instant of tackle contact for flexion, lateral flexion and axial rotation, plotted by tackle height (regular, low) and shoulder dominance (dominant, solid line; non-dominant, dashed line). Positive values denote flexion, lateral flexion towards the contact side, and axial rotation towards the contact side. *$p < 0.05$ between conditions. $n = 15$.

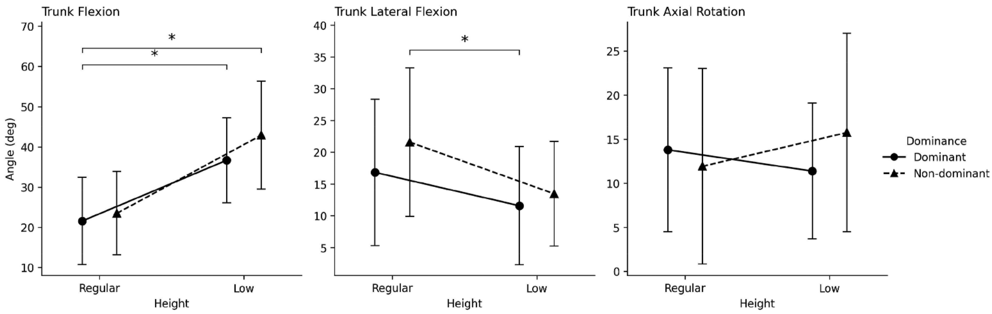

Figure 3. Mean (± SD) trunk joint angles (°; thorax relative to pelvis) at the instant of tackle contact for flexion, lateral flexion and axial rotation, plotted by tackle height (regular, low) and shoulder dominance (dominant, solid line; non-dominant, dashed line). Positive values denote flexion, lateral flexion towards the contact side, and axial rotation towards the contact side. *$p < 0.05$ between conditions. $n = 15$.

Neck joint angles

Figure 4 illustrates the 3D neck joint angles across dominance and tackle height. Tackling type had a significant effect on neck joint flexion angle ($F(3, 100.02) = 12.05$, $p < 0.001$). LND produced significantly greater neck flexion than RND ($t(100.23) = 5.06$, $p < 0.001$, $d = 1.30$, 95% CI [0.61, 2.00]) and R ($t(100.23) = 4.61$, $p < 0.001$, $d = 1.18$, 95% CI [0.49, 1.88]); L also exceeded RND ($t(100.39) = 3.53$, $p = 0.004$, $d = 0.94$, 95% CI [0.22, 1.66]) and R ($t(100.39) = 3.09$, $p = 0.015$, $d = 0.83$, 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 ($F(3, 100.09) = 9.11$, $p < 0.001$). R produced greater side bending than L ($t(101.66) = -4.53$, $p < 0.001$, $d = -1.21$, 95% CI [−1.93, −0.49]) and LND ($t(101.02) = -3.97$, $p < 0.001$, $d = -1.02$, 95% CI [−1.71, −0.33]), while RND was also greater than L ($t(101.66) = -3.07$, $p = 0.017$, $d = -0.82$, 95% CI [−1.54, −0.10]).

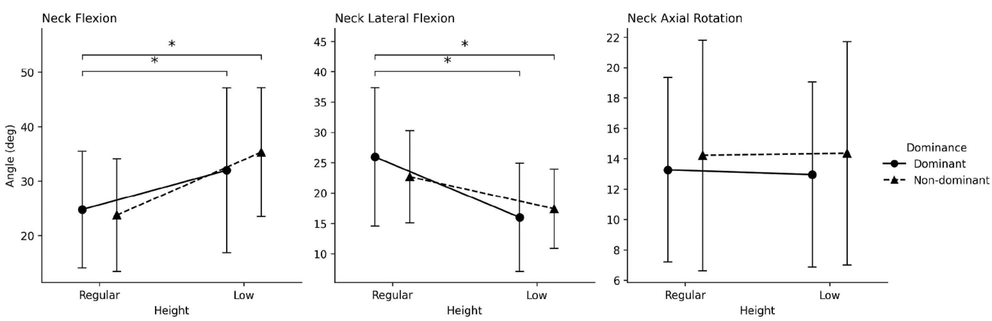

Figure 4. Mean (± SD) neck joint angles (°; head relative to thorax) at the instant of tackle contact for flexion, lateral flexion and axial rotation, plotted by tackle height (regular, low) and shoulder dominance (dominant, solid line; non-dominant, dashed line). Positive values denote flexion, lateral flexion towards the contact side, and axial rotation towards the contact side. *$p < 0.05$ between conditions. $n = 15$.

Ankle, knee and hip joint angles

Figure 5 illustrates the sagittal-plane ankle, knee and hip flexion joint angles across dominance and tackle height. 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.)

Centre-of-mass velocity

Tackling type had no significant effect on centre-of-mass 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.

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 participants towards more flexed trunk and neck joint angles at the point of contact. While any additional effects of using the non-dominant shoulder were small, the largest deviations were observed when both constraints were combined. Trunk segment/joint flexion angle increased most in the LND 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 required postural changes. Bilateral differences between R and RND, and

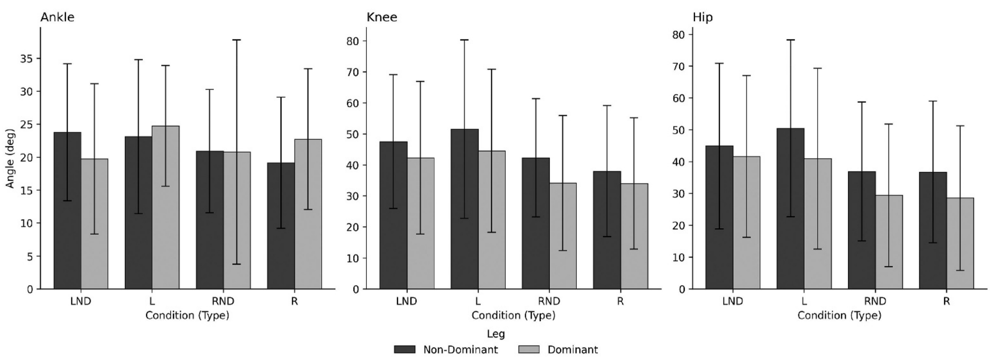

Figure 5. Mean (± SD) sagittal-plane ankle, knee and hip flexion angles (°) at the instant of tackle contact for the non-dominant (dark bars) and dominant (light bars) sides across the four conditions: LND (low height, non-dominant shoulder), L (low height, dominant shoulder), RND (regular height, non-dominant shoulder) and R (regular height, dominant shoulder). Positive values denote dorsiflexion (ankle) and flexion (knee, hip). $n = 15$.

between L and LND, were trivial (d = 0.08–0.12), suggesting minimal shoulder-side asymmetry at this developmental stage and a potential opportunity for coaches to consolidate bilateral proficiency before the player forms long-term habits.

Participants performed the L 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. This partly aligns with tackle-bag studies in adults which suggest that low tackles are characterised by greater trunk joint flexion at impact (Edwards, Tahu, et al., 2022; Kawasaki et al., 2018). A more flexed trunk and neck posture may make it more difficult to sustain an 'eyes-up, head-up' position under a live- and full-contact scenario, thus increasing the likelihood that the head enters a hazardous space and makes contact with an opponent's knee or boot, an event that has been associated with a higher head-injury risk during tackling (Tierney et al., 2018). Despite this, laboratory evidence also indicates that more distally orientated movement mechanics, meaning greater contribution from joints further from the trunk, such as the knee and ankle, can support low contact and that the relationship between technique change and head loading may differ by cohort (Kerr et al., 2018). 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 (Kerr et al., 2018). In skilled collegiate players, video instruction was associated with greater knee flexion and reduced peak head linear acceleration, whereas in less-experienced high-school players, this trend was reversed (Kerr et al., 2018). Relative to that evidence, the participants in the current study showed a more proximal strategy at the point of contact with no clear increase in knee flexion or change of COM velocity from R to L tackles. This suggests that the mechanics underpinning body height 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-impact posture can meaningfully shape impact posture in tackle-bag trials (Kawasaki et al., 2018). Greater contralateral trunk axial rotation and larger hip abduction measured pre-impact were associated with a more downward-orientated trunk posture at contact, which is biomechanically consistent with greater trunk joint flexion at impact (Kawasaki et al., 2018). 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 tackle research in youths should therefore quantify the full pre-contact window alongside contact-instant kinematics, ideally using continuous kinematic analysis (e.g., Statistical Parametric Mapping, SPM1D) to identify when, during the approach-contact sequence, key postural changes emerge (Pataky, 2012). Despite this, cohort-based explanations should be approached with caution because maturation status, strength level and movement coordination were not assessed (Chtourou et al., 2012; Wachholz et al., 2020). 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.

Instrumented-mouthguard data from community rugby suggest that U13 players accrue most of their weekly head-acceleration events during training, whereas U19 players experience higher-magnitude events during matches (Bussey et al., 2024). In this context, the greater trunk and neck flexion observed here under low-target conditions may make it more difficult to sustain an eyes-up, head-up posture as contact intensity increases in later age grades, although, because head loading was not measured, this remains a hypothesis to be tested directly (Bussey et al., 2024). 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 style 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 with the mid-torso resulted in lower tackler head acceleration than contacting the lower torso (Edwards, Gardner, et al., 2022). 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 (Bussey et al., 2024; Edwards, Gardner, et al., 2022).

At both regular and low tackle heights, the non-dominant side produced trunk, lateral and lower-limb flexion similar to the dominant side, indicating that target height, rather than shoulder dominance, was the primary driver of posture in these trials. This contrasts with adult studies, which typically report a dominant-shoulder preference reflected in success rates and impact characteristics rather than in trunk flexion, suggesting that a strong side preference develops with age and exposure (Seminati et al., 2017). The present findings align with developmental research showing that adolescent players display mixed-laterality profiles in complex movements rather than fixed one-sided dominance, although minor dominance effects cannot be ruled out, given the sample size and the variability typical of adolescent movement (Castañer et al., 2018). This may represent an opportunity for coaching intervention to consolidate bilateral proficiency before poor unilaterally dominant habits emerge, ideally targeting the sensitive period for coordination development between ~8 and 12 years (Garrett & Headrick, 2025). From around 14 years, when most boys experience peak growth and substantial size mismatches appear in youth teams, the volume of full-speed collisions could be reduced in favour of bilaterally orientated tackle practice that preserves technique shape under low-target conditions, particularly on the non-dominant side (Hirtz & Starosta, 2002; Malina et al., 2004). Only once correct technique, defined as level change through hip and knee flexion with stable trunk control and head-to-the-side positioning, is consistently demonstrated should approach speed and contact intensity be progressively increased (Bussey et al., 2024).

The present study used tackle-bag trials at fixed target heights which improves experimental control but limits ecological validity. A single marker at the greater trochanter height was used to divide the regular and low zones, with no exclusion band separating them. In future research, including a neutral buffer of approximately 10–15 cm around the divider could provide cleaner separation between contact zones and reduce the likelihood of impacts occurring on the boundary between conditions. In the present models, target height explained posture far more than shoulder side did with only a small side difference 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 scenarios, ball carriers can adapt their movement in response to the tackler, which may in turn alter the tackler's positioning at contact (Edwards, Tahu, et al., 2022), a condition that is difficult to replicate under laboratory conditions. A further limitation is that body segment angles were extracted at the contact instant, which may not capture pre-contact strategies such as peak knee or hip flexion being adopted earlier in the approach. Future research should therefore biomechanically examine a pre-contact window (for example, two steps before contact and the final step) and use a live-opponent design with objective speed measurements (for example, timing gates). Wearable sensors (e.g., IMUs) to quantify approach speed and lower-limb actions under more representative conditions would also enhance the ecological validity of such an investigation.

Lastly, our sample comprised adolescent males (age: 14.86 ± 0.77 years) from a single developmental pathway thus limiting the generalisability of the results across different maturational stages, including the aforementioned proposed sensitive period for coordination development that occurs around 8 to 12 years and periods of rapid growth which could include bouts of 'adolescent [movement] awkwardness' (Garrett & Headrick, 2025; Hirtz & Starosta, 2002). Future studies should recruit younger, more diverse cohorts that include female players and functional dominance profiling (e.g., bilateral strength and skill assessments) to determine whether critical periods exist for acquiring robust tackle mechanics across both shoulders, in both sexes.

Lower tackle height was linked to greater trunk and neck flexion at contact, especially when tackles were made with the non-dominant shoulder. From a coaching perspective, this suggests that some adolescent players respond to a lower target by folding forward through the trunk rather than lowering their body position with increased hip and knee flexion. Because this contact posture may make it harder to maintain an upright head and trunk position at contact, coaches should emphasise lowering through the hips and knees, keeping the eyes up, and positioning the head to the side of the ball carrier. Although the shoulder side alone had only a limited effect, the combination of a low target and a non-dominant shoulder caused the greatest postural change, indicating that this may be the condition where tackle posture is most likely to break down. Practising tackle technique bilaterally from an early stage may therefore help players maintain better body control and more consistent contact mechanics when tackling on either side and at lower target heights.

Conclusion

Adolescent players demonstrated greater trunk and neck flexion when tackling a low target with the largest deviations occurring when that target was tackled with the non-dominant shoulder. Approach speed remained consistent across conditions, suggesting that any differences are likely attributable to coordination rather than to differences in speed. At an above hip tackle 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.

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