



The kinematics of 1-on-1 rugby tackling: a study using 3-dimensional motion analysis

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Background: Although past studies using video analysis indicated that the arm tackle and head-in-front shoulder tackle are possible risks for shoulder dislocation, the underlying mechanisms of tackling-related shoulder dislocation have not been sufficiently investigated. This study aimed to analyze the kinematic aspects of these tackling motions in 1-on-1 tackles in an experimental setting using a 3-dimensional motion-capture system.

Methods: A total of 65 one-on-one tackles were recorded using a marker-based, automatic, digitizing motion-capture system. A documented tackle was classified into 1 of 3 types, which was decided based on the first point of contact on the ball carrier and the head position at the time of impact: shoulder tackle (reference tackle), arm tackle, and head-in-front tackle. The orientations of the head, trunk, and shoulder at impact were calculated and statistically compared with each other.

Results: The distribution of tackles recorded in this study was as follows: 38 shoulder, 23 arm, and 4 head-in-front tackles. In comparison with the shoulder tackle as a reference, shoulder abduction on the side of impact was higher in both the arm and head-in-front tackles, while shoulder external rotation was lower in the head-in-front tackles. In the latter type of tackle, significant decreases in neck extension and ipsilateral neck rotation were also indicated.

Conclusion: The kinematics in both the arm tackle and the head-in-front tackle is significantly different from that in the shoulder tackle and may represent a distinct risk factor for shoulder dislocation.

Level of Evidence: Basic Science Study; Kinesiology

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Rugby union is one of the most popular contact sports, and it involves 1-on-1 duels between players during competition. The Laws of World Rugby define a “tackle” as “the method of holding a ball-carrier and bringing that player to ground.”³⁶ These tackle events occur on average 150–200 times

per game in elite competitions,^{27,32} and their outcomes directly influence the result of the match and put the players at risk of shoulder dislocation.

Past epidemiologic studies have revealed that more than 60% of contact injuries, such as shoulder dislocations, concussions, and stingers, are caused by tackling, with front-on tackles resulting in the highest number of injuries.^{8,10,15,16,24,27} The increase in injuries may be because they expose the tackler to the greatest amount of impact force. Improper tackling techniques, which involve inappropriate posture at impact, are another important risk factor for contact injury.¹¹ Several researchers have shown that a tackler's skill and the orientation of his or her body segments at impact influence the outcome of the tackle and the incidence of injury.^{12,13,23} Thus, an understanding of kinematics during rugby tackling may contribute to improved tackling performance as well as the prevention of contact injury.

A study of tackling injuries in professional rugby players reported that arm tackles accounted for the greatest number of shoulder injuries when tackling.⁸ Although the mechanism of injury is not fully understood, it is speculated that an extended, abducted, and externally rotated arm position during tackles destabilizes the shoulder and thus increases the risk of shoulder injury.^{2,22,23,31} In addition to this common mechanism, recent video analysis has demonstrated that the "head-in-front" shoulder tackle, during which the tackler's head is positioned in front of the ball carrier, was an alternative tackle with an increased risk of shoulder dislocation.²³ Although video analysis of real-world injuries is one of the major tools to assume injury mechanisms as described earlier, this method has several limitations. Because it is rare to capture an injury event on video—and even if video is available—issues with perspective often make it difficult to determine the postures, positions, and impact configurations accurately.³

In this study, we analyzed tackling motion in the 1-on-1 maneuver by using a 3-dimensional (3D) motion-capture system, which has become a common tool for analyzing sport-specific motions.^{1,17,28} A documented tackle was classified into 1 of 3 types as referred to earlier, which was decided based on the first point of contact on the ball carrier and the head position at the time of impact: arm tackle, shoulder tackle, and head-in-front tackle. The purpose of this study was to characterize the body posture at impact during 3 different tackles, as well as to speculate on the risk of resulting shoulder dislocation. We hypothesized that there would be a critical difference in the neck and shoulder orientations of each tackle and that this may affect the risk of shoulder dislocation during rugby tackles.

Materials and methods

This was a controlled laboratory study that planned to record various 1-on-1 rugby tackles in an experimental setting to analyze the kinematic characteristics.

Participants

After providing written informed consent, 15 elite rugby players (11 collegiate and 4 professional players) with no history of shoulder or elbow surgery were enrolled in this study. The average age of the players was 22.3 ± 1.9 years (95% confidence interval, 21.2–23.2 years). The demographic characteristics of the subjects are summarized in [Table S1](#).

Experimental setting

We recorded the tackling motions using an infrared motion-capture system (Vicon MX; Vicon, Oxford, UK) at the Japan Institute of Sports Sciences in Tokyo, Japan. Twenty synchronized infrared cameras (250 Hz) were placed around a 10×10 -m² field to provide an unobstructed 360° view of the subject ([Fig. 1, d](#)). A skilled physical therapist placed 38 elastic reflective spheres with a diameter of 12.5 mm on the subject's skin, overlying designated anatomic landmarks, using double-sided and athletic tape ([Fig. 1, a-c](#)). The anatomic landmarks for marker placement included the following: seventh spinous process of the cervical spine, sternoclavicular joint, xiphoid process of the sternum, seventh spinous process of the thoracic spine, acromion, medial and lateral epicondyles of the humerus, radial and ulnar styloid processes, third metacarpal, anterior superior iliac spine, posterior superior iliac spine, greater trochanter, lateral and medial femoral epicondyles, and lateral and medial malleoli. In addition, 5 markers were attached to the headgear on the top and the frontal, occipital, and right and left sides of the head, and 2 markers were attached to each heel and over the third metatarsal styloid process of the foot. These marker placements were determined based on previous studies.^{17,25,30,37,38} To record more accurate 3D positions of the markers, the tacklers wore only tight-fitting shorts, headgear, and training shoes.

After a standard warm-up sequence, the subjects performed a real 1-on-1 duel in which players took turns being either the ball carrier or the tackler. Both players started 10 m apart ([Fig. 2, a](#)). Each player was instructed to perform to the same standard as he would in a competition. The aim for the ball carrier was the same as in a game of rugby, which was to try to beat the tackler by running free. The defender was also instructed to stop the ball carrier by means of tackling.

Analysis procedures

Each tackler performed 5 trials with a randomly selected subject, and all of the trials were used in the analysis except for cases in which adverse events occurred involving the markers or cases in which the tackler completely missed the ball carrier. In total, 65 effective trials in 15 subjects (38 normal shoulder tackles, 23 arm tackles, and 4 head-in-front shoulder tackles) were selected and underwent kinematic analysis. Three-dimensional reconstruction and labeling from measured markers were performed for the subjects by use of Nexus software (version 1.8.5; Vicon) ([Fig. 2, e-g](#)), and kinematic analyses were carried out using Bodybuilder software (version 3.5; Vicon). The trajectory of markers was filtered by a fourth-order zero-lag Butterworth filter with a cutoff of 6 Hz.³⁴ The local coordinate systems were established on each body segment: hand, forearm, upper

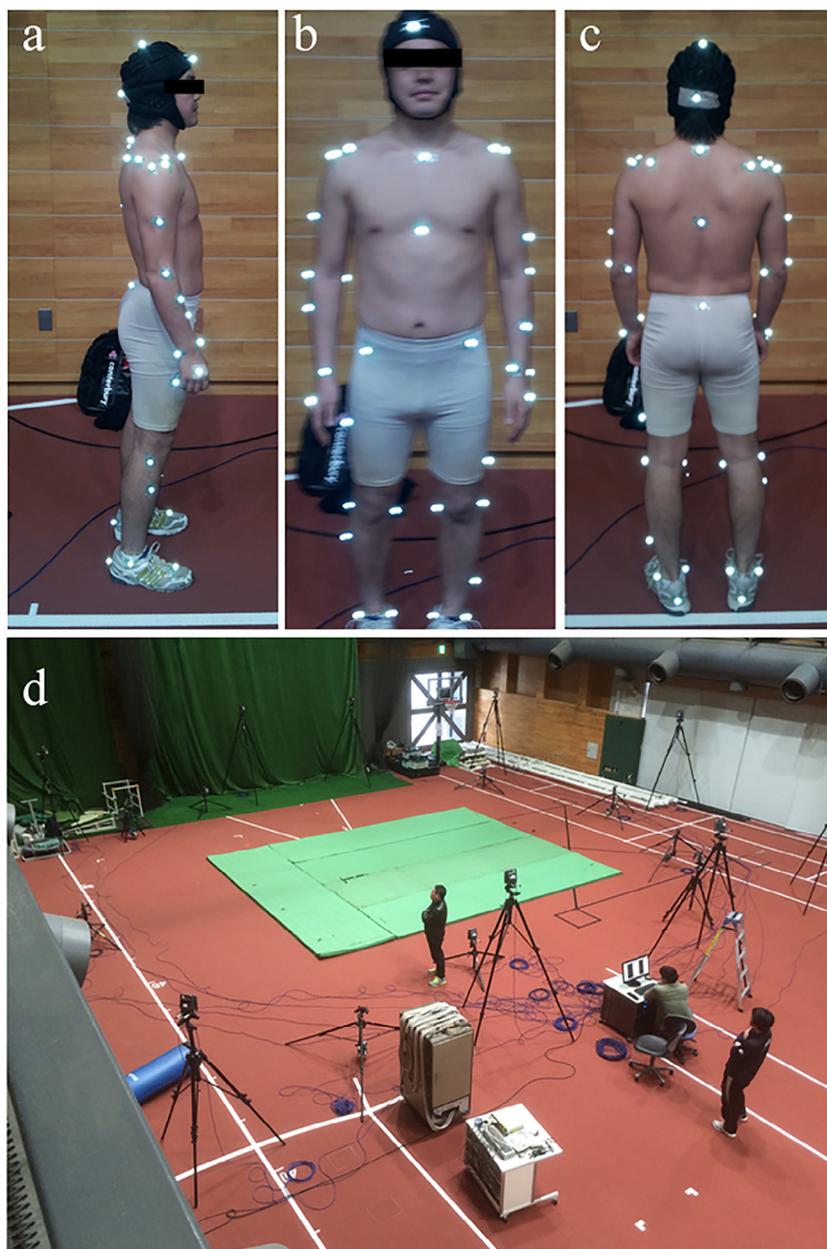


Figure 1 (a-c) Marker settings on subject. (d) Experimental setting.

arm, trunk, pelvis, thigh, lower leg, and foot. The coordinate systems of these segments were determined mathematically based on the location of the anatomic landmarks in reference to a previously described method^{37,38} and were used to calculate 3D rotations at the neck, trunk, shoulder, hip, knee, and ankle using the typical Eulerian sequence. For the shoulder joint analysis, the Euler angle sequence was adopted to describe the abduction-adduction, horizontal abduction-adduction, and internal-external rotation angles of the upper arm relative to the trunk. We regarded 90° of shoulder abduction as the reference measurement plane for shoulder horizontal abduction-adduction. We used 0° of shoulder internal-external rotation as the reference position, with external rotation expressed as positive values and internal rotation as negative values. We defined 0° of shoulder abduction-adduction as the reference position, with abduction expressed as positive values. We used 0° of shoulder horizontal

abduction-adduction as the reference position, with horizontal abduction expressed as negative values (Fig. 3).

The tackling motion was divided into 3 phases: the foot plant 2 steps before the impact, the foot plant just before the impact, and the impact (IM0). The frame of the tackle impact (IM0) to the ball carrier was subsequently identified from the initial displacement of the markers. Because this study only focused on the upper-body orientation at the moment of the tackle impact, characteristic kinematic parameters of the shoulder, neck, and trunk at IM0 were chosen for statistical analysis.^{4,6}

Prior to the main experiments, a pilot study was performed to determine whether a system with a sufficient number of high-speed cameras would make it possible to analyze the tackling motion in 3 dimensions. Each marker was assessed to identify the frequency of detection and timing anomalies.¹⁷

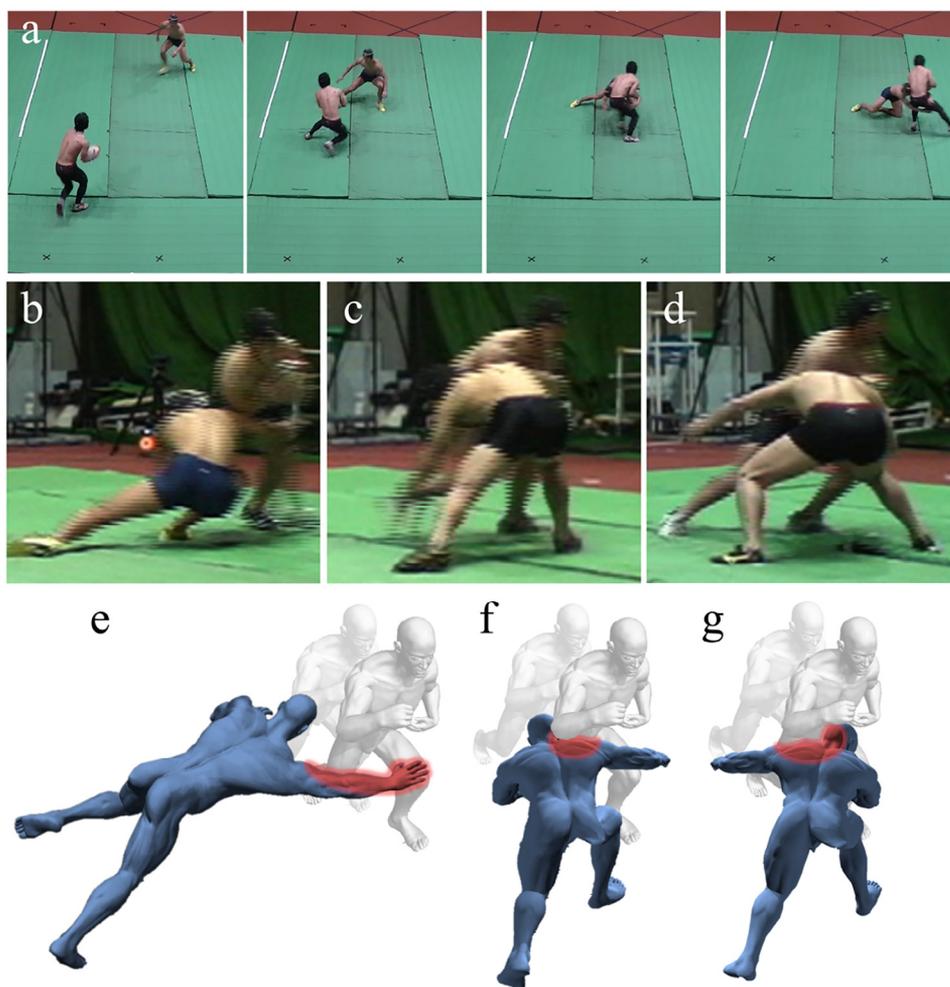


Figure 2 (a) Sequence of 1-on-1 duels. (b, e) Arm tackle. (c, f) Shoulder tackle. (d, g) Head-in-front tackle.

Definitions of tackles

In a normal ideal tackle, it is recommended that the tackler's head is positioned at the side of the ball carrier.^{12,26,35} In this study, a documented tackle was classified into 1 of 3 types based on the tackler's first point of contact on the ball carrier and the head position at IM0 by using the following definitions: For an arm tackle (Fig. 2, b, e), the first point of contact was between the hand and upper arm. For a shoulder tackle (Fig. 2, c, f), the first point of contact was between the shoulder and neck. For a head-in-front tackle (Fig. 2, d, g), the first contact point was the same as that in the shoulder tackle but the head was positioned in front of the ball carrier.²⁹ We also evaluated whether all of these tackles were legal according to the laws of World Rugby.

The ball carrier's movements, such as straight running or cutting, just before the impact were also analyzed to address the effects of these movements on the types of tackles.

Statistical analysis

In this study, we applied parametric tests for the comparison analysis because all of the data were normally distributed (Shapiro-Wilk test). Before the main analysis, Pearson correlation analyses

among the variables of orientations were performed. The primary analysis aimed to compare the shoulder, neck, and trunk orientations between the tasks to elucidate the characteristics of these tackles. Comparisons of these orientations of the 2 distinct tackles (arm and head-in-front tackles) with the normal shoulder tackle as a reference were performed to elucidate the characteristics of these tackles with 1-way repeated-measures analysis of variance, followed by the Games-Howell post hoc test. A secondary analysis was performed to address the effects of the ball carrier's movements (running straight or cutting) and the tackle type using the χ^2 test. $P < .05$ was considered statistically significant, and all tests were 2-sided. The data analyses were conducted with SPSS software for Macintosh (Apple, Cupertino, CA, USA), version 21.0 (IBM, Armonk, NY, USA).

Results

In this study, 65 trials (38 normal shoulder tackles, 23 arm tackles, and 4 head-in-front tackles) were selected and the neck, shoulder, and trunk orientations at impact were analyzed. All of these were evaluated as legal tackles. Typical cases of each tackle are shown in Figure 4.

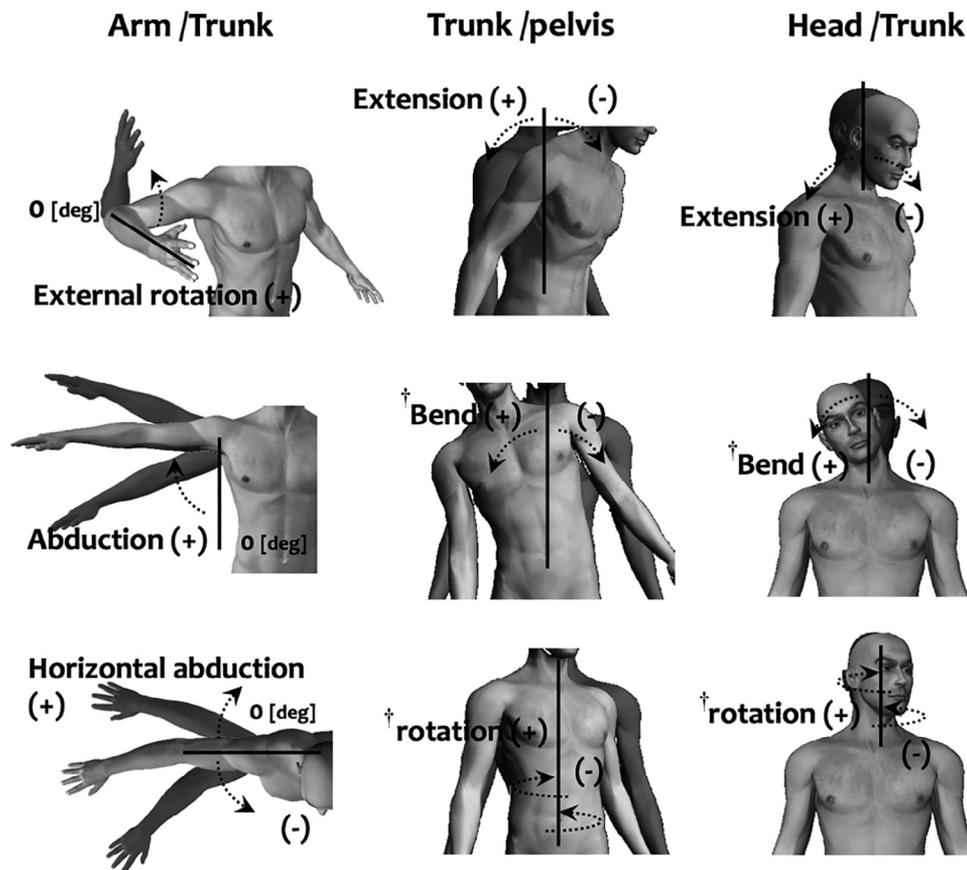


Figure 3 Segments of interest. The daggers indicate that a positive direction is the same as the impacted side of the shoulder.

Before the main analyses, Pearson correlations between the orientations were addressed among all types of tackles. Scatter plots and linear correlations showed that the following 3 pairs of variables at impact were significantly correlated with each other: neck extension and shoulder abduction ($r = -0.30$, $P = .03$), neck rotation and shoulder external rotation ($r = 0.29$, $P = .04$), and shoulder abduction and horizontal abduction ($r = -0.49$, $P < .001$) at the time of impact (Supplementary Fig. S1).

In the main analysis, neck, shoulder, and trunk orientations at impact were compared between the different types of tackles. In comparison with the shoulder tackle as the reference, shoulder abduction was significantly higher in the arm tackle ($P < .001$) and external rotation of the shoulder was lower in the head-in-front tackle ($P = .02$). In addition, neck extension was significantly lower in the head-in-front tackle in comparison with the normal shoulder tackle ($P < .001$). The mean values for each orientation of the body segments during the impact are summarized in Table I.

In the secondary analysis, the effect of the ball carrier's movement on the tackle types was assessed. Among 65 trials, the ball carrier changed his running course by cutting in 19 trials (29.3%, Table II). Compared with the shoulder tackle, the frequency of the arm tackle was significantly increased if the ball carrier changed his course (odds ratio, 6.9; $P < .001$).

Discussion

In this study, the normal shoulder tackle ($n = 38$) demonstrated mean shoulder abduction of 75° , external rotation of 54° , and horizontal abduction of -30° at impact. In addition to this common tackle, we observed 2 other situations, the arm tackle ($n = 23$) and the head-in-front tackle ($n = 4$), in which the tackler more likely to undergo shoulder dislocation during a 1-on-1 front tackle.^{8,23}

Risk of shoulder dislocation in arm tackle

The arm tackle had a significantly higher shoulder abduction angle than the shoulder tackle at impact ($P < .001$). This finding could be explained by the fact that when the tackler fails to approach the opponent ball carrier in a 1-on-1 duel, the tackler has no choice but to catch and wrap the ball carrier using the arm, instead of ideally hitting with the shoulder.²³ Regarding the orientation of the shoulder joint, a longer lever arm with greater abduction may be responsible for the less stable shoulder at impact. This results in greater shoulder external rotation and horizontal abduction to be forcibly moved to an end range of the shoulder, which appears to be a risk factor for shoulder dislocation.^{5,20,21,23,31}

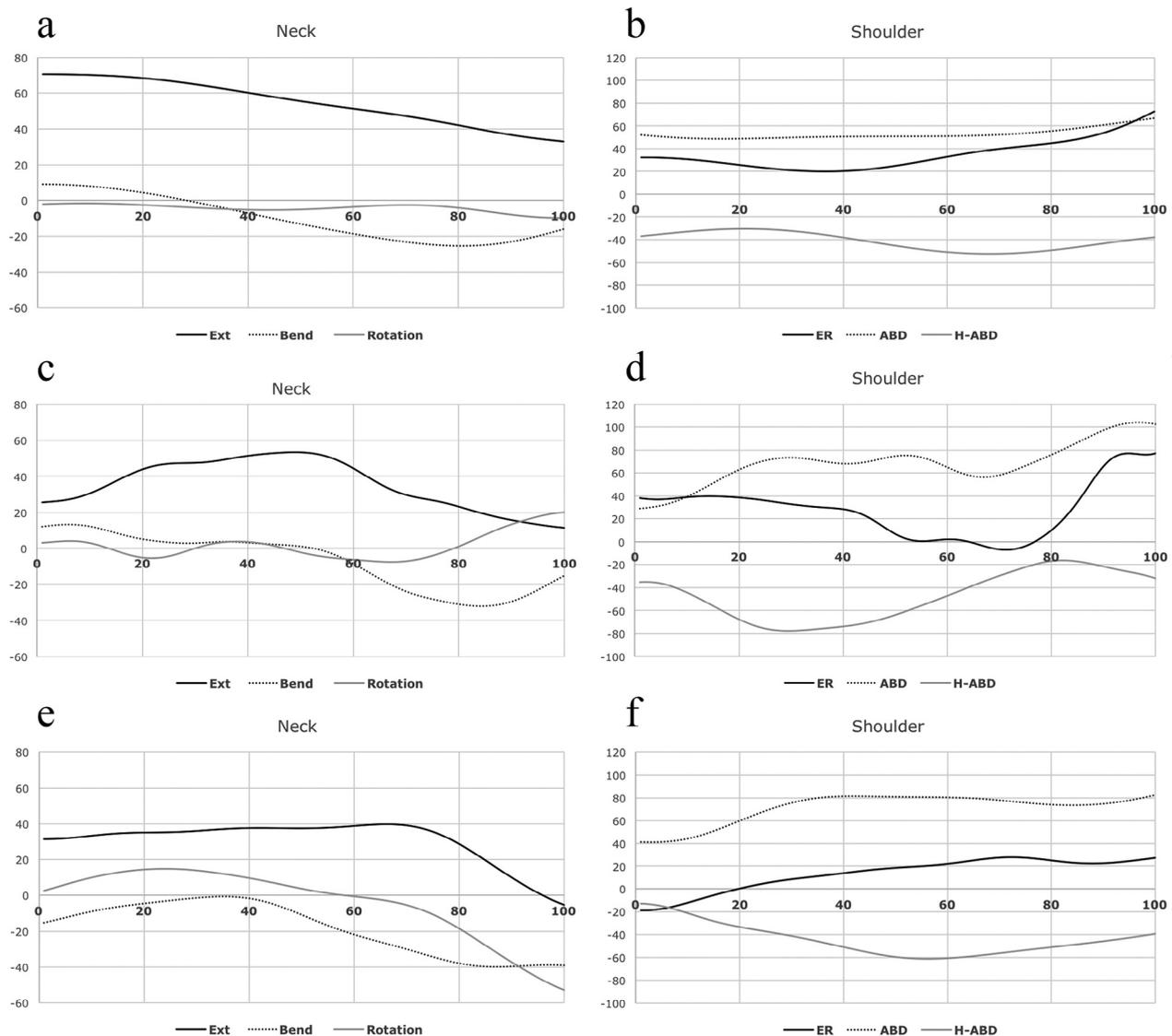


Figure 4 Case example of each tackle. Neck and shoulder orientations are represented from 2 footsteps before impact (0% on the x-axis) to the impact (100% on the x-axis). A positive direction on the y-axis is the same as the direction to the impacted side of the shoulder. (a, b) Shoulder tackle. (c, d) Arm tackle. (e, f) Head-in-front tackle. *Ext*, extension; *ER*, external rotation; *ABD*, abduction; *H-ABD*, horizontal abduction.

Our study also demonstrated that arm tackles tended to occur more frequently when the ball carrier changed his running course (odds ratio, 6.9). Past studies that designed a 1-on-1 tackling maneuver, as in our study, mentioned that the ball carrier's side step and relative running speed were important with regard to incomplete tackles.^{32,33} Thus, we believe that instruction on the ideal approach to the ball carrier is needed to prevent this type of tackle.

Risk of shoulder dislocation in head-in-front tackle

In the head-in-front tackles, the tacklers successfully kept their body positions square to the ball carrier in the ap-

proach phase, and the subsequent contact occurred firmly with their shoulder.²³ These characteristics were the same as those of the "normal" shoulder tackle, which is recommended by World Rugby,³⁵ except that the tacklers placed the head in front of the ball carrier. Our study demonstrated that the head-in-front tackle, similarly to the arm tackle, tended to be characterized by greater shoulder abduction than with the normal shoulder tackle, resulting in a less stable shoulder,^{20,21} although this tendency was not statistically significant because of the small sample size ($n = 4$). However, contrary to the other 2 tackle types, the head-in-front tackle had significantly lower shoulder external rotation at impact than the normal shoulder tackle ($P = .02$). In addition, it was evident that significantly less neck extension ($P < .001$) and a tendency for less ipsilateral rotation

Table I Variables of each orientation and comparison between tackles (1-way analysis of variance and Games-Howell test)

Variable	Mean (95% CI), °		
	Shoulder tackle* (n = 38)	Arm tackle (n = 23)	Head-in-front shoulder tackle (n = 4)
Neck			
Extension	28 (22 to 34)	28 (20 to 36), <i>P</i> = .90	13.2 (6 to 20), <i>P</i> < .001 [†]
Bending [‡]	-12 (-16 to -7)	-13 (-21 to -4), <i>P</i> = .97	-5 (-20 to 11), <i>P</i> = .44
Rotation [‡]	-19 (-23 to -15)	-18 (-26 to -10), <i>P</i> = .74	-35 (-68 to -3), <i>P</i> = .40
Shoulder			
ER	54 (48 to 60)	61 (49 to 73), <i>P</i> = .42	33 (20 to 47), <i>P</i> = .02 [†]
Abduction	75 (68 to 82)	95 (84 to 107), <i>P</i> < .001 [†]	97 (59 to 136), <i>P</i> = .28
Habd	-30 (-35 to -26)	-36 (-43 to -28), <i>P</i> = .36	-46 (-67 to -25), <i>P</i> = .44
Trunk			
Extension	-59 (-63 to -55)	-59 (-66 to -52), <i>P</i> = .85	-55 (-65 to -44), <i>P</i> = .48
Bending [‡]	-22 (-27 to -17)	-13 (-23 to -3), <i>P</i> = .08	-25 (-49 to -1), <i>P</i> = .88
Rotation [‡]	4 (-2 to 9)	10 (3 to 16), <i>P</i> = .92	7 (2 to 12), <i>P</i> = .42

CI, confidence interval; ER, external rotation; Habd, horizontal abduction.

* Reference of comparison.

[†] Statistically significant.

[‡] A positive direction is the same as the impacted side of the shoulder.

Table II Summary of tackle types (N = 65)

Type of tackling	Ball carrier's running course just before impact, n (row %)		Odds ratio (95% CI)
	Straight	Cutting	
Arm (n = 23)	10 (43.5)	13 (56.5)	6.9 (2.1-23.0), <i>P</i> < .001*
Shoulder (n = 38)	32 (84.2)	6 (15.8)	— (reference)
Head in front (n = 4)	4 (100)	0 (0)	NE, <i>P</i> = .53 [†]
Total (N = 65)	46 (70.8)	19 (29.2)	—

CI, confidence interval; NE, not estimated.

* Statistically significant.

[†] Fisher exact test.

occurred in comparison with the normal shoulder tackle (Fig. 4). These kinematic characteristics were consistent with a previous report that investigated the mechanisms of primary shoulder dislocation by real-world video analysis and were different from the arm tackle.²³ Although it remains unknown why the head-in-front tackle poses an increased risk of shoulder dislocation, there may be several hypotheses: First, several researchers have mentioned that if the neck position is distorted because of a change in the direction of gaze, the integration of sensory coordinates may be disrupted.^{7,9,19} Second, our hypothesis is that neck orientation may affect scapular position, which leads to an altered shearing force on the glenoid. In fact, past investigators demonstrated that neck orientation affects scapular position; the subject with neck flexion tends to have less scapular tipping, as well as less glenohumeral range of motion.¹⁸ We

therefore assumed that a tackler's inappropriate posture with lowering and contralateral rotation of the head decreases proprioception of the affected arm and that the posture also influences the shearing force on the glenohumeral joint via scapular orientation.¹³ Both of these are important factors in anterior shoulder dislocation. Nevertheless, it remains unresolved from our study whether a levering force or direct arm contusion to the glenoid is essential for this type of shoulder dislocation. Thus, we should perform further exploration to clarify this point in the near future.

Limitations

Our study had several limitations that should be noted. First, our study provided no information about scapular motion or the kinetic aspects of the shoulder joint, both of which are important in understanding risk factors for shoulder injury. Although the humerothoracic angle in this study still provides valuable information for assessing shoulder orientation, further information on the kinematics of the glenohumeral joint and kinetic analysis using other methods will help to clarify the characteristics of tackling in the future.

Second, the motions of the body segments were measured using traditional motion-capture methods. Skin motion artifacts may have introduced significant errors, although a past study demonstrated that the artifact of sensors on the skin surface is minimal with less than 120° of arm elevation.¹⁴

Finally, there is a possibility that the orientation of the body segments demonstrated in this study may differ from the orientation in real-world shoulder dislocation injuries. We should therefore keep other key factors involved in shoulder dislocation in mind, including the possible existence of kinetic

aspects in the injury mechanisms that are not reflected in the present evidence.

Conclusion

This study indicated that both the arm tackle and the head-in-front tackle have higher angles of shoulder abduction at impact, while the latter tackle also involves significantly lower shoulder external rotation with less neck extension than the normal shoulder tackle. These findings indicated that the mechanism of shoulder dislocation may be different in each of the tackles. Further study is needed to clarify whether these issues may play a role in helping to prevent shoulder dislocation in rugby tackling.

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Disclaimer

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Supplementary data

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