Video analysis of tackling situations leading to concussion in collegiate rugby union

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Received: August 8, 2018 / Accepted: November 9, 2018

Abstract The purpose of this study was to clarify the tackling characteristics of tacklers relationship causing concussion based on match video records in the collegiate rugby union. Twenty-three tackling situations leading to concussion were identified based on injury data and video records. Additionally, 94 tackling situations in which concussion did not occur were extracted from the same matches. Overall, one hundred and seventeen tackling situations were analyzed in detail, and categorized into three tackle phases and outcomes. Logistic regression analysis was performed to clarify which tackling characteristics in the tackler relationship had a higher chance of concussion. The chance of concussion occurring to a tackler was significantly higher for collision tackle (odds ratio [OR] 84.00, 95% CI 8.27–853.11), making initial contact with tackler's head/neck (OR 23.47, 95% CI 4.80–114.71), no arm usage by tackler (OR 3.54, 95% CI 1.23–10.20) and tackle break by ball-carrier (OR 5.76, 95% CI 1.67–19.85). Conversely, tacklers were significantly less likely to suffer concussion when the ball-carrier performed a side step before initial contact (OR 0.11, 95% CI 0.01–0.85). In conclusion, tackles leading to concussion were related to various factors in the time period before and after tackle as well as in the moment of tackle. The results of this study suggest that further research needs to be done, given the relationship between each tackling characteristic. Moreover, we consider that players and coaching staff should improve tackle skill safety by clarifying the common contributing factors to both suffering concussion and tackle performance.

Keywords : rugby union, concussion, tackle, video analysis

Introduction

In rugby union, players are involved in more tackling situations than in other contact situations¹⁾. Therefore, tackles are the most frequent situations in which injuries happen at any competition level²⁻⁴⁾. Concussion is especially common in tacklers⁵⁻⁷⁾. According to a systematic review on head injuries, Prien et al. showed that rugby union had a higher incidence of concussion (per 1000 player-hours) than any other contact/collision sport, including American football⁸⁾. In addition, rugby players under 18 years old had the highest incidence of concussion (per 1000 athlete exposures) in comparison to other young athletes⁹⁾.

World Rugby has provided information on the assessment and management of concussed players, such as the Sports Concussion Assessment Tool (SCAT) and Graduated Return to Play (RTP) protocol. It has been proposed that the assessment of concussed players should be made using SCAT or other sideline assessment tools and management after concussion should follow RTP protocol with a stepwise process¹⁰⁾. In addition, the most advanced Head Injury Assessment (HIA, formally pitch-side concussion assessment) process was introduced at the Rugby World Cup 2015¹¹⁾.

On the other hand, rugby union has succeeded in decreasing the number of severe injuries by introduction of some injury prevention programs, for example, RugbySmart in New Zealand and BokSmart in South Africa.

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Scrum-related spinal cord injuries decreased by introducing RugbySmart¹²⁾. Similarly, since BokSmart was introduced, youth rugby union players have had a significantly lower likelihood of catastrophic injuries occurring, including spinal cord injuries, in comparison to before the introduction of BokSmart¹³⁾. Thus, although the effectiveness of injury prevention programs has been shown for spinal cord injuries, effective injury prevention programs for concussion do not have just one point of view. Therefore, concussion prevention is still an important topic.

For developing the prevention of concussion, it is essential to clarify inciting events causing concussion. Research on inciting events leading to concussion and HIA with video records has progressed rapidly in recent years¹⁴⁻¹⁷⁾. Previous research, targeting the European professional level, suggested there was a higher risk of concussion when the tackler accelerated into a tackle or had head contact with the ball-carrier's head^{14,17)}. Sobue et al. showed that concussion occurred significantly more often during tackles with incorrect head positioning (i.e. in front of the ball-carrier)¹⁸⁾. The study analyzed dangerous contact play, tackles with incorrect head positioning, the duration and number of steps taken by the ball-carrier prior to a tackle, and clarified the relationship between the incidence of concussion¹⁸⁾. This study provided important suggestions for the prevention of concussion in tacklers, however, further analysis of tackles causing concussion is required for younger players at a community level who are technically immature.

The purpose of this study was to clarify the tackling characteristics leading to concussion based on match video records in the collegiate rugby union. We hypothesized that the incidence of concussion depends on the movement of the tacklers and ball-carrier before a tackle. We believe that the results of the present study provide important information toward concussion prevention.

Materials and Methods

Match concussion data. Players from a Japanese collegiate rugby union team were recruited for the study. All matches, which were conducted from the 2008–2009 playing season to the 2013–2014 playing season, were included in our analysis. In total, 402 players (ages 18–24 years) took part during 6 playing seasons, of which 250 players played more than one full season. Players were excluded from the study who enrolled in the team after a given season started or retired from the team before the season was completed. The Ethics Committee of the Faculty of Health and Sport Science at the University of Tsukuba approved the present study (Reference numbers: 27-88), and all players provided written informed consent before participating.

Over 6 playing seasons, total exposure time was 5300 player-hours in 265 matches. In all playing seasons, medically-trained persons recorded injuries according to

the consensus statement for injury surveillance¹⁹⁾. Furthermore, every player who suffered a head impact event, or who was suspected of concussion in a match²⁰⁾ received medical screening by a team doctor in accordance with the concussion guidance published by World Rugby²¹⁾. In the present study, all suspected or confirmed concussions were included in the analysis²⁰⁾. A priori power analysis indicated that to achieve a power (1- β) of 0.80 with a confidence level of 95% ($\alpha = 0.05$) and effect size (Cramer's V) of 0.50 and $df = 4$, an estimated total sample size of 48 events, including both injury and non-injury events, would be required.

Video analysis. The video analysis was composed of three steps. At first, we identified concussion events caused by tackling based on injury surveillance data, and then picked up those scenes from reviewing the match video records. In this study, a tackle was defined as “any event where one or more tacklers attempted to stop or impede the ball-carrier whether or not the ball-carrier was brought to ground”²²⁾.

Secondly, all tackles which the concussed player made before the concussion happened in the match were extracted and included in the video analysis as controls. However, tackles were excluded from the analysis when we did not code them because of difficulty in identification of the precise tackling situations or poor quality of the video recording.

Finally, two evaluators experienced as medically-trained personnel in rugby coded all tackling events from 20 factors in three phases and tackle outcomes, which were featured in previous research on video analysis of tackling situations (Table 1 and 2)²²⁻²⁴⁾. The three tackle-phases in tackling situations are: pre-contact (up to 0.5 seconds preceding first contact), contact (first instance of contact) and post-contact (until identified outcomes of the tackling situation in Table 2)^{22,23)}. In addition, we divided outcomes of the tackling situation into tackle performance outcomes and tackle results²³⁾. Tackling factors were analyzed separately to seek for any association of each tackle-phase and tackle outcome with concussion.

We calculated the kappa statistic (κ) to test the inter-tester reliability of the two raters for each of the coded tackling characteristics. Five players who sustained concussion by tackling were randomly selected. The κ coefficients between 0.41 and 0.60 showed moderate agreement between repeated measures, between 0.61 and 0.80 represented fair to good agreement, and between 0.81 and 0.99 showed excellent agreement²⁵⁾. The κ statistic results for inter-tester reliability were shown as follows: $\kappa = 0.85$ (pre-contact), $\kappa = 0.84$ (contact), $\kappa = 0.81$ (post-contact), $\kappa = 0.87$ (tackle outcomes).

Statistical analysis. We performed logistic regression analysis with the SPSS version 24.0 package (IBM Japan Inc, Tokyo, Japan) after descriptive statistics (frequency,

Table 1. Tackling characteristics of pre-contact phase variable and their descriptions

Categorical variables	Descriptions
Stance	
Flat footed	Tackler standing square with feet aligned and flat on the ground
Back foot	Tackler stepping backwards as ball-carrier approaches
Split forward	Tackler standing with staggered stance
No stance	Tackler diving or sliding into contact
Direction of movement of tackler	
Forward	Toward the ball-carrier
Backwards	Back pedaling, i.e. away a ball-carrier
Lateral	Towards the touchline (across the field)
No movement	Tackler did not move before tackle situation
Head position	
Up and forward	Towards ball-carrier
Away	Away from ball-carrier
Down	Towards the ground
In motion	Tackler's head was moving in attempt to follow the ball-carrier
Speed of tackler	
Fast	Running/sprinting (purposeful running with maximal effort, high knee lift)
Moderate	Jogging (non-purposeful slow running with low knee lift)
Slow	Stationary/walking (no or few visible foot movement)
Speed of ball-carrier	
Fast	Running/sprinting (purposeful running with maximal effort, high knee lift)
Moderate	Jogging (non-purposeful slow running with low knee lift)
Slow	Stationary/walking (no or few visible foot movement)
Evasive maneuver performed by ball-carrier	
Straight run	Ball-carrier ran straight at the defense or goal-line
Side step	Ball-carrier performed an evasive step initiated by either leg
Arcing run	Ball-carrier performed arcing run
Lateral run	Ball-carrier performed a run from touchline to touchline
Diagonal run	Ball-carrier ran at an angle, instead of straight at the tackler
Be tackled	Ball-carrier was tackled by the other tacklers and no movement any direction
No movement	Ball-carrier did not move before tackle situation
Orientation of tackler in relation to ball-carrier	
In front	Tackler and ball-carrier moving head on towards each other
Side	Tackler moving in from the ball-carrier's side
Oblique	Tackler moving into ball-carrier at an angle
Behind	Tackler chasing ball-carrier towards own try-line
Attacking pattern of play	
Immediate attack	When the ball-carrier received the ball directly from breakdown, such as "pick and go"
Close attack	When the ball-carrier received the ball through no more than one pass from breakdown
Middle attack	When the ball-carrier received the ball through a pass from the first receiver
Wide attack	When the ball-carrier received the ball through a pass from outside of the first receiver
Counter-attack	When the ball-carrier received the ball through an turnover or the even ball
Phase continuation	When the ball-carrier received the ball through continuation of the phase, such as "offloads pass"
Position of tackler and ball-carrier	
PR & HO	The forward players who usually wear jersey No.1, 2 and 3
LO	The forward players who usually wear jersey No.4 and 5
FL & No.8	The forward players who usually wear jersey No.6, 7 and 8
SH & SO	The back players who usually wear jersey No.9 and 10
CTB	The back players who usually wear jersey No.12 and 13
WTB & FB	The back players who usually wear jersey No.11, 14 and 15

Table 2. Tackling characteristics of contact phase, post-contact phase, tackle outcomes and their descriptions

Categorical variables	Descriptions
<i>Contact phase</i>	
Type of tackle	
Arm tackle	Tackler impedes ball-carrier with upper limbs
Collision tackle	Tackler impedes ball-carrier without binding
Jersey tackle	Tackler holds ball-carrier's jersey
Lift tackle	Tackler raises ball-carrier's hip above ball-carrier's head
Shoulder tackle	Tackler contacts ball-carrier with the shoulder as the first point of contact followed by use of arms
Smother tackle	Tackler uses chest and warps both arms around ball-carrier
Tap tackle	Tackler trips ball-carrier with hand on lower limb below the knee
Direction of tackler	
Front	Tackler contacts in front of the ball-carrier
Side	Tackler contacts with ball-carrier's side
Oblique	Tackler contacts with ball-carrier at an angle
Behind	Tackler contacts with ball-carrier's from behind
Ball-carrier body region struck during tackle	
Head/neck	Above the shoulder with any connection with the head/neck
Chest region	From ball-carrier's shoulder level to the arm pit level, including the arms
Trunk region	Above the ball-carrier's hip level to the arm pit level
Lower leg region	Area between ball-carrier's hips and toes
Tackler body region struck during tackle as the first point of contact	
Head/neck	Tackler contacts the ball-carrier with the head/neck
Shoulder	Tackler contacts the ball-carrier with the shoulder
Chest	Tackler contacts the ball-carrier with the chest
Arm	Tackler contacts the ball-carrier with the arm
Hand	Tackler contacts the ball-carrier with the hand
Head placement	
Above	Tackler's head higher than ball-carrier's body
Beside	Tackler's head next to ball-carrier's body
In front	Tackler's head in front of ball-carrier's body
Behind	Tackler's head at the back of ball-carrier's body
<i>Post-contact phase</i>	
Leg drive by tackler	
Absent	No leg drive
Moderate	Moderate knee movement, with no high lift
Strong	High, rapid knee lift
Leg drive by ball-carrier	
Absent	No leg drive
Moderate	Moderate knee movement, with no high lift
Strong	High, rapid knee lift
Arm usage	
Pulling	Tacklers uses arm after initial contact to pull ball-carrier towards him
Wrapping	Tacklers uses arms to enclose region of ball-carrier's body
No arm usage	Tacklers did not keep using their arms
<i>Tackle outcomes</i>	
Tackler performance outcomes	
Offload	The ball-carrier is able to pass the ball to a teammate during tackle
Tackle break	The ball-carrier successfully penetrates the attempted tackle and continues to advance
Move forward	The ball-carrier is tackled, but does not go to ground and continues to move forward
Maul formed	The ball-carrier does not go to ground, subsequently a maul begins
Tackle completed	When an offload, tackle break, move forward or maul formed does not occur – either player goes to ground or ball-carrier is held up and cannot progress further
Tackle result	
Failure	When ball-carrier was able to offload the ball, or break an attempted tackle, or form maul, or an infringement was committed, or when a try was scored
Success	After contact, the tackler prevents the ball-carrier and ball progressing towards his try-line and does not concede a penalty

%), to exclude tackling characteristics that had a percentage frequency of 0% from independent variables of the logistic regression analysis. We also calculated the Fisher's chi-square statistic and Cramer's V as the effect size using a chi-square test with SAS version 9.4 (SAS institute Japan, Tokyo, Japan). Tackling characteristics that had a slight relationship to concussion occurrence were excluded from the logistic regression analysis. Cramer's V of 0.10–0.30, 0.30–0.50, and > 0.50 were considered small, moderate, and large, respectively²⁶. We reported the odds ratios (OR) and 95% confidence intervals (95% CI) by multiple logistic regression analysis ($P < 0.05$). We put selected tackling characteristics in multiple logistic regression based on binomial logistic regression ($P < 0.05$). When categorical variables were put into multiple logistic regression analysis, entry variables were computed relative to a reference or base category. For independent variables, we selected characteristics with the highest frequency as the reference category. For the dependent variable, we selected "no concussion" as the base category. In this study, if the OR of a certain tackling characteristic was more than 1.0, concussion was more likely to occur, compared to the reference category. Conversely, if the OR of a certain tackling characteristic was less than 1.0, concussion was less likely to occur compared to the reference category.

Results

During six playing seasons, a total of 56 concussions occurred in the 265 matches, and we identified 40 concussions (71.4%) from video records of the matches, of which 23 concussions were the result of tackling. In addition, we extracted 94 tackling situations as controls, which the tacklers performed before sustaining a concussion in the same match. In total, 117 tackling situations were identified from video footage. Tables 3 and 4 show the frequency distribution of all the tackle situations and effect size (Cramer's V).

In the pre-contact phase, tacklers were significantly less likely to sustain a concussion when the ball-carrier performed a side step initiated by either leg (OR = 0.11 [95% CI: 0.01–0.85]; $P = 0.035$), in comparison to when the ball-carrier ran straight towards tacklers (Table 5). In the contact phase, tacklers were significantly more likely to sustain a concussion when they performed a collision tackle (OR = 84.00 [95% CI: 8.27–853.11]; $P = 0.000$), in comparison to a shoulder tackle (Table 5). Tacklers had a significantly higher likelihood of concussion when tacklers contacted with their head/neck as the first point of contact (OR = 23.47 [95% CI: 4.80–114.71]; $P = 0.000$), compared to making initial contact with their shoulder (Table 5). In the post-contact phase, tacklers were significantly more likely to sustain a concussion when they did not keep pulling, gripping or wrapping the ball-carrier with their arms (OR = 3.54 [95% CI: 1.23–10.20]; $P =$

0.019), compared to when they wrapped the ball-carrier (Table 5). The chance of concussion occurring in the tackler was significantly higher when the ball-carrier successfully penetrated the attempted tackle (OR = 5.76 [95% CI: 1.67–19.85]; $P = 0.006$), compared to tackle completed (Table 5). The tackler also seemed to be significantly more likely to experience a concussion when the ball-carrier was tackled, but did not go to the ground and continued to move forward (OR = 3.39 [95% CI: 0.92–12.55]; $P = 0.068$), although this was not significant (Table 5).

Discussion

This study is the first research analyzing tackle situations in which collegiate rugby players experienced a concussion during games. In the previous study, all injured player's previous non-injury situations in the same match and previous matches were extracted as controls¹⁵. Since the game aspect and tactics change for the opponent team, we considered that it is difficult to compare by simply including tackles extracted from other matches. Therefore, in the present study, all tackles before concussion was experienced by the concussed tackler were extracted as controls from the same matches in a different method compared to the previous study. When we estimated the number of concussions according to a systematic review, there were 3.9 concussions in 50 matches regardless of inciting events (Pooled match concussion incidence: 3.89/1000 player-hours)⁸. In the present study, we identified 40 concussions in 265 matches during six playing seasons based on injury data and video records. It was then calculated at 7.5 concussions in 50 matches, indicating more concussions occurred than estimated. However, we used 23 tackles leading to concussion in logistic regression analysis. Furthermore, it is an important issue to increase the number of tackles leading to concussion so as to improve the accuracy of logistic regression analysis. Therefore, we consider that further research is needed for the development of a research environment collecting longitudinal injury data and video records to clarify the tackling characteristics leading to concussion, with high accuracy.

In this study, we have shown that five tackling characteristics affect concussion for a tackler. Four tackling characteristics have a significantly high risk of concussion for the tackler: (1) collision tackle in the contact phase, in which tacklers impede the ball-carrier without binding, (2) tackler's head/neck as the first point of contact in the contact phase, (3) no arm usage in the post-contact phase, in which tacklers did not keep using their arms until the post-contact phase, (4) tackle break in tackle outcomes, the ball-carrier successfully penetrates the attempted tackle and continues to advance. Conversely, concussion is significantly less likely to occur in one tackling characteristic: (1) side step by the ball-carrier in the pre-contact phase, in which the ball-carrier performs an evasive step initiated by either leg.

Table 3. The frequency distribution for occurring concussion and effect size in pre-contact phase

Categorical variables	Concussion (n = 23)	No injury (n = 94)	Fisher's χ^2 test	P	Effect size (Cramer's V)
	n (%)	n (%)			
Pre-contact phase					
Stance			2.01	0.559	0.14
Flat footed	11 (47.8)	33 (39.3)			
Back foot	0	1 (1.2)			
Split forward	8 (34.8)	24 (28.6)			
No stance	4 (17.4)	26 (31.0)			
Direction of movement of tackler			1.62	0.705	0.12
Forward	13 (56.5)	47 (50.0)			
Backwards	0	1 (1.1)			
Lateral	9 (39.1)	34 (36.2)			
No movement	1 (4.3)	12 (12.8)			
Head position			2.65	0.333	0.16
Up and forward	17 (77.3)	70 (80.5)			
Away	0	0			
Down	4 (18.2)	7 (8.0)			
In motion	1 (4.5)	10 (11.5)			
Speed of tackler			0.31	0.880	0.05
Fast	9 (39.1)	32 (34.0)			
Moderate	7 (30.4)	28 (29.8)			
Slow	7 (30.4)	34 (36.2)			
Speed of ball-carrier			0.13	0.887	0.03
Fast	14 (60.9)	61 (64.9)			
Moderate	6 (26.1)	22 (23.4)			
Slow	3 (13.0)	11 (11.7)			
Evasive maneuver performed by ball-carrier			13.50	0.048	0.34
Straight run	17 (73.9)	32 (34.0)			
Side step	1 (4.3)	18 (19.1)			
Arcing run	1 (4.3)	8 (8.5)			
Lateral run	0	1 (1.1)			
Diagonal run	0	8 (8.5)			
Be tackled	4 (17.4)	23 (24.5)			
No movement	0	4 (4.3)			
Orientation of tackler in relation to ball-carrier			2.02	0.722	0.13
In front	10 (43.5)	42 (44.7)			
Side	4 (17.4)	20 (21.3)			
Oblique	9 (39.1)	27 (28.7)			
Behind	0	5 (5.3)			
Attacking pattern of play			6.66	0.254	0.24
Immediate attack	3 (13.0)	15 (16.0)			
Close attack	11 (47.8)	22 (23.4)			
Middle attack	4 (17.4)	23 (24.5)			
Wide attack	1 (4.3)	2 (2.1)			
Counter-attack	1 (4.3)	13 (13.8)			
Phase continuation	3 (13.0)	19 (20.2)			
Position of tackler			3.50	0.551	0.17
PR & HO	5 (21.7)	16 (17.0)			
LO	3 (13.0)	9 (9.6)			
FL & No.8	7 (30.4)	26 (27.7)			
SH & SO	4 (17.4)	20 (21.3)			
CTB	2 (8.7)	20 (21.3)			
WTB & FB	2 (8.7)	3 (3.2)			
Position of ball-carrier			6.35	0.296	0.23
PR & HO	6 (26.1)	19 (20.2)			
LO	1 (4.3)	10 (10.6)			
FL & No.8	9 (39.1)	19 (20.2)			
SH & SO	2 (8.7)	6 (6.4)			
CTB	1 (4.3)	14 (14.9)			
WTB & FB	4 (17.4)	26 (27.7)			

Table 4. The frequency distribution for occurring concussion and effect size in contact phase, post-contact phase and tackle outcomes

	Concussion (n = 23)	No injury (n = 94)	Fisher's χ^2 test	P	Effect size (Cramer's V)
Categorical variables	n (%)	n (%)			
Contact phase					
Type of tackle			33.17	0.000	0.54
Arm tackle	4 (17.4)	14 (15.1)			
Collision tackle	8 (34.8)	1 (1.1)			
Jersey tackle	0	10 (10.8)			
Lift tackle	0	0			
Shoulder tackle	4 (17.4)	42 (45.2)			
Smother tackle	7 (30.4)	26 (28.0)			
Tap tackle	0	0			
Direction of tackler			5.72	0.138	0.22
Front	8 (34.8)	31 (33.0)			
Side	8 (34.8)	40 (42.6)			
Oblique	7 (30.4)	13 (13.8)			
Behind	0	10 (10.6)			
Ball-carrier body region struck during tackle			5.10	0.174	0.21
Head/neck	0	1 (1.1)			
Chest region	5 (22.7)	34 (36.6)			
Trunk region	15 (68.2)	39 (41.9)			
Lower leg region	2 (9.1)	19 (20.4)			
Tackler body region struck during tackle			31.61	0.000	0.52
Head/neck	11 (50.0)	5 (5.4)			
Shoulder	3 (13.6)	32 (34.4)			
Chest	4 (18.2)	25 (26.9)			
Arm	4 (18.2)	18 (19.4)			
Hand	0	13 (14.0)			
Head placement			8.25	0.046	0.29
Above	2 (9.1)	21 (27.3)			
Beside	7 (31.8)	21 (27.3)			
In front	10 (45.5)	15 (19.5)			
Behind	3 (13.6)	20 (26.0)			
Post-contact phase					
Leg drive by tackler			6.12	0.050	0.23
Absent	22 (95.7)	67 (71.3)			
Moderate	1 (4.3)	19 (20.2)			
Strong	0	8 (8.5)			
Leg drive by ball-carrier			9.45	0.009	0.28
Absent	9 (39.1)	37 (39.4)			
Moderate	3 (13.0)	38 (40.4)			
Strong	11 (47.8)	19 (20.2)			
Arm usage			7.06	0.035	0.25
Pulling	2 (9.1)	16 (17.0)			
Wrapping	6 (27.3)	47 (50.0)			
No arm usage	14 (63.6)	31 (33.0)			
Tackle outcomes					
Tackler performance outcomes			9.20	0.040	0.28
Offload	3 (13.0)	13 (13.8)			
Tackle break	9 (39.1)	15 (16.0)			
Move forward	6 (26.1)	17 (18.1)			
Maul formed	0	1 (1.1)			
Tackle completed	5 (21.7)	48 (51.1)			
Tackle result			2.59	0.149	0.15
Failure	12 (52.2)	32 (34.0)			
Success	11 (47.8)	62 (66.0)			

Table 5. Results of logistic regression analysis for tackling factors related to concussion events

Extracted tackling factors	Adjusted OR (95% CI)	P
<i>Pre-contact phase</i>		
Evasive maneuver performed by ball-carrier (straight)	Reference	
Side step	0.11 (0.01–0.85)	0.035
Arcing run	0.24 (0.03–2.04)	0.189
Be tackled	0.33 (0.10–1.10)	0.071
<i>Contact phase</i>		
Type of tackle (shoulder tackle)*	Reference	
Arm tackle	3.00 (0.66–13.61)	0.154
Collision tackle	84.00 (8.27–853.11)	0.000
Smother tackle	2.83 (0.75–10.61)	0.123
Tackler body region as the first point of contact (shoulder)*	Reference	
Head/neck	23.47 (4.80–114.71)	0.000
Chest	1.71 (0.35–8.33)	0.509
Arm	2.37 (0.48–11.79)	0.292
<i>Post-contact phase</i>		
Arm usage (wrapping)	Reference	
Pulling	0.98 (0.18–5.35)	0.981
No arm usage	3.54 (1.23–10.20)	0.019
<i>Tackle outcomes</i>		
Tackle performance outcomes (tackle completed)	Reference	
Offload	2.22 (0.47–10.51)	0.317
Tackle break	5.76 (1.67–19.85)	0.006
Move forward	3.39 (0.92–12.55)	0.068

OR, odds ratios; 95% CI, 95% confidence intervals.

* We put separately in multiple logistic regression analysis because there was a multi-collinearity between type of tackle and tackler body region.

We have shown that a specific tackling characteristic, a side step by the ball-carrier in the pre-contact phase, decreases the chance of concussion for the tackler. This finding is not shown in previous studies on tackling. Quarrie et al. reported that the incidence increased with increasing speed of both ball-carrier and tackler coming into a tackling situation²⁴⁾. On the other hand, Wheeler and Sayers showed that the speed of the ball-carrier toward the tackler decreased relatively when the ball-carrier performed a side step, in comparison to when the ball-carrier ran straight toward a tackler²⁷⁾. Therefore, we consider that a tackler is significantly less likely to sustain concussion when the ball-carrier performs a side step.

In addition, the combinations of several tackling characteristics lead the tacklers to experience concussion. For example, the side step by the ball-carrier in the pre-contact phase was extracted as a contributing factor to suffering concussion. However, as this factor is identified as part of the pre-contact phase, the concussion would happen with another contributing factor in the following contact phase. In the present study, however, we only analyzed a fragmented tackling characteristic related to the occurrence of concussion. Therefore, we recommend that further research needs to be conducted, given the relation-

ships among each tackling characteristic.

A tackler had a significantly higher risk of concussion when the tackle type was a collision tackle or when tacklers did not keep using their arms until the post-contact phase. Our findings regarding the type of tackle is in line with the results of previous research²²⁾. Fuller et al. showed that collision tackles significantly increased the risk of injury for tacklers and the ball-carrier²²⁾. Therefore, tacklers might have a high risk of concussion when tacklers did not use their arms during tackling situations. Additionally, some results of the present study concur with the Hendricks et al. report that tackling characteristics are associated with tackle performance²³⁾. Hendricks et al. reported that a collision tackle had a higher likelihood of tackle failure when compared to a shoulder tackle, and using tackler's arms for either pulling or wrapping the ball-carrier after contact significantly increased the chances of tackle success²³⁾. Tacklers seem to have a higher risk of concussion and tackle failure when they perform a collision tackle and/or do not keep using their arms. Accordingly, we should emphasize safe and effective skills for tacklers, such as binding by their arms from making initial contact through bringing the ball-carrier to the ground.

Tacklers were significantly more likely to sustain concussion when they contacted with their head/neck as the first point of contact. Our finding is in line with the results of previous research on injury scenes using video records in rugby union^{15,28}. It was suggested that tacklers had a higher risk of concussion if tacklers made contact with their head as the first contact point. Therefore, tacklers should initially contact the ball-carrier with their shoulder to prevent concussion in comparison to initially contacting with their head/neck. In addition, Sobue et al. reported that concussion for tacklers occurred significantly more often during tackles with incorrect head positioning¹⁸. Our result concurs with the previous study (Table 4)¹⁸. However, using multiple logistic regression analysis, we did not find that a tackler had a significant risk of concussion when his head was in front of the ball-carrier. We consider that further research on concussion caused by tackling is needed to determine the correct placement of a tackler's head.

A tackle break by the ball-carrier increased the risk of concussion by 5.76 times. It has been believed that safe and effective skills during tackles are able to reduce the risk of injury as well as creating successful outcomes of contact events. In the present study, we have shown that tacklers are significantly more likely to sustain concussion when the ball-carrier successfully penetrates an attempted tackle. It was suggested that coaching effective tackle techniques might prevent concussion. Medical staff and coaching staff should place an emphasis on educating players on the tackling characteristics related to reducing concussion, such as avoiding head-first contact and binding the arms during tackling situations. In addition, players and coaching staff need to determine whether these characteristics have a positive influence on tackle performance. In addition, according to the previous research, no research has yet clarified the tackling characteristics leading to tackle success and failure in the concussed tacklers. Therefore, we consider that players and coaching staff can improve tackle skill safety by clarifying the common contributing factors to both concussion occurring and tackle performance.

Conclusions

We clarified tackling characteristics leading to concussion based on injury data and match video records of collegiate rugby union players. We have shown that the risk of a tackler experiencing concussion is related to tackling characteristics. Tacklers should especially be conscious of safe and useful skills, such as contacting the ball-carrier with their shoulder or binding by their arms from making initial contact through bringing the ball-carrier to the ground. Tacklers were significantly less likely to sustain concussion when the ball-carrier performed a side step initiated by either leg. Thus, we recommend that further research needs to be done, given the relationships be-

tween tackling characteristics. Moreover, we consider that players and coaching staff should improve tackle skill safety by clarifying the common contributing factors to both concussion occurring and tackle performance.

Conflict of Interests

The authors declare no conflict of interests associated with this work.

Acknowledgments

We would like to acknowledge players of the University of Tsukuba Rugby Football Club for their participation and cooperation in this study. Also, we appreciate the contribution made by the medical staff at the University of Tsukuba Rugby Football Club in recording match injuries. This work was supported by JSPS KAKENHI Grant Number16H00722. The authors declare no conflict of interest associated with this work.

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