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Video analysis of concussion injury mechanism in under-18 rugby

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ABSTRACT

Background: Understanding the mechanism of injury is necessary for the development of effective injury prevention strategies. Video analysis of injuries provides valuable information on the playing situation and athlete-movement patterns, which can be used to formulate these strategies. Therefore, we conducted a video analysis of the mechanism of concussion injury in junior-level rugby union and compared it with a representative and matched non-injury sample.

Methods: Injury reports for 18 concussion events were collected from the 2011 to 2013 under-18 Craven Week tournaments. Also, video footage was recorded for all 3 years. On the basis of the injury events, a representative 'control' sample of matched non-injury events in the same players was identified. The video footage, which had been recorded at each tournament, was then retrospectively analysed and coded. 10 injury events (5 tackle, 4 ruck, 1 aerial collision) and 83 non-injury events were analysed.

Results: All concussions were a result of contact with an opponent and 60% of players were unaware of the impending contact. For the measurement of *head position on contact*, 43% had a 'down' position, 29% the 'up and forward' and 29% the 'away' position (n=7). The speed of the injured tackler was observed as 'slow' in 60% of injurious tackles (n=5). In 3 of the 4 rucks in which injury occurred (75%), the concussed player was acting defensively either in the capacity of 'support' (n=2) or as the 'jackal' (n=1).

Conclusions: Training interventions aimed at improving peripheral vision, strengthening of the cervical muscles, targeted conditioning programmes to reduce the effects of fatigue, and emphasising safe and effective playing techniques have the potential to reduce the risk of sustaining a concussion injury.

Practical implications

- Better understanding of concussion injury mechanisms in youth rugby union.
- Injury prevention programmes may offer targeted training interventions to prevent concussion in youth rugby.
- A video analysis method to describe and compare injury mechanisms of concussion to a representative non-injury sample.

INTRODUCTION

A concussion is defined as "a complex pathophysiological process affecting the brain, induced by biomechanical forces".[1] On the basis of a meta-analysis of 29 papers, Gardner *et al*[2] reported an overall incidence of match play concussion in men's rugby union of 4.7 concussions per 1000 player match hours (range 0.2–17.1). Considering the level of play, elite players have a rate of 0.40 concussions per 1000 player match hours (0.3–7.8), schoolboys 0.6 per 1000 player match hours (0.2–10.6), and community-level or subelite-level players 2.1 concussions per 1000 player match hours (1.2–6.9).[2]

Epidemiological studies serve to identify the extent of the problem and, in doing so, satisfy the first step in van Mechelen's 'sequence of prevention' model and the Translating Research into Injury Prevention Practice (TRIPP) model.[3 4] In both injury prevention models, the second step is to establish the aetiology and the mechanisms of injury. A weakness of many sports injury studies is that the injury mechanisms have been insufficiently described to identify suitable injury prevention strategies.[5] Furthermore, a multifactorial approach is required to account for all the factors involved, that is, the inciting event and also the global and local injury mechanisms.[5 6]

A systematic video analysis of injuries provides valuable information on the playing situation and athlete movement patterns, which can be used to formulate injury prevention strategies.[7] Video analysis has been utilised in rugby union to study injury mechanisms in tackle contact situations[8–10] and specifically for concussion in sports such as American football[11] and ice hockey.[12–14] In the Canadian NHL, for example, 3½ years of video records and all cases of medically diagnosed concussions were analysed using a standardised framework for coding the mechanisms of concussions.[12–14] When

studying injury using video analysis, the majority of studies are limited to studying the injury event only. The more favourable approach would be to understand the athlete's injury event in comparison with a representative 'control' sample of non-injury events. Using this approach, one would be able to identify differences or deficiencies in the injury event compared with the non-injury event. Moreover, in a technically demanding sport such as rugby, where technical proficiency is a risk factor for injury,[15 16] this approach will allow for the study of technical discrepancies between the injury and representative non-injury sample.

The implementation of an effective injury prevention strategy relies on a clarification of the extent of the injury problem, and the identification of the injury mechanism. Given the breadth of epidemiological studies on concussion in rugby, the studies identifying the mechanism of injury are lacking. Therefore, we conducted a video analysis of the mechanism of concussion injury in junior level rugby union and compared it with a representative and matched non-injury sample.

METHODS

Overview

Injury surveillance was completed as previously described between 2011 and 2013 at the annual South African Rugby Union (SARU) Coca-Cola Youth Week tournaments.[17] Focusing on the under-18 Craven Week tournaments only, data were obtained from the SARU injury database that is part of an ongoing injury surveillance project coordinated in conjunction with the BokSmart National Rugby Safety Programme.[18] Video footage containing the concussion injury events at the under-18 Craven Week tournament was also accessed for analysis from the SARU video database. Over the 3 years, 18 concussions were recorded. However, only 10 were available for analysis due to the poor quality of the video footage. On the basis of the 10 injury events (5 tackle events—4 tackler injured and 1 ball-carrier injured; 4 ruck and 1 aerial collision), 83 non-injury events were identified (19 tackle, 61 ruck and 3 aerial collisions). The concussion event was first analysed in a similar fashion to that by Hutchison *et al*,[13] using descriptors specific to concussion. Thereafter, both the injury and non-injury events were analysed using coding variables for each phase of play, and for general playing situational variables as outlined by to Hendricks *et al*.[19 20] The authors were granted access to these databases by SARU and the UCT Human Research Ethics Committee (injury database HREC Ref: 438/2011; video database HREC Ref: R042/2013).

Injury data collection

The under-18 Craven Week tournament is an annual fixture aimed at showcasing the country's top schoolboy rugby players. Often a precursor to provincial and national selection, these tournaments are highly contended and thought to be associated with a high injury incidence.[15] Details about each injury sustained during the tournaments were recorded on an injury collection form that was designed on the basis of the Consensus Statement for injury surveillance.[21] Information collected included the player's team, body height, body weight, age, whether the player had medical insurance or not, and the presence or absence of protective gear during the inciting event. Written informed consent allowing for the analysis of recorded information was provided prior to the tournament by all players and by the player's parent or legal guardian in the event of the player being younger than 18 years of age. In addition, assent was required by the injured player or by the player's parent or legal guardian at the time of recording the injury. If a player, by virtue of the nature of their injury on the day, was unable to give written assent, verbal assent was acquired after an explanation of the nature of the study was given.

Data were obtained from the annual SARU injury surveillance project that forms part of the BokSmart National Rugby Safety Programme.[18] Video footage containing the concussion events at the under-18 Craven Week tournament was also accessed for analysis from the SARU video database.

Concussion definition

Before every tournament, all tournament doctors were informed of the most recent concussion protocols and consensus documents to evaluate and manage concussion. World Rugby (then called IRB) Regulation 10 (http://www.worldrugby.org) and SARU Concussion management protocols (http://www.boksmart.com) were initially used in 2011 and 2012; these were based on the previous 2008 Concussion Consensus Statement.[22] From 2013 onwards, the updated 2012 Concussion Consensus Statement,[1] World Rugby Regulation 10 and SARU Concussion protocols were used. These were circulated to the tournament doctors and discussed with them.

Video analysis

Video footage was analysed using Sports Code elite V.6.5.1, using an Apple iMac (Apple, USA) positioned at eye level. The analysis software allows control over the time lapse during each movement, and the recording and saving of each coded instance into a database. During the analysis, the analyst is at liberty to pause, rewind and watch the footage in slow motion. The highest frequency the analyst was able to slow down the motion of the footage was 25 Hz (25 frames per second).

Each concussion was analysed using a list of concussion descriptors that were specific to describing the injury mechanism of concussion but non-specific to the phase of play (tables 1 and 2). For example, *acceleration of the head, head position precontact* and whether the

Table 1 Definitions for Concussion descriptors

Operational variable	Definitions
Scenario—identifies the context that precipitated the eventual injury[12]	
With teammate	Injury occurs as a result of actions/involvement of teammates
With opponent	Injury occurs because of actions/involvement with members of opposing team
Fall/trip	Independent of interference from other players, player loses footing and trips/falls
Other	Any situation not described by above scenarios
Inconclusive	Unable to definitively identify scenario/result of combination of scenarios
Player position	
Hooker	Identified by number on playing jersey or on injury report
Prop	Identified by number on playing jersey or on injury report
Second row	Identified by number on playing jersey or on injury report
Flanker	Identified by number on playing jersey or on injury report
Number eight	Identified by number on playing jersey or on injury report
Scrum Half	Identified by number on playing jersey or on injury report
Fly-half	Identified by number on playing jersey or on injury report
Centre	Identified by number on playing jersey or on injury report
Wing	Identified by number on playing jersey or on injury report
Back	Identified by number on playing jersey or on injury report
Body region: concussed player—area of concussive contact[12]	
Head/face	Initial contact to area of head/face
Neck	Initial contact to neck, that is, area between shoulders and head
Shoulders/arms	Initial contact to shoulders/arms
Torso	Initial contact to torso, that is, body NOT including head and limbs
Hips and below	Initial contact to hip area or below, that is, hip to ankle
Inconclusive	Unable to definitively identify body region/combination of regions
Object or body region of other player—anatomical region or object concussed player makes concussive hit onto	
Head	Concussion contact to area of head/face
Neck	Concussion contact to neck, that is, area between shoulders and head
Shoulders/arms	Concussion contact to shoulders/arms
Torso	Concussion contact to torso, that is, body NOT including head and limbs
Hips and below	Concussion contact to hip area or below, that is, hip to ankle
With ground	Concussion contact occurs onto ground
With pole	Concussion contact occurs into pole
Inconclusive	Unable to definitively identify body region/combination of regions
Body location—refers to anatomical aspect of the region struck (eg, if contact is to forehead=anterior)[12]	
Anterior	Front
Posterior	Back
Lateral	Side
Inconclusive	Unable to definitively report
Acceleration direction of head—identifies biomechanical plane(s) of concussed player's head motion[12]	
Sagittal	Forward—backward movements
Coronal	Side-to-side movements
Transverse	Rotational or twisting movements
Multiplane	Movements incorporating more than one plane
Inconclusive	Unable to definitively identify plane
Head position pre—contact: concussed	
Up and forward	Toward object/contact player
Away	Away from object/contact player
Down	Towards the ground
In motion	Player's head was moving
Head position on contact: concussed player	
Up and forward	Towards object/contact player
Away	Away from object/contact player
Down	Towards the ground
In motion	Player's head was moving

contact was an *anticipated hit*. The list was largely adapted from the 'heads-up checklist (HUC)', a standardised observational tool designed to describe situational factors and injury mechanisms related to concussion in ice hockey.[12] Subsequent to the specific analyses of the mechanism of concussion injury, descriptors for the

Table 2 Definitions for Concussion descriptors

Operational variable	Definitions
Speed at which player is moving prior to injurious event[19 20]	
Stationary	No visible foot movement
Slow	Walking
Moderate	Jogging (non-purposeful slow running with low knee lift)
Fast	Running/sprinting (purposeful running with maximal effort, high knee lift
Speed at which other involved player(s) are moving prior to injurious event[19 20]	
Stationary	No visible foot movement
Slow	Walking
Moderate	Jogging (non-purposeful slow running with low knee lift)
Fast	Running/sprinting (purposeful running with maximal effort, high knee lift
Protective gear: concussed player[12]	
Scrum cap	Concussed player was wearing a scrum cap
Mouthguard	Concussed player was wearing a mouthguard
Both	Concussed player was wearing both a scrum cap and a mouthguard
None	Player was wearing neither a scrum cap nor a mouthguard
Anticipated hit—whether the player was aware of impending contact situation[12]	
Yes	Concussed player was aware of/attuned to impending contact
No	Concussed player was unaware of/oblivious to impending contact
On-field medical attention[12]	
Yes	Player received immediate on-field medical attention
No	Player did not receive immediate on-field medical attention
Game status	
First day/stage game	Game is a qualifier taking place on a day other than the final day
Final day game	Game is on the final day of the tournament
Score at time of injury—from perspective of concussed player's team	
Winning	Concussed player's team is winning the game
Losing	Concussed player's team is losing the game
Tied game	The game is tied at the time of injury
Time played in current game, minute[12]	
0–20	Player has been on the field playing for between 0 and 20 min
20–40	Player has been on the field playing for between 20 and 40 min
40–60	Player has been on the field playing for between 40 and 60 min
60–80	Player has been on the field playing for between 60 and 80 min

phase of play (ie, tackle, ruck or aerial collision) in which the concussion occurred were analysed. Tackle descriptors were analysed in similar manner to Hendricks *et al*.[19 20] Video analysis research for the ruck and aerial collision is limited, and therefore descriptors for the ruck and aerial collision were based on coaching resources and consultations with rugby coaches, sports scientists and rugby administrators. Depending on the phase of play in which the injury occurred (eg, tackle, ruck or aerial collision), all the player's previous non-injury situations in the same phase of play, within the same match and previous matches were identified and analysed as controls. Match situational variables were analysed for all injury and non-injury events.

Statistical analyses was performed by STATA V.12. Given the small sample size, descriptive statistics are reported. Frequency percentage tables were generated for each descriptor under injury and non-injury events. Concussion incidence rate was based on the player match-exposure and the number of concussion events and reported per 1000 player match-hours with corresponding 95% CIs.

Reliability

Three players were randomly selected using a random number generator (http://www.random.org/). Each player's injury and non-injury events were coded on two separate occasions, separated by at least 1 week. The κ statistics were used to test the intrareliability of the coder for each of the three players. For concussion variables κ=0.92, for match situation κ=0.98 and for ruck κ=0.96. For the tackle, precontact κ=0.77, contact κ=0.74, post-contact κ=0.91, and performance outcome κ=1. The κ values between 0.81 and 0.99 represent 'excellent agreement', and values between 0.61 and 0.80 represent 'substantial agreement'.

RESULTS

Player demographics

The average (±SD) age, height, mass and body mass index of the concussed players was 18.1±0.4 years, 183.2 ±7.9 cm, 90.2±10.1 kg and 26.9±2.6 kg/m², respectively. For the 10 players analysed in this study, 5 of the concussed players were not wearing protective gear (ie,

neither a mouthguard nor a scrum cap), 4 players were using a mouthguard and 1 player was using both a mouthguard and a scrum cap.

Performance outcome

Only one of the injurious tackles was 'completed' (n=1 of the 5), as opposed to 53% of non-injury tackles (n=10 of the 19). From a tackler perspective, 60% of concussive tackles were '*unsuccessful*' (n=3 of the 5), and 11 of the 19 non-injury tackles were '*successful*' (58%).

Incidence

Over the 3 years, 18 concussions were recorded, representing 11% of all injuries and translating into an incidence rate of 5.8 concussions per 1000 player hours (95% CI 3.1 to 8.5). There was no significant difference in incidence rate between 2011 and 2012 with a rate of 3.8 (95% CI 0.1 to 7.5) and 3.9 (95% CI 0.1 to 7.8) concussions per 1000 player hours, respectively. In 2013, the incidence rate increased to 9.52 concussions per 1000 player hours (95% CI 3.6 to 15.4).

Injury mechanism

A total of 10 concussions were analysed, of which 5 occurred during the tackle (4 to the tackler and 1 to the ball-carrier), 4 during the ruck and 1 during an aerial collision (table 3). All 10 concussions analysed occurred after contact with an opponent. In terms of anticipating contact, 60% (n=10) of the players were unaware of the impending contact. Fifty per cent of the injured players were forwards (2 flankers, 2 hookers and 1 lock, respectively) and 50% were backline players (2 fullbacks, 2 centres and 1 wing, respectively). In 50% (n=10) of the cases, the injured player's team was losing, 20% drawing and 30% winning. On-field medical attention was received immediately after the injury event by 9 of the 10 players. One player was attended to during half time and subsequently removed from the game.

The 'up and forward' head position represented 40% (n=10) of all *precontact head positions* while 30% of players assumed a 'down' head position and 20% an 'away' position (1 *precontact head position* was unidentifiable). In *head position on contact*, 30% of players were observed displaying a 'down' position, 20% the 'up and forward' position and 20% the 'away' position (3 *head position on contact* events were unidentifiable, n=10). Contact to the 'head/face' of the concussed player was noted in all injury events (n=10). In contrast, the body region of the other player most commonly contacted in concussion events was 'hips and below' (50%, n=10).

Seventy per cent of concussions occurred as a result of contact to the 'anterior' side of the head, with 20% as a result of contact to the 'posterior' side of the head (1 body location unidentifiable, n=10). Acceleration of the head was found to occur within the 'sagittal' plane 50% of the time. Only 20% of the concussed players were moving at a 'fast' speed preceding the concussion. The majority (70%, n=10) of injured players were either

Table 3 Frequency and percentage of descriptors for concussive event

	n	%
Scenario		
With teammate	0	0
With opponent	10	100
Fall/trip	0	0
Other	0	0
Inconclusive	0	0
Player position		
Back	2	20
Centre	2	20
Flanker	2	20
Hooker	2	20
Second row	1	10
Wing	1	10
Prop	0	0
Number eight	0	0
Scrum half	0	0
Fly-half	0	0
Head position precontact: concussed player		
Up and forward	4	40
Down	3	30
Away	2	20
In motion	0	0
Head position on contact		
Up and forward	2	20
Down	3	30
Away	2	20
In motion	0	0
Body region: concussed player		
Head/face	10	100
Neck	0	0
Shoulder/arms	0	0
Torso	0	0
Hips and below	0	0
Body region or object with which concussive contact was made		
Head/face	0	0
Neck	0	0
Shoulder/arms	1	10
Torso	0	0
Hips and below	5	50
With ground	2	20
Body location		
Anterior	7	70
Posterior	2	20
Lateral	0	0
Acceleration of head		
Coronal	1	10
Sagittal	5	50
Transverse	0	0
Multiplane	0	0
Speed of concussed player		
Stationary	5	50
Slow	2	20
Moderate	1	10
Fast	2	20
Speed of other player		
Stationary	0	0

Continued

Table 3 Continued

	n	%
Slow	0	0
Moderate	6	60
Fast	4	40
Movement speed of body region in contact: injured player		
Stationary	3	30
Slow	1	10
Moderate	2	20
Fast	4	40
Movement speed of body region in contact: other player		
Stationary	0	0
Slow	0	0
Moderate	4	40
Fast	4	40
Protective gear		
Scrum cap only	0	0
Mouthguard only	4	40
Both	1	10
None	5	50
Anticipated hit		
No	6	60
Yes	4	40
On-field medical attention		
No	1	10
Yes	9	90
Score at time of injury		
Winning	3	30
Losing	5	50
Tied game	2	20
Time played in current game, minute		
0–20	1	10
20–40	3	30
40–60	3	30
60–80	3	30

'stationary' (50%) or moving at a pace categorised as 'slow' (20%). In contrast, the 'other' players involved in the inciting event were moving at a 'moderate' (60%, n=10) and 'fast' (40%) pace.

Injury and non-injury playing situations

Sixty per cent (n=10) of injury events occurred in the 'fourth quarter', whereas non-injury events were more evenly distributed between quarters with 45%, 24%, 19% and 12% occurring in the first, second, third and fourth quarters, respectively (n=83). Two of the four injurious rucks (50%) occurred in the 'defensive in-goal area/try-line to defensive 22 m', whereas the majority (53%, n=60) of non-injury rucks occurred in the 'defensive half-way line to defensive 22 m'. All (n=4) aerial collision situations (injury and non-injury) occurred within the 'ball-carriers 22 m to the half-way line'. Two injurious tackles occurred within the 'ball-carrier's 22 m to the half way line' and two were within the 'defensive half-way line to defensive 22 m', with the remaining one occurring in the 'defensive in-goal area/try-line to defensive 22 m' (n=5). The majority (42%) of non-injury tackles occurred in the 'defensive half-way line to defensive 22 m' (n=19).

Tackle descriptors for injury and non-injury events

The body position of the tackler in injury events was distributed as follows: 20% 'upright', 20% 'medium', 20% 'low', 20% 'upright to low', 20% 'medium to low' (n=5; table 4). The head position of the tackler in 60% (n=5) of injury situations was 'up and forward' (20% 'down', 20% 'tracking'). The speed of the tackler was observed as 'slow' in 60% (n=5) of injurious tackles. The speed of the tackler in matched non-injury tackles were distributed as follows – 42% 'slow', 32% 'moderate' and 26% 'fast' (n=19). The majority (80%, n=5) of ball-carriers were travelling 'fast' in injury situations, and in non-injury tackles 63% (n=19) were travelling 'fast' and 37% 'moderately'. The ball-carrier's visual awareness was 'apparent' in 80% (n=5) of injurious tackles and 83% (n=19) of matched non-injury tackle events. However, in the one event where the injury was sustained by the ball-carrier, visual awareness was 'absent'. In all the matched non-injury events for the ball-carrier (n=6), the ball-carrier's visual awareness was observed as 'apparent'.

The direction of the tackle was 'front' in four of the five injurious tackles, with one being from the 'side'. The body regions of the concussed tacklers who were struck were 'head and neck' in 75% and 'shoulder/arm' in 25% (n=4). In all matched non-injury tackle events, the body region of the tackler struck was 'shoulder/arm' (n=19). The head placement of the concussed tackler was observed as 'in-front' in three of the four concussive tackles, with the remaining one being 'beside'. The concussed ball-carrier was contacted at the 'shoulder/arm'. Ball-carrier fend was 'absent' in 80% of injurious tackles, whereas in non-injury tackles 47% of ball-carriers fended 'moderately', in 42% fending was 'absent' and in 11% 'strong'(n=19).

Three of four concussed tacklers did not drive their legs after contact. The 'legs' were the most common body region to hit the ground first for the tackler in injury (80%) and non-injury (76%) tackle events (n=5 and n=17, respectively). The concussed ball-carrier's first body region on the ground was the 'shoulder/arm'.

Ruck descriptors for injury and non-injury events

In three of the four injurious rucks (75%), the concussed player was acting defensively either in the capacity of 'support' (n=2) or as the 'jackal' (n=1; table 5). The role of non-injured players was distributed as follows: 43% were 'support attack', 39% 'support defence', 10% 'jackal' and 8% 'ball-carrier' (n=61). In three of the four concussive rucks (75%), the attacking team was 'clearing the ruck'. In non-injury rucks, the attack was 'clearing the ruck' 52% of the time and 'protecting the ball' 48% (n=61) of the time. The defensive team were 'competing for the ball' in 75% of injurious rucks. Similarly, in non-injury rucks, the defensive team was 'competing for the ball' on the majority (70%,

Table 4 Frequency and percentage of descriptors for concussive event (C) and non-injury (NI) event during precontact and contact

Precontact	C (n)	Per cent	NI (n)	Per cent
Body position of tackler				
Upright	1	20	3	16
Medium	1	20	5	26
Low	1	20	2	11
Upright to medium	1	20	2	11
Upright to low	0	0	6	32
Medium to upright	0	0	0	0
Medium to low	1	20	1	5
Low to upright	0	0	0	0
Low to medium	0	0	0	0
Tackler stance				
Flat-footed	1	20	1	5
Back-foot	0	0	1	5
Split forward	2	40	10	53
No stance	2	40	7	37
Head position of tackler				
Down	1	20	5	26
Tracking	1	20	7	37
Up and forward	3	60	5	26
Away	0	0	0	0
Arm position of tackler				
Elbows bent with hands raised	0	0	1	5
Hands above shoulders	3	60	4	21
Hands dropped	2	40	13	68
Speed of tackler				
Slow	3	60	8	42
Moderate	0	0	6	32
Fast	2	40	5	26
Speed of ball-carrier				
Slow	0	0	0	0
Moderate	1	20	7	37
Fast	4	80	12	63
Direction of movement of tackler				
Forwards	4	80	11	58
Backwards	0	0	1	5
Lateral	1	20	7	37
Interpersonal distance between ball-carrier and tackler				
Near	5	100	11	58
Moderate	0	0	8	42
Distant	0	0	0	0
Direction of movement of ball-carrier				
Straight	2	40	11	58
Side-step	1	20	1	5
Arcing run	1	20	0	0
Lateral run	0	0	3	16
Diagonal run	1	20	4	21
Orientation of tackler in relation to ball-carrier				
In-front	4	80	9	47
Side	1	20	6	32
Oblique	0	0	3	16
Behind	0	0	1	5
Ball-carrier visual awareness				
Absent	1	20	2	11
Apparent	4	80	16	84
Unsure	0	0	1	5

Contact	C (n)	Per cent	NI (n)	Per cent
Type of tackle				
Arm	1	20	7	37
Collision	1	20	1	5
Jersey	0	0	1	5
Shoulder (dive)	0	0	1	5
Shoulder (opposite leading leg)	1	20	4	21
Shoulder (same leading leg)	2	40	5	26
Smother tackle	0	0	0	0
Tap tackle	0	0	0	0
Direction of Tackle				
Front	4	80	8	42
Side	1	0	7	37
Oblique	0	0	2	11
Behind	0	20	2	11
Body region of tackler struck				
Legs	0	0	0	0
Mid-torso	0	0	0	0
Shoulder/arm	2	40	19	100
Head and neck	3	60	0	0
Body region of ball-carrier struck				
Legs	1	20	7	37
Mid-torso	3	60	5	26
Shoulder/arm	1	20	7	37
Head and neck	0	0	0	0
Ball-carrier fend				
Absent	4	80	8	42
Moderate	1	20	9	47
Strong	0	0	2	11
Tackle sequence				
One-on-one	3	60	13	68
Sequential	1	20	5	26
Simultaneous	1	20	1	5
Attacking sequential	0	0	0	0
Impact force				
Low	1	20	3	16
Medium	2	40	12	63
High	2	40	4	21

Continued

Table 4 Continued

Precontact	C (n)	Per cent	NI (n)	Per cent	Contact	C (n)	Per cent	NI (n)	Per cent
Attacking support									
Distant	0	0	1	5					
Near	3	60	8	42					
Immediate	2	40	10	53					
Defensive support									
Distant	0	0	1	5					
Near	5	100	6	63					
Immediate	0	0	12	32					

n=61) of occasions. The attack maintained possession in all concussive rucks and in 90% of non-injury rucks.

Aerial collision for injury and non-injury events

In the injurious aerial collision, both players involved were unaware of the impending contact (n=1; table 5). With regard to the *speed of player(s)*, both players involved in injurious collision were moving at a pace classified as 'fast' (the injured player was the defensive player). In the matched non-injurious aerial collisions, all the defenders were moving at a pace classified as 'moderate' and the attackers were observed as 'slow' on all the occasions. Impact was 'high' in the injury event versus 'low' in all non-injury events. In the inciting event, the concussed player failed to *land on (his) feet in a stable manner*, whereas in all non-injury events this was maintained (n=3). The 'attacker was higher than defender' in the majority of injury (100%, n=1) and non-injury (67%, n=3) events. In the inciting event, the concussed player failed to *land on (his) feet in a stable manner*, whereas in all non-injury events this was maintained (n=3).

DISCUSSION

Insight into the injury mechanism of concussion in youth rugby

This is the first study to describe the global and local injury mechanisms of concussion and compares it with a representative and matched non-injury sample in youth rugby, which is an important aspect in formulating effective injury prevention strategies.[5 6] Over a 3-year period, 18 concussions were recorded, and only 10 were available for analysis due to the poor quality of the video footage. This small sample of concussion events over 3 years highlights the challenge with conducting a study of this nature. Owing to the small sample size, the study should be considered preliminary, and therefore any conclusive remarks are difficult to make. That said, the study provides insight into the injury mechanism of concussion in youth rugby, where otherwise data would not exist, and the data can be interpreted in the context of the current injury prevention strategies for concussion.

Situational factors associated with concussion

In describing the situational factors associated with concussion, all injuries occurred as a result of contact 'with opponent'. The ability to tolerate and engage in frequent physical contact with the opponent is a prerequisite for participation in rugby. Therefore, it is not surprising that contact with an opponent is a major feature in the series of events leading to concussion. For the concussive events analysed, the players were unaware of the impending contact. This finding is in line with Garraway *et al*[23] who found that tackle injury was more likely to occur when the player was unaware of opponents' movements. An explanation for this is that a player can sustain far greater forces without injury if the cervical muscles are tensed, which occurs when the athlete anticipates the collision. It is postulated that activating the neck and posterior shoulder muscles reduces the risk of concussion by mobilising the head, thereby decreasing the resultant acceleration of impact to the head.[24]

Coaching players to increase awareness and anticipation of ensuing contact may therefore be a worthwhile preventative measure for concussion.[24]

Match period and concussion

The majority of concussive events took place in the fourth quarter. This finding is consistent with previous literature, highlighting the role of fatigue in concussion risk.[25 26] A reduction in tackle technique proficiency has also been associated with fatigue in rugby league players, increasing the potential for unsafe tackles.[27] In ice hockey, in-game fatigue was a significant predictor of concussion.[26] This may warrant the need to coach contact technique during a state of fatigue for safe and effective execution during match play.[27]

Tackle contact techniques and concussion

The tackle situation contributed 50% of concussion injuries, which is higher than previously reported.[28 29] The low sample size of this study, however, needs to be considered. The majority of injurious tackles were classified as 'front-on' with injury occurring to the tackler, a finding consistent with others who found that tackles from the front resulted in more injuries.[8–10] While the

Table 5 Frequency and percentage of descriptors for concussive event (C) and non-injury event (NI) during aerial collision and ruck

Aerial collision	C (n)	Per cent	NI (n)	Per cent	Ruck	C (n)	Per cent	NI (n)	Per cent
Number of players involved					Role at ruck: player of interest				
2	1	100	0	0	Ball-carrier	1	25	5	8
3	0	0	2	67	Jackal	1	25	6	10
4	0	0	0	0	Support attack	0	0	26	43
5	0	0	1	33	Support defence	2	50	24	39
Number of attackers					Number of players on attack				
1	1	100	2	67	1–2	1	25	10	16
2	0	0	0	0	3–5	3	75	49	80
3	0	0	1	33	6–8	0	0	2	3
Number of defenders					Number of players on defence				
1	1	100	0	0	0	0	0	3	5
2	0	0	3	100	1–2	2	50	32	52
					3–5	2	50	26	43
Awareness of impending contact: attacking player					Activity at ruck: attack				
Yes	0	0	3	100	Clearing the ruck	3	75	32	52
No	1	100	0	0	Protecting the ball	1	25	29	48
Awareness of impending contact: defensive player					Activity at the ruck: defence				
Yes	0	0	3	100	Competing for the ball	3	75	43	70
No	1	100	0	0	Support	1	25	10	13
					No active engagement	0	0	8	16
Speed of defensive player					Infringement				
Slow	0	0	0	0	No	3	75	50	82
Moderate	0	0	3	100	Yes	1	25	11	18
Fast	1	100	0	0					
Speed of attacking player					Attacker possession				
Slow	0	0	3	100	Maintained possession	4	100	55	90
Moderate	0	0	0	0	Lost possession	0	0	6	10
Fast	1	100	0	0					
Impact									
Low	0	0	3	100					
Medium	0	0	0	0					
High	1	100	0	0					
First body region in contact: attacking player									
Head/face	0	0	0	0					
Neck	0	0	0	0					
Shoulder/arms	0	0	1	33					
Torso	0	0	1	33					
Hips and below	1	100	0	0					
Inconclusive	0	0	1	33					
First body region in contact: defensive player									
Head/face	1	100	0	0					
Neck	0	0	0	0					
Shoulder/arms	0	0	1	33					
Torso	0	0	2	67					
Hips and below	0	0	0	0					
Inconclusive	0	0	0	0					
Body position									
Controlled	1	100	3	100					
Uncontrolled	0	0	0	0					
Relative position of attacker/defender									
Attacker higher than defender	1	100	2	67					
Defender higher than attacker	0	0	0	0					
Same level	0	0	1	33					
Lands on feet/stable									
Yes	0	0	3	100					
No	1	100	0	0					

Continued

Table 5 Continued

Aerial collision	C (n)	Per cent	NI (n)	Per cent	Ruck	C (n)	Per cent	NI (n)	Per cent
Who gained possession of the ball									
Attacker	0	0	0	0					
Defender	0	0	1	100					
Infringement									
Yes	0	0	0	0					
No	1	100	3	100					

nature of the game necessitates a high frequency of this type of tackle, the coaching of safe and effective techniques for all tackle types must be emphasised.

'Head up and facing the ball-carrier before contact', that is, 'up and forward', is specified in the list of instructions for safe and effective contact techniques.[16 19] In this study, concussed players displayed a precontact position of head 'up and forward'. However, on contact, the majority of players displayed a 'down' or 'away' head position. When a player tucks his chin on his chest into the 'down' position during a tackle, the risk for head or neck injury increases.[10] This may be a target area for coaching interventions as players need to ensure that the 'up and forward' head position is maintained into contact and not only in preparation for contact.

Concussive impact may occur when a person's body and head are travelling at a particular speed and strike a solid object or when a head at rest is struck by a moving object.[30] In 7 of the 10 concussive events, the injured player was either stationary or moving at a pace categorized as 'slow'. In particular, most injured tacklers were categorised as either 'stationary' or 'slow', suggesting that difference in speed is a risk factor for concussion. Speed differences on contact during rugby have been noted before as a risk factor for injury in rugby.[16 23] That said, the speed difference between players on contact, as a risk factor for injury, should not be interpreted in isolation.[15 31]

In the majority of injuries to the tackler, *leg drive by the tackler* was observed to be 'absent'. BokSmart recommendations on safe tackling techniques emphasise the need for a player to maintain leg drive after contact.[16] This particular technical point also increases the probability of tackle success.[19]

Ruck contact techniques and concussion

Rucks contributed the second largest proportion of concussions. In three of the four concussive rucks, the team on attack was 'clearing the ruck' while the defensive team was observed to be 'competing for the ball'. These situations are characterised by players darting or charging into a mass of players, exposing players to potential risk of injury.[32] Considering the observation that three of the four players injured in the ruck were acting in defence (2 as 'support' and 1 as 'the jackal'), it seems that players fulfilling a defensive role in the ruck at the time the attack are clearing are more susceptible to concussive impacts. Additionally, all three of the players were unaware of the impending contact at the time of their injuries. It may therefore be useful to incorporate a coaching emphasis on 'maintaining awareness' for players engaging defensively during a ruck.

Strengths, limitations and implications

As mentioned earlier, the study is limited by its small sample size, and this ultimately restricted the statistical analyses. That said, the data are important as 3 years of concussion data in youth rugby are reported, and should be seen as setting the foundation for a longitudinal study with more injury and non-injury events. Future concussion research and application may benefit more from a refined video analysis coding system, similar to Hutchison *et al*'s[12] checklist in ice hockey.

Summary

This study represents an attempt to move beyond epidemiological studies by establishing the aetiology and injury mechanism underlying youth concussion and, in doing so, progressing the process of injury prevention. On the basis of the findings, training interventions aimed at improving peripheral vision, targeted conditioning programmes to reduce the effects of fatigue and emphasising safe and effective playing techniques should be structured with the goal of reducing the risk of concussion. While an elimination of concussion in rugby is unlikely, continued research in this area is essential to providing a foundation for the development of effective education, evaluation and prevention strategies.

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Contributors SH was responsible for write-up of the manuscript and study conceptualisation. SO was responsible for data collection. NB and SMF

assisted with data collection and data analyses. CR and WV set up injury data collection and access to video. JCB collected injury data. ML assisted in all aspects. All the authors edited the manuscript.

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Notes