Article:
Tierney, GJ orcid.org/0000-0002-4666-4473, Denvir, K, Farrell, G et al. (1 more author) (2018) The Effect of Tackler Technique on Head Injury Assessment Risk in Elite Rugby Union. Medicine & Science in Sports & Exercise, 50 (3). pp. 603-608. ISSN 0195-9131

https://doi.org/10.1249/MSS.0000000000001461

The effect of tackler technique on head injury assessment risk in elite rugby union

Gregory J. Tierney[1]

gtierne@tcd.ie

Karl Denvir[2]

Karl.Denvir@leinsterrugby.ie

Garreth Farrell[2]

garreth.farrell@leinsterrugby.ie

Ciaran K. Simms[1]

csimms@tcd.ie

[1]Trinity Centre for Bioengineering, Trinity College Dublin, Ireland

[2]Leinster Rugby, Dublin, Ireland

Corresponding Author:

Gregory Tierney

Trinity Centre for Bioengineering

Trinity College Dublin

Dublin 2, Ireland

gtierne@tcd.ie

+353 89 2381688

ABSTRACT

Purpose: To use match video evidence of tackles in elite level rugby union in order to identify tackler proficiency characteristics, for both Lower Body and Upper Body Tackles, that result in Head Injury Assessments (HIA) for the tackler.

Methods: A review of international rugby union matches (2013-2017) and Pro 12/ERC Champions Cup matches (2014-2017) from a professional rugby union club was conducted. HIA (n=74) and non-HIA tackles (n=233) were categorised as either front-on or side-on Upper Body or Lower Body Tackles and scored for tackling proficiency characteristics. A Chi-Square test ($p<0.05$) and Phi and Cramer's V were calculated to compare HIA and non-HIA tackling proficiency characteristics.

Results: In both front- and side-on Upper Body and Lower Body Tackles, "head up and forward/face up" and "head placement on correct side of ball carrier" were identified as having a lower propensity to result in a HIA for the tackler. For both front-on and side-on Upper Body Tackles, "identify/track ball carrier onto shoulder" and "shortening steps" were identified. Additionally, "Straight back, centre of gravity forward of support base" and "Identify/track ball carrier onto shoulder" were identified for front-on and side-on Lower Body Tackles respectively.

Conclusion: This study identified tackle characteristics that had a lower propensity to result in a HIA for the tackler in both front-on and side-on Upper Body and Lower Body Tackles.

Key Words: Concussion, Head Impact, Tackling, Injury Prevention

INTRODUCTION

Tackling is a dynamic and integral part of rugby union with some players making over 30 tackles per game (9). Tackling is the most common cause of contact in the game (11) as well as the main cause of injury and concussion (4, 5, 12, 31, 38). Concussion has been defined as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (29). The incidence of concussion in rugby union is high (8.9/1000 player hours) (8) and growing (8, 32). Proficient tackle technique is important for safe participation in rugby union (20, 21), and poor tackle technique is reportedly a risk factor for injury (6, 23, 38).

Analysis of match video evidence has been used to identify injury risk factors in rugby union (6, 10, 31) as well as head impact and concussion risk (12, 23, 24, 38). Video analysis techniques have also been used for analysing concussion injuries in rugby league (18), ice hockey (25) and soccer (2). One early rugby union study used match video evidence to identify the nature of injury by examining injury type and location (40). This study also looked at the occurrence of tackle characteristics (e.g. leg drive, wrap arms) and tackle type (e.g. smother, shoulder charge) during tackle-related injuries. A recent study (38) on direct head impacts in rugby reported that tackles account for 60% of direct head impacts in elite level rugby union. The study also categorised legal tackles as either Upper Body or Lower Body Tackles. An Upper Body Tackle (UBT) was defined by the tackler's intended initial contact being above the ball carrier's hip (38) while a Lower Body Tackle (LBT) was defined as the tackler's intended initial contact being at or below the ball carrier's hip. The study also demonstrated that tacklers were at most risk of sustaining a direct head impact, and hence concussion, and that the risk of sustaining a direct head impact is greater during an Upper Body Tackle versus a Lower Body Tackle.

In conducting an in-depth video analysis on South African youth level rugby union players, tackle technique characteristics associated with general injury causation and prevention were identified by Burger et al (6). As a result, technical based criteria were created for ball carrier and tackler proficiency in front- and side-on tackles based on studies that examined tackling proficiency in collision sports (15-17, 22) as well as tackle technique guidelines from the South African governing body for rugby union (39). The criteria were then appraised by a group of rugby union coaches, medical personnel and sport scientists and a detailed list of technical criteria for both ball carrier and tackler front- and side-on tackles was proposed (6). However, they focussed on general injury for tackles in a youth level rugby union competition, even though the mechanism of injury in terms of the inciting event is not the same for all types of injury (3). It is possible that specific tackling characteristics are linked to concussion injury prevention for the tackler for Upper Body and Lower Body Tackles, but the details of these are unknown.

Accordingly, the aim of this study was to use match video evidence of tackles in elite level rugby union to identify a number of tackler characteristics, for both Lower Body and Upper Body Tackles, that result in Head Injury Assessments (HIA) for the tackler. The HIA was introduced in 2012 by World Rugby as the pitch side assessment process for concussion injuries (13) and has previously been described in detail (14). In brief, the aim of the HIA is to create a standardised tool for the medical assessment of concussion injuries in rugby and to improve patient education (28). A player enters the HIA protocol by displaying on-field signs and symptoms of concussion and is subsequently removed from play (28). The HIA assesses a range of concussive symptoms including both immediate and delayed memory difficulties, cognitive ability, balance and player discomfort (28). In the HIA, if a player's score is positive, they are removed from play and must follow the return-to-play protocol (26). Therefore, a reduction in tackle-related HIAs would have a strong influence on concussion injury reduction.

The approach for this study was undertaken utilising tackle based technical criteria lists created by Burger et al. (2016) (6) to develop and implement technical based concussion prevention strategies for tackling.

METHODS

Research design and data collection. A qualitative observational case-control study design was used to identify specific tackler characteristics (Table 1-4) associated with HIA and non-HIA tackles in men's professional rugby union using video evidence. A tackle was defined as "when the ball-carrier was contacted (hit and/or held) by an opponent without reference to whether the ball-carrier went to ground" (31). A HIA tackle was defined as when a tackler received a direct/indirect head impact in the tackle and was subsequently removed from play for a Head Injury Assessment (HIA) and did not return to play for the remainder of the game. The data was freely available online and no medical data was obtained/reported in this study. Hence, ethical permission was not required similar to other rugby union video analysis studies on head impacts (38) and knee injuries (30). A non-HIA tackle was defined as when a player did not receive an injury/head impact in the tackle and was not removed from play for the remainder of the game.

To provide non-HIA cases as a control cohort, the tackle technique data from Tierney et al. (33) was utilised. In brief, this data consists of tackles from three randomly selected games involving an Irish professional club team from the 2014/15 Champions Cup. The study looked at the effect of player time-in-game on tackle technique deterioration. Therefore, only the tackles involving tacklers who remained on the field for the duration of the game were analysed. This also ensured only non-HIA/injured players were included in the control cohort. As a result of this approach, a total of 92 Upper Body Tackles and 30 Lower Body Tackles for

front-on tackles and 75 Upper Body Tackles and 36 Lower Body Tackles for side-on tackles were analysed as control cases.

In order to obtain video evidence of tackle-related HIA cases, all Pro 12 and European Rugby Champions Cup games from 2014-2017 of the same Irish professional rugby club team were reviewed. However, this approach resulted in a low HIA sample size (n=19). In order to increase this sample size, additional video data was collected by retrospectively reviewing international test rugby union matches. This subset was compiled of all matches from the RBS 6 Nations 2014-2017, Guinness Autumn Test Series 2013-2016, Rugby World Cup warm-up games 2015 (Home nation games only), the Rugby World Cup 2015 (all games) and the British and Irish Lions Tour 2017. Based on these two approaches, a total of 74 HIA cases were identified (19 Upper Body and 19 Lower Body for front-on tackles and 23 Upper Body and 13 Lower Body for side-on tackles). This video data was obtained from freely available online resources. Although a HIA can occur from an impact to the body (28), a direct head impact was identified in every video.

Technical proficiency criteria. The tackler technique characteristics are based on the work of Burger et al. (2016) (6) who developed technical criteria for tackler proficiency in front-on and side-on tackles. Any tackles that were initiated outside the ball carrier's estimated peripheral vision were considered side-on tackles (6, 19).

Two reviewers (a Senior Sports Physiotherapist and a Biomechanist) analysed each video together. Any cases involving uncertainty between reviewers were resolved by a discussion until a consensus was reached. The videos were analysed using Sports Code (Version 8) enabling a frame-by-frame viewing of the tackle. Reviewers could watch the clips as many times as necessary. A minimum of two camera view videos (25 fps) were available for each tackle. The tackle was split into three main phases (22); pre-contact (0.5 s preceding contact),

contact (first instance of contact) and post-contact with the technical proficiency characteristics assigned to these phases. A player was scored either 1 or 0 for each technical proficiency characteristic depending on whether or not they exhibited that particular characteristic.

Statistical Analysis. All statistics were calculated using SPSS (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.). For each tackler proficiency characteristic, Pearson's Chi-Square and Phi and Cramer's V calculations were conducted (1). Statistical significance was set at $p<0.05$. A Phi and Cramer's V value less than 0.1, between 0.1 and less than 0.3, between 0.3 and less than 0.5 and 0.5 or greater were considered indicative of a trivial, small, moderate and large Effect Sizes (ES) respectively (7).

Reliability. Fifteen front-on and fifteen side-on tackles (including HIA and non-HIA cases) were randomly selected using a random number generator (http://www.random.org/). The two reviewers then conducted the analysis on these 30 cases, for each tackler proficiency characteristic, at least one week after conducting the initial set of cases. Intra-rater reliability was then assessed using Cohen's Kappa (K). To assess for inter-rater reliability, an external reviewer (ex-player) conducted the analysis on the same 30 cases using the same protocol as the two main reviewers. Similarly, inter-rater reliability was then assessed using Cohen's Kappa (K). A Cohen's Kappa value greater than 0.8 indicates almost perfect agreement (27). For front-on tackles, a Cohen's Kappa value of 0.867 and 0.859 were calculated for intra- and inter-rater reliability, respectively. For side-on tackles, a Cohen's Kappa value of 0.960 and 0.861 were calculated for intra-rater reliability and inter-rater reliability, respectively.

RESULTS

Upper Body Tackles. For front-on Upper Body Tackles (Table 1), the main tackle phase that influenced HIA causation for the tackler was the pre-contact phase of the tackle. The

tackler characteristics "identify/track ball carrier onto shoulder" ($p<0.01$, ES=Moderate), "head up and forward/face up" ($p<0.01$; ES=Large) and "shortening steps" ($p<0.01$; ES=Small) all had a lower propensity to result in a HIA for the tackler. In the contact phase, "head placement on correct side of ball carrier" ($p<0.01$; ES=Large) had a lower propensity to result in a HIA for the tackler. This was also the case for "arm usage (punch forward and wrap i.e. hit-and-stick)" ($p<0.01$; ES=Moderate) in the post-contact phase.

Similarly, for side-on Upper Body Tackles (Table 2), "identify/track ball carrier onto shoulder" ($p<0.01$, ES=Moderate), "head up and forward/face up" ($p<0.01$; ES=Large) and "shortening steps" ($p<0.01$; ES=Moderate) all had a lower propensity to result in a HIA for the tackler in the pre-contact phase of the tackle. This was similar for "head placement on correct side/behind ball carrier" ($p<0.01$; ES=Large) in the contact phase. Differences were observed on the "arm usage (punch forward and wrap i.e. hit-and-stick)" and "pull ball carrier with arms to ground" (both $p<0.01$; ES=Large) between HIA and non-HIA cases in the post-contact phase of the tackle. In 35% (n=8) of side-on Upper Body Tackles, it was another tackler from the same team that impacted the tackler's head who received the HIA. This was due to both team mates tackling the same ball carrier. In one case, both tacklers received HIAs.

TABLE 1

Tackler Upper Body Tackle front-on proficiency results for HIA and non-HIA tackles (includes % occurrence, p values, Phi and Cramer's V and interpretations).

	HIA (n=19)	Non-HIA (n=92)	p value	Phi and Cramer's V	Interpretation
Pre-contact					
Identify/track ball carrier onto shoulder	11 (58%)	89 (97%)	**<0.01**	0.49	Moderate
Body position - Upright to low	7 (37%)	29 (32%)	0.65	0.04	Trivial
Straight back, centre of gravity forward of support base	5 (26%)	27 (29%)	0.79	0.03	Trivial
Square to ball carrier	14 (74%)	81 (88%)	0.11	0.15	Small
Boxer stance (elbows close, hands up)	8 (42%)	58 (63%)	0.09	0.16	Small
Head up and forward/face up	11 (58%)	90 (98%)	**<0.01**	0.53	Large
Shortening steps	4 (21%)	56 (61%)	**<0.01**	0.29	Small
Approach from front/oblique	19 (100%)	91 (99%)	0.65	0.04	Trivial
Contact					
Explosiveness on contact	5 (26%)	16 (17%)	0.37	0.09	Trivial
Contact with shoulder opposite leading	8 (42%)	49 (53%)	0.38	0.17	Small
Head placement on correct side of ball carrier	3 (16%)	86 (94%)	**<0.01**	0.73	Large
Post-contact					
Shoulder usage (drive into contact)	2 (11%)	23 (25%)	0.17	0.13	Small
Arm usage (punch forward and wrap i.e. hit-and-stick)	4 (21%)	56 (61%)	**<0.01**	0.30	Moderate
Leg drive on contact	0 (0%)	9 (10%)	0.16	0.14	Small
Release ball carrier and compete for possession	0 (0%)	15 (16%)	0.06	0.18	Small

TABLE 2

Tackler Upper Body Tackle side-on proficiency results for HIA and non-HIA tackles (includes % occurrence, p values, Phi and Cramer's V and interpretations).

	HIA (n=23)	Non-HIA (n=75)	p value	Phi and Cramer's V	Interpretation
Pre-contact					
Identify/track ball carrier onto shoulder	14 (61%)	73 (97%)	**<0.01**	0.49	Moderate
Body position - Upright to low	2 (9%)	9 (12%)	0.66	0.04	Trivial
Straight back, centre of gravity forward of support base	1 (4%)	8 (10%)	0.36	0.09	Trivial
Head up and forward/face up	16 (70%)	75(100%)	**<0.01**	0.50	Large
Shortening steps	2 (9%)	38 (51%)	**<0.01**	0.36	Moderate
Contact					
Explosiveness on contact	3 (13%)	5 (7%)	0.33	0.10	Small
Head placement on correct side/behind ball carrier	9 (39%)	74 (99%)	**<0.01**	0.70	Large
Post-contact					
Shoulder usage (drive into contact)	3 (13%)	6 (8%)	0.46	0.07	Trivial
Arm usage (punch forward and wrap i.e. hit-and-stick)	5 (22%)	60 (80%)	**<0.01**	0.52	Large
Pull ball carrier with arms to ground	5 (22%)	60 (80%)	**<0.01**	0.52	Large
Release ball carrier and compete for possession	0 (0%)	8 (11%)	0.10	0.17	Small

Lower Body Tackles. For front-on Lower Body Tackles (Table 3), "straight back, centre of gravity forward of support base" ($p=0.04$; ES=Small), "head up and forward/face up" ($p<0.01$; ES=Large) and "head placement on correct side of ball carrier" ($p<0.01$; ES=Large)

all had a lower propensity to result in a HIA for the tackler. Differences were observed on "arm usage (punch forward and wrap i.e. hit-and-stick)" ($p<0.01$; ES=Moderate) between HIA and non-HIA cases in the post-contact phase of the tackle.

For side-on Lower Body Tackles (Table 4), "identify/track ball carrier onto shoulder" ($p<0.01$; ES=Moderate), "head up and forward/face up" ($p<0.01$; ES=Large) and "head placement on correct side/behind ball carrier" ($p<0.01$; ES=Large) all had a lower propensity to result in a HIA for the tackler. Differences were observed on the "arm usage (punch forward and wrap i.e. hit-and-stick)" ($p=0.02$; ES=Moderate) and "pull ball carrier with arms to ground" ($p=0.01$; ES=Moderate) between HIA and non-HIA cases in the post-contact phase of the tackle. In one side-on Lower Body Tackle, it was another tackler from the same team that impacted the tackler's head who received the HIA. This was due to both team mates tackling the same ball carrier.

TABLE 3

Tackler Lower Body Tackle front-on proficiency results for HIA and non-HIA tackles (includes % occurrence, p values, Phi and Cramer's V and interpretations).

	HIA (n=19)	Non-HIA (n=30)	p value	Phi and Cramer's V	Interpretation
Pre-contact					
Identify/track ball carrier onto shoulder	18 (95%)	28 (93%)	0.84	0.03	Trivial
Body position - Upright to low	18 (95%)	27 (90%)	0.56	0.08	Trivial
Straight back, centre of gravity forward of support base	3 (16%)	13 (43%)	**0.04**	0.29	Small
Square to ball carrier	13 (68%)	26 (87%)	0.12	0.22	Small
Boxer stance (elbows close, hands up)	8 (42%)	17 (57%)	0.32	0.14	Small
Head up and forward/face up	2 (11%)	25 (83%)	**<0.01**	0.71	Large
Shortening steps	5 (26%)	13 (43%)	0.23	0.17	Small
Approach from front/oblique	19 (100%)	30 (100%)	1.00	0.00	Trivial
Contact					
Explosiveness on contact	1 (5%)	6 (20%)	0.15	0.20	Small
Contact with shoulder opposite leading	11 (58%)	23 (77%)	0.17	0.20	Small
Head placement on correct side of ball carrier	2 (11%)	28 (93%)	**<0.01**	0.83	Large
Contact in centre of gravity	9 (47%)	19 (63%)	0.27	0.16	Small
Post-contact					
Shoulder usage (drive into contact)	1 (5%)	8 (27%)	0.06	0.27	Small
Arm usage (punch forward and wrap i.e. hit-and-stick)	4 (21%)	20 (67%)	**<0.01**	0.45	Moderate
Leg drive on contact	1 (5%)	6 (20%)	0.15	0.21	Small
Release ball carrier and compete for possession	0 (0%)	1 (3%)	0.42	0.12	Small

TABLE 4

Tackler Lower Body Tackle side-on proficiency results for HIA and non-HIA tackles (includes % occurrence, p values, Phi and Cramer's V and interpretations).

	HIA (n=13)	Non-HIA (n=36)	p value	Phi and Cramer's V	Interpretation
Pre-contact					
Identify/track ball carrier onto shoulder	8 (62%)	35 (97%)	**<0.01**	0.48	Moderate
Body position - Upright to low	11 (85%)	30 (83%)	0.92	0.02	Trivial
Straight back, centre of gravity forward of support base	3 (23%)	15 (42%)	0.23	0.17	Small
Head up and forward/face up	3 (23%)	33 (92%)	**<0.01**	0.69	Large
Shortening steps	5 (39%)	15 (42%)	0.84	0.03	Trivial
Contact					
Explosiveness on contact	2 (15%)	4 (11%)	0.69	0.06	Trivial
Head placement on correct side/behind ball carrier	5 (39%)	32 (89%)	**<0.01**	0.52	Large
Contact in centre of gravity	6 (46%)	17 (47%)	0.95	0.01	Trivial
Post-contact					
Shoulder usage (drive into contact)	2 (15%)	9 (25%)	0.48	0.10	Small
Arm usage (punch forward and wrap i.e. hit-and-stick)	4 (31%)	25 (69%)	**0.02**	0.35	Moderate
Pull ball carrier with arms to ground	5 (39%)	28 (78%)	**0.01**	0.37	Moderate
Release ball carrier and compete for possession	0 (0%)	2 (6%)	0.39	0.12	Small

DISCUSSION

This study used match video evidence to identify tackle characteristics that have a lower propensity to result in a HIA for the tackler. In contrast to Burger et al. (2016) (6), a number of specific tackler proficiency variables were identified as having a lower propensity to result in a HIA for the tackler, especially "identify/track ball carrier onto shoulder", "head up and forward/face up", "straight back, centre of gravity forward of support base" and "head placement on correct side of ball carrier". The results from this study provide an evidence-base to assist elite level coaches to develop and implement concussion prevention strategies for tacklers.

Upper Body Tackles. When a tackler did not identify/track the ball carrier onto their shoulder, they generally placed their head in line with the ball carrier's trajectory which increased the risk of the tackler's head being impacted. An ability to exhibit the characteristic "head up and forward/face up" resulted in the tackler being able to track the ball carrier's motion and be aware of their surrounding environment. Thus, the tacklers susceptibility to receiving a head impact was reduced, particularly if the ball carrier exhibited an evasive manoeuvre or fend.

When "shortening steps" was not exhibited, the tackler generally planted his feet during the pre- contact phase of the tackle. This finding is consistent with Tierney et al. (38), who reported that foot planting was a risk factor for head impact causation. Tacklers exhibiting "shortening steps" ensured their feet remained active and afforded them time to orientate themselves properly as well as adapt to changes in the ball carrier's motion/trajectory. It has also been reported that 'shortening steps" reduces general injury risk for the tackler in front-on tackles (6) as well as increases the tackler's likelihood of dominating the tackle (34).

Post-contact tackling characteristics such as "arm usage (punch forward and wrap i.e. hit-and-stick)" and "pull ball carrier with arms to ground" both exhibited differences between HIA and

non-HIA cases. However, head impacts in all the cases recorded occurred before the post-contact phase of the tackle. Therefore, instead of these tackling characteristics being identified as lowering the propensity to result in a head impact, they may be more an indicator for sideline medical staff that a head impact has potentially occurred. This is also the case for Lower Body Tackles.

For 35% of side-on Upper Body Tackles HIA cases and one side-on Lower Body Tackle HIA case, it was another tackler from the same team that impacted the tackler's head who received the HIA. This was due to both team mates tackling the same ball carrier. This indicates the importance of environmental awareness and effective communication between tacklers when engaging in a tackle with two tacklers. In terms of tackler characteristics, the same principles can be applied as with a single tackler case e.g. exhibiting "shortening steps" may have afforded the impacted player time to orientate themselves properly and avoid the head impact.

Lower Body Tackles. For front-on Lower Body Tackles the "straight back, centre of gravity forward of support base" had a lower propensity to result in a HIA for the tackler. Further analysis identified that in 95% of front-on Lower Body Tackle HIA cases where the tackler did not exhibit "straight back, centre of gravity forward of support base" the tackler's head was facing down (i.e. not exhibiting the "head up and forward/face up" characteristic). Thus, the tackler may have been unaware of the ball carriers' oncoming motion and their surrounding environment. This increased the susceptibility of a HIA related head impact as it made the tackler unable to prepare for the impending contact. In 69% of Lower Body Tackle front-on HIA cases, placing the tackler's centre of gravity behind their support base meant that the tackler's weight was transmitted through their heels, resulting in foot planting and the aforementioned breakdown in tackle proficiency.

For side-on Lower Body Tackles, an inability to "identify/track the ball carrier onto the shoulder" had a higher propensity to result in a HIA for the tackler. In 15% of Lower Body Tackle side-on HIA cases, the tackler, instead of tracking the ball carrier onto their shoulder, dove in front of the oncoming ball carrier with their head facing downward, making no attempt to use the shoulders.

The dynamic and open nature of the tackle. The tackle is a dynamic and open phase of play and this must be appreciated when analysing tackling characteristics (6, 19). It is possible that certain proficiency characteristics may have influenced other proficiency characteristics. For example, failure to exhibit the "straight back, centre of gravity forward of support base" may have affected the tackler's ability to exhibit the "head up and forward/face up". In some tackle scenarios, poor tackle proficiency was due to a defensive error. The tackler was forced to perform a tackle as a result of a teammate's missed tackle or incorrect positioning in the defensive line. In these circumstances, the tackler may not have identified the ball carrier in a timely fashion having focused their attention on another opposing player. Thus, this would have prevented them from reacting to the ball carrier's motion and executing a technically proficient tackle. This not only highlights the importance of correct tackle technique but on-field communication and also of having a clearly defined defensive system in place where players have well defined roles and responsibilities.

The judgement made by the tackler arises in a dynamic situation in which the ball carrier can adjust his running speed and direction. Part of the skill of the ball carrier is to be unpredictable ensuring that the tackler does not make an effective tackle. Further research should examine ball carrier characteristics (6, 33, 34) which may have a higher propensity to result in a HIA for the tackler as well as the biomechanics of head injuries (35-37).

Study limitations. This study utilised a definition based on a player being removed for a Head Injury Assessment and subsequently not returning to the field of play. Although this is a strong indication of concussion, it is not fully robust for concussion diagnosis. Access to player medical notes would have clarified this. This study only identified HIA's as a result of a direct head impact however it is possible that a HIA can occur from a non-direct head impact (28). Although the HIA sample size was larger than the injury sample size utilised by Burger et al. (6), the study would have benefited from a larger HIA sample size. For the control cases, only three games were selected and only one team was utilised, meaning the results could be team specific. This study analysed elite club level rugby union games however the results may be applicable to both youth and amateur level rugby union as well as other contact sports such as American Football. Further research is needed to clarify this. Nonetheless the findings from this study can be utilised for a baseline of injury prevention techniques.

CONCLUSION

Analysis of match video evidence from elite level Rugby Union games shows that there are tackle proficiency characteristics which are more likely to result in a HIA for the tackler. In both front- and side-on Upper Body and Lower Body Tackles, "head up and forward/face up" and "head placement on correct side of ball carrier" were identified as having a lower propensity to result in a HIA for the tackler. Additionally, "identify/track ball carrier onto shoulder" and "shortening steps" were identified as having a lower propensity for HIA causation with both front- and side-on Upper Body Tackles. The "Straight back, centre of gravity forward of support base" and "Identify/track ball carrier onto shoulder" were identified as having a lower propensity for HIA causation with front- and side-on Lower Body Tackles,

respectively. These results provide evidence based data for coaches to develop and implement technical based HIA prevention strategies for tackling.

Acknowledgements. The authors declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The authors would like to thank John Buckley for helping to identify tackles during the video footage review stage. Funding for this study was provided by the Irish Research Council. The results of this study do not constitute endorsement by the American College of Sports Medicine.

Conflicts of interest. The authors report no conflicts of interest

REFERENCES

1. Altman DG. Practical statistics for medical research. Boca Raton (FL): CRC press; 1990. p. 229-77.

2. Andersen TE, Arnason A, Engebretsen L, Bahr R. Mechanisms of head injuries in elite football. Br J Sports Med. 2004;38(6):690-6.

3. Bahr R, Krosshaug T. Understanding injury mechanisms: a key component of preventing injuries in sport. Br J Sports Med. 2005;39(6):324-9.

4. Bathgate A, Best JP, Craig G, Jamieson M. A prospective study of injuries to elite Australian rugby union players. Br J Sports Med. 2002;36(4):265-9.

5. Best JP, McIntosh AS, Savage TN. Rugby World Cup 2003 injury surveillance project. Br J Sports Med. 2005;39(11):812-7.

6. Burger N, Lambert MI, Viljoen W, Brown JC, Readhead C, Hendricks S. Tackle technique and tackle-related injuries in high-level South African Rugby Union under-18 players: real-match video analysis. Br J Sports Med. 2016;50(15):932-38.

7. Cohen J. Statistical power and analysis for the behavioral sciences. 2 ed. Hillsdale (NJ): Lawrence Erlbaum Associates; 1988. p. 77-82

8. Cross M, Kemp S, Smith A, Trewartha G, Stokes K. Professional Rugby Union players have a 60% greater risk of time loss injury after concussion: a 2-season prospective study of clinical outcomes. Br J Sports Med. 2016;50(15):926-31.

9. Deutsch M, Kearney G, Rehrer N. Time–motion analysis of professional rugby union players during match-play. J Sports Sci. 2007;25(4):461-72.

10. Fuller CW, Ashton T, Brooks JH, Cancea RJ, Hall J, Kemp SP. Injury risks associated with tackling in rugby union. Br J Sports Med. 2010;44(3):159-67.

11. Fuller CW, Brooks JH, Cancea RJ, Hall J, Kemp SP. Contact events in rugby union and their propensity to cause injury. Br J Sports Med. 2007;41(12):862-7.

12. Fuller CW, Taylor A, Raftery M. Epidemiology of concussion in men's elite Rugby-7s (Sevens World Series) and Rugby-15s (Rugby World Cup, Junior World Championship and Rugby Trophy, Pacific Nations Cup and English Premiership). Br J Sports Med. 2015;49(7):478-83.

13. Fuller GW, Kemp SP, Decq P. The International Rugby Board (IRB) Pitch Side Concussion Assessment trial: a pilot test accuracy study. Br J Sports Med. 2015; 49(8):529-35.

14. Fuller GW, Kemp SPT, Raftery M. The accuracy and reproducibility of video assessment in the pitch-side management of concussion in elite rugby. J Sci Med Sport. 2017;20(3):246-9.

15. Gabbett T, Kelly J. Does fast defensive line speed influence tackling proficiency in collision sport athletes? Int J Sports Sci Coach. 2007;2(4):467-72.

16. Gabbett T, Ryan P. Tackling technique, injury risk, and playing performance in high-performance collision sport athletes. Int J Sports Sci Coach. 2009;4(4):521-33.

17. Gabbett TJ. Influence of fatigue on tackling technique in rugby league players. J Strength Cond Res. 2008;22(2):625-32.

18. Gardner AJ, Iverson GL, Quinn TN, Makdissi M, Levi CR, Shultz SR, et al. A preliminary video analysis of concussion in the National Rugby League. Brain Inj. 2015;29(10):1182-5.

19. Garraway W, Lee A, Macleod D, Telfer J, Deary IJ, Murray GD. Factors influencing tackle injuries in rugby union football. Br J Sports Med. 1999;33(1):37-41.

20. Hendricks S, Lambert M. Tackling in rugby: Coaching strategies for effective technique and injury prevention. Int J Sports Sci Coach. 2010;5(1):117-36.

21. Hendricks S, Lambert M. Theoretical model describing the relationship between the number of tackles in which a player engages, tackle injury risk and tackle performance. J Sports Sci Med. 2014;13(3):715.

22. Hendricks S, Matthews B, Roode B, Lambert M. Tackler characteristics associated with tackle performance in rugby union. Eur J Sports Sci. 2014;14(8):753-62.

23. Hendricks S, O'Connor S, Lambert M, Brown J, Burger N, Mc Fie S, et al. Contact technique and concussions in the South African under-18 Coca-Cola Craven Week Rugby tournament. Eur J Sport Sci. 2015;15(6):557-64.

24. Hendricks S, O'Connor S, Lambert M, Brown JC, Burger N, Mc Fie S, et al. Video analysis of concussion injury mechanism in under-18 rugby. BMJ Open Sport Exerc Med. 2016;2(1):e000053.

25. Hutchison MG, Comper P, Meeuwisse WH, Echemendia RJ. A systematic video analysis of National Hockey League (NHL) concussions, part I: who, when, where and what? Br J Sports Med. 2015;49(8):547-51

26. Kemp S, Patricios J, Raftery M. Is the content and duration of the graduated return to play protocol after concussion demanding enough? A challenge for Berlin 2016. Br J Sports Med. 2016;50(11):644-5.

27. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977:159-74.

28. McCrory P, Johnston K, Meeuwisse W, Aubry M, Cantu R, Dvorak J, et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. Br J Sports Med. 2005;39(4):196-204.

29. McCrory P, Meeuwisse WH, Aubry M, Cantu B, Dvořák J, Echemendia RJ, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. Br J Sports Med. 2013;47(5):250-8.

30. Montgomery C, Blackburn J, Withers D, Tierney G, Moran C, Simms C. Mechanisms of ACL injury in professional rugby union: a systematic video analysis of 36 cases. Br J Sports Med. 2016:1-8. doi: 10.1136/bjsports-2016-096425

31. Quarrie KL, Hopkins WG. Tackle Injuries in Professional Rugby Union. Am J Sports Med. 2008;36(9):1705-16.

32. Rugby Football Union. England Professional Rugby Injury Surveillance Project [internet]. Rugby Football Union. 2015. [cited 2017 Feb 15]. Available from: http://www.englandrugby.com/mm/Document/General/General/01/30/80/08/EnglandProfessionalRugbyInjurySurveillanceProjectReport2013_2014_Neutral.pdf

33. Tierney GJ, Denvir K, Farrell G, Simms CK. Does player time-in-game affect tackle technique in elite level rugby union? J Sci Med Sport. 2017.1-5. doi: 10.1016/j.jsams.2017.06.023

34. Tierney GJ, Denvir K, Farrell G, Simms CK. The effect of technique on tackle gainline success outcomes in elite level rugby union. Int J Sports Sci Coach. 2017.1-10. doi:10.1177/1747954117711866

35. Tierney GJ, Joodaki H, Krosshaug T, Forman JL, Crandall JR, Simms CK, editors. The kinematics of head impacts in contact sport: an initial assessment of the potential of model based image matching. ISBS-Conference Proceedings Archive; 2016. p. 108-11.

36. Tierney GJ, Joodaki H, Krosshaug T, Forman JL, Crandall JR, Simms CK. Assessment of model-based image-matching for future reconstruction of unhelmeted sport head impact kinematics. Sports Biomech. 2017:1-15. doi: 10.1080/14763141.2016.1271905.

37. Tierney GJ, Krosshaug T, Wilson F, Simms CK, editors. An Assessment of a Novel Approach for Determining the Player Kinematics in Elite Rugby Union Players. IRCOBI Conference Proceedings; 2015. p. 180-1.

38. Tierney GJ, Lawler J, Denvir K, McQuilkin K, Simms C. Risks associated with significant head impact events in elite rugby union. Brain Inj. 2016;30(11):1350-61.

39. Viljoen W, Treu P, Swart B. SA Rugby BokSmart: Safe and Effective Techniques in Rugby-Practical Guidelines [internet]. 2009. [cited 2017 Feb 15]. Available from: http://www.sarugby.co.za/boksmart/pdf/BokSmart%20-%20Safe%20Rugby%20Techniques%20Practical%20guidelines.pdf

40. Wilson BD, Quarrie KL, Milburn PD, Chalmers DJ. The nature and circumstances of tackle injuries in rugby union. J Sci Med Sport. 1999;2(2):153-62.