



Sanctioned illegal high tackles significantly increase concussion risk to both tacklers and ball carriers in elite men's Rugby Union

Ross Tucker ^{1,2}, Ben Hester,² Sharief Hendricks ³, James Brown ¹, Éanna C Falvey ^{2,4}

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¹Institute of Sport and Exercise Medicine, Department of Exercise, University of Stellenbosch, Stellenbosch, South Africa

²World Rugby, Dublin, Ireland

³Division of Physiological Sciences and Health through Physical Activity, Lifestyle and Sport, Department of Human Biology, University of Cape Town, Observatory, Western Cape, South Africa

⁴Department of Medicine, University College Cork, Cork, Ireland

Correspondence to

Professor Ross Tucker;
ross@sportsscientists.com

ABSTRACT

Objectives Tackles making contact above the sternum increase concussion and head injury assessment (HIA) risk in Rugby Union. The sport has introduced harsher sanctions to change tackler behaviours to reduce this risk. This increased high tackle sanction numbers, though it is unknown whether sanction severity is associated with injury risk.

Methods The sanction decision made by match officials for tackles resulting in 157 HIA1 removals, of which 91 were confirmed concussions, was evaluated. The propensity of sanction types, ranging from no foul play to red card, was compared after calculating concussion and HIA1 numbers per 1000 tackles of each sanction, using total tackle number of each sanction type from one season of two elite professional competitions.

Results HIA1 removal and concussion risk increased as sanction severity increased. Red-carded tackles were 271.5 (95% CI 143.8 to 512.6) times more likely to result in concussions than legal tackles. Tacklers and ball carriers were more likely to experience concussions from sanctioned high tackles, with tackler risk 28.5 (95% CI 13.5 to 59.9) times higher for sanctioned high tackles compared with legal tackles, and ball carrier risk elevated 133.7-fold (95% CI 65.5 to 272.8) after sanctioned high tackles.

Conclusion Sanctioned high tackles significantly increase concussion and HIA1 risk to both tacklers and ball carriers. Current decision-making frameworks that guide sanction decisions do identify tackle behaviours that elevate clinical risk. Both tacklers and ball carriers would be less likely to experience concussions and head injuries if the frequency of illegal high tackles is decreased.

INTRODUCTION

Head injury and concussions are a major concern in tackle-collision sports such as rugby union,¹ and prevention efforts ranging from protective equipment and rule changes have been implemented in these sports to reduce their incidence.^{2–4} World Rugby, rugby union's governing body, has adopted various policies aimed at changing tackle behaviour by more harshly sanctioning head contact.⁵

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Head injury risk has been shown to be significantly elevated when high tackles, involving contact or proximity of players' heads, are made. In response, World Rugby have implemented directives aimed at sanctioning such illegal high tackles more harshly, in an attempt to drive behaviour change to reduce concussion risk.

WHAT THIS STUDY ADDS

⇒ Concussion and HIA1 removal risk are significantly higher when illegal high tackles are made than when legal tackles are made. The concussion risk increases as the sanction severity increases, with red-carded tackles 272-fold more likely to result in concussion than legal tackles, and 6-fold more likely to cause concussions than yellow-carded tackles. Significantly, both tacklers and ball carriers experience increased risk of concussion as a result of sanctioned high tackles.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Directives to sanction high tackles have been controversial, since they result in increased numbers of red cards. This study shows that the processes and frameworks developed to guide these sanction decisions are identifying and targeting behaviours that do increase concussion risk significantly. Rugby Union should continue to seek ways to reduce the prevalence of the highest risk tackle behaviours.

The specific behaviours targeted by this primary injury prevention strategy were identified by video analyses of injury mechanisms that showed that head injury assessment (HIA) removals were significantly more likely from higher contact tackles that placed the tackler's head and ball carrier's head or shoulders in proximity or contact than when lower contact tackles were made.^{6 7} Since head contact to the ball carrier was already illegal in law, harsher sanctions for such tackles were

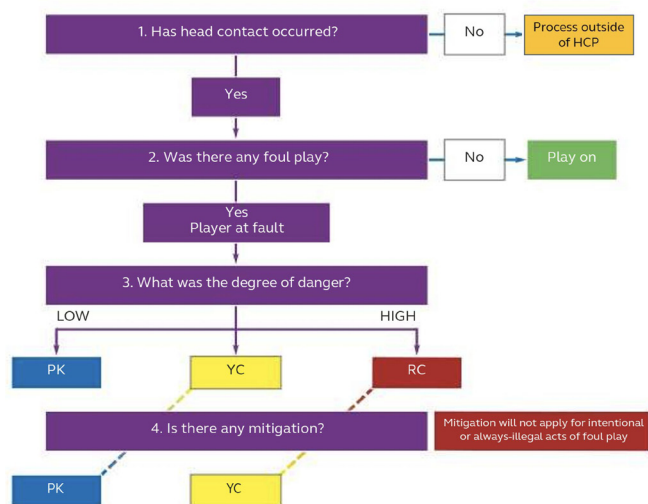


Figure 1 Head contact process (HCP) for sanctioning of head contact during play, introduced in 2021 and modified in 2023. Used with permission. Available online 9. RC, red card; YC, yellow card.

introduced to lower tackle height in order to reduce the frequency of such tackles.⁵

To improve sanction consistency and effectiveness of the behaviour change intervention, World Rugby produced the High Tackle Sanction Framework (HTSF) in 2019.⁸ This decision-making tool provided a systematic approach for Match Officials when assessing head impacts in tackles. The HTSF enabled officials to assess the degree of danger in a tackle, based on characteristics previously found to increase HIA risk,⁶ and then to apply mitigation to arrive at a final sanction.

In 2020, the HTSF was replaced by the head contact process (HCP, figure 1), a simplified decision-making tool which involved four questions to determine the final sanction outcome, and which also applied to head contact at the ruck.⁹

One implication of these decision-making processes is that red-carded tackles can be defined and differentiated from yellow-carded tackles, based on danger and mitigating factors. That is, a red-carded tackle can be defined as one causing head contact as a result of foul play, that is high in danger and has no mitigating factors. A yellow-carded tackle may be defined as a tackle causing head contact due to foul play, but which is either low in danger without mitigating factors, or high in danger with mitigating factors. Finally, a tackle that is illegal but not carded (penalty kick only) is definable as a head-contact tackle caused by foul play that is low in danger, with mitigating factors present.

A question posed by many in the game is whether these sanctions are reflective of the clinical outcome (injury)? That is, are tackles that meet red and yellow card (RC and YC) definitions more likely to cause concussions than legal and lesser-sanctioned tackles? If concussion risk increases with sanction severity, it would support that components of the HCP that identify danger and

mitigation are sensitive to the clinical risk in the sanctioned tackles.

The aim of this study was to compare the propensity of legal tackles to that of sanctioned tackles to cause concussions and HIA cases. We hypothesised that the relative risk of HIAs and concussive injury for both tacklers and ball carriers would increase as sanction severity increases, indicating that foul play is more likely to cause injuries, and that the risk is highest for those tackles deemed high in danger and without mitigation (that is, red-carded tackles).

METHODS

This study was a retrospective analysis of all tackle-related HIAs and concussions during the 2021/2022 Super Rugby (91 matches, SR) and Premiership (156 matches, PRL) competitions. HIA removal from play is indicated when a head impact is observed, which necessitates either the permanent removal of players who are diagnosed as concussed by virtue of displaying criteria 1 signs, or the temporary removal of players for an off-field screen that is based on the SCAT6.¹ All HIAs and concussions during these competitions are captured by the match-day or team medical doctor, and entered into the World Rugby SCRM database that tracks players who are removed from play.¹⁰ All players consent to the use of anonymous data as part of their consent to access the HIA Protocol at the start of each season.

For this analysis, we considered both diagnosed concussions and HIA1 removals, since the latter indicate head impacts sufficient to force players off the field, and thus have an effect on match play, and which may have clinical significance despite not always reaching the threshold for a concussion diagnosis at the time of assessment. A concussion diagnosis is confirmed during the HIA2 and HIA3, which include full SCAT6 assessments performed 2 hours and 48–72 hours after head impact.¹⁰

33 HIA1 removals were not included in the analysis as they did not happen in tackles, but were the result of match activities including kick contests (n=4), mauls (n=3), rucks (n=14) and open play contests for the ball (n=12).

Video footage of all HIA1 removals resulting from tackles was analysed by the World Rugby Game Analysis Unit, with the sanction outcome of injurious tackles coded as ‘Legal’ (no sanction given on the field), ‘Penalty’, ‘Yellow Card’ or ‘Red Card’, depending on the decision made by the referee. A control cohort of tackles from 20 randomly selected matches (Super Rugby=8, PRL=12) was also coded to estimate total number of non-injurious tackles in the analysed competitions. These matches were chosen on the basis of not having HIA1 removals or RC sanctions, and to represent all the teams in the two competitions at least once. This estimate was compared with World Rugby and Opta game analytics coding of tackles and rucks in these competitions, and considered to be accurate as it was within 5% of the coded number in each of the two competitions. Tackles were coded as

tackle events, where one or more tacklers attempt to stop or impede a ball carrier, regardless of whether the ball carrier was brought to ground.¹¹ The sanction outcome of these control tackles was obtained from game analysis data coded by World Rugby's Game Analysis unit. In all sanctioned tackle events, it was the tackler who received the sanction.

The propensity of each sanction decision to result in both concussions and HIA1 removals was calculated as concussions and HIA1 removals per 1000 tackles of each sanction type (eg, concussions per 1000 red-carded tackles). The risk of an HIA1 removal or concussion from a sanctioned tackle relative to a legal tackle was expressed by calculating the ratio of the head injury propensities of sanctioned tackle to that of legal tackles. All data, propensity and the propensity ratio, are presented as means with 95% CI calculated.^{12,13} Propensity ratio values and 95% CI were calculated using Stata (Statacorp, Texas, 2014). Differences were considered significant if the 95% CI did not overlap.

A final analysis explored how the odds of a concussion changed as a function of incremental increases in sanction severity. A χ^2 test for trend was performed on concussions (vs non-concussions) as the outcome and sanction (legal=0, penalty=1, YC=2, RC=3) as the exposure. This test can be performed on exposure categories that have a natural order and tests whether there is an increasing/decreasing trend in the proportion of concussed cases over the four sanction (exposure) categories. This test computes the odds for each sanction (exposure) category and calculates an overall p value (<0.05 considered evidence to reject null hypothesis) for linear trend or dose response.¹² An OR, using the odds for concussion from a legal tackle as the reference, was then

computed for each sanction. The test was performed in Stata (StataCorp. 2023. *Stata Statistical Software: Release 18*. College Station, TX: StataCorp LLC.) using the *tabodds* command.

RESULTS

157 tackle-related HIA1 removals occurred in the two competitions (PRL=102 HIA1s and SR=55 HIA1s). 91 were diagnosed as concussions (PRL=60, SR=31). The average tackle event number per match was 194 in SR and 187 in PRL, which provided a total tackle event cohort of 46892 in the two competitions. Overall concussion propensity was 1.9 concussions per 1000 tackle events (95% CI 1.6 to 2.4), and HIA1 removals occurred 3.3 times per 1000 tackle events (95% CI 2.9 to 3.9). Tacklers accounted for 66% of concussions, and 61% of tackle-related HIA1 removals.

Legal tackles had a concussion propensity of 1.5 concussions per 1000 legal tackle events (95% CI 1.2 to 1.9). Tackler concussion propensity from legal tackles (1.1 concussions per 1000 tackle events, 95% CI 0.9 to 1.5) was higher than ball carrier propensity from legal tackles (0.4 concussions per 1000 tackle events, 95% CI 0.2 to 0.6, propensity rate ratio for tackler vs ball carrier 2.9, 95% CI 1.7 to 4.9).

Foul play and concussion propensity

Sanctioned high tackles made up 0.5% of control tackles (n=252, 1.0 per match) and 23.1% of concussions. 27 RCs were issued (one every 9.1 matches), 11 of which resulted in a concussion (n=9 ball-carrier, and 2 tacklers, who received the RC sanction for the tackle).

Figure 2A shows the propensity of high tackles sanctioned with penalties, YCs and RCs to result in concussions.

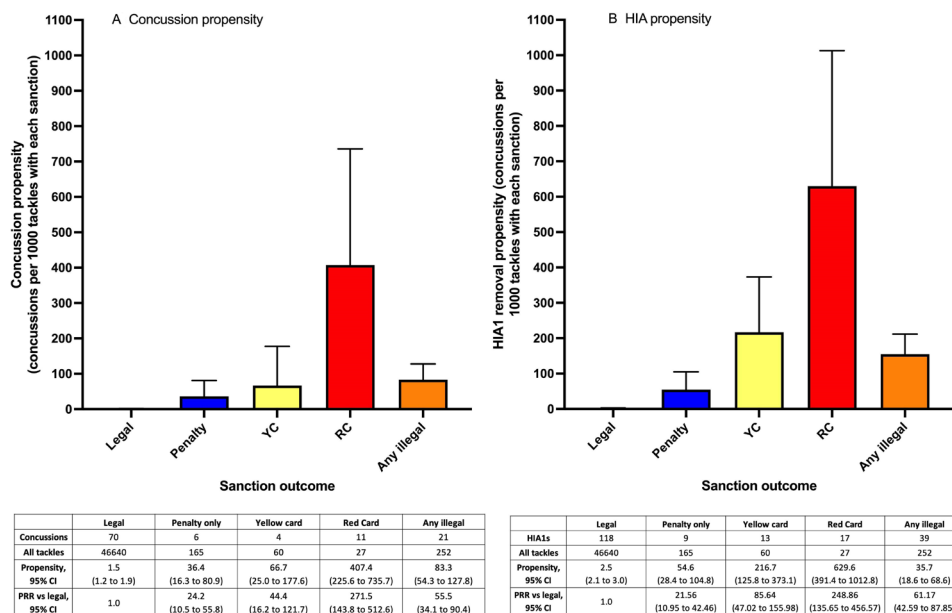


Figure 2 Concussion (A) and head injury assessment (HIA) (B) propensity for tackles with a range of sanctions. Number of concussions/HIAs and total tackles are shown in the tables beneath the corresponding figure, with calculated propensity and propensity rate ratio (PRR) for sanctioned tackles versus legal tackles. RC, red card; YC, yellow card.

The number of concussions and total sanction outcomes are shown beneath the figure for the relevant tackle sanction.

Concussion propensity was 407.4 concussions per 1000 red-carded tackle events (95% CI 225.6 to 735.7). The propensity ratio for RC compared with legal tackle events was 271.5 (143.8 to 512.6). Red-carded tackle events were significantly more likely to result in concussion than yellow-carded tackle events, which had a propensity of 66.7 (25.0 to 177.6) concussions per 1000 yellow-carded tackle events (propensity ratio RC vs YC tackles 6.1, 95% CI 2.0 to 19.2). Red-carded tackle propensity was 11.2 (4.1 to 30.3) times greater than for tackles sanctioned with penalty decisions only (407.4 vs 36.4 (16.3 to 80.9) concussions per 1000 penalty sanctions).

Collectively, sanctioned high tackles were significantly more likely to result in concussions than legal tackles. The propensity of a sanctioned high tackle to result in concussion to either player was 83.3 concussions per 1000 illegal tackles (54.3 to 127.8), equating to one concussion every 12 sanctioned high tackles. Compared with the legal tackle propensity (1.5 concussions per 1000 tackles, or one concussion every 666.3 legal tackles), foul play was 55.5 times more likely to result in concussion (95% CI 34.1 to 90.4).

Overall effect of foul play on HIA propensity

Figure 2B shows the HIA propensity as a function of sanction outcome. Of the 157 tackle-related HIAs, 39 (24.8%) were sanctioned for head contact foul play. The likelihood of an HIA removal increased with increasing sanction severity. The propensity for an HIA1 removal from a red-carded tackle was 629.6 HIAs per 1000 red-carded tackle events (figure 2B). This was significantly higher than for legal tackles (2.5 HIAs per 1000 legal tackles, propensity ratio 248.9, 135.7 to 456.6), penalised tackles (54.6 HIAs per 1000 tackles, propensity ratio 11.5, 6.3 to 21.2) and yellow-carded tackles (216.7 HIAs per 1000 yellow-carded tackles, propensity ratio 2.9, 1.6 to 5.3)

Tackler versus ball carrier HIA risk

Both tacklers and ball carriers were significantly more likely to suffer concussions following sanctioned high tackles (table 1). Tackler concussion propensity was 66.4 times (16.2 to 272.8) higher for red-carded tackles than legal tackles, though these were rare (n=2 tackler concussions from red-carded tackles). Any sanctioned high tackle (n=8, propensity 31.8, 15.9 to 63.5 tackler concussions per 1000 tackles) was 28.5 times more likely to result in a tackler concussion than a legal tackle (propensity ratio 28.5, 13.5 to 59.9).

Ball carrier concussion risk was greatest in red-carded tackles (propensity 333.3 concussions per 1000 red-carded tackles, propensity ratio for RC vs legal tackles 863.7, 388.0 to 1922.5), with ball carrier concussion propensity decreasing as sanction severity decreased from red carded to penalty only sanctioned tackles (table 1).

For HIA1 removal risk, tackler propensity was 35.7 (18.6 to 68.8) HIAs per 1000 sanctioned high tackles (propensity ratio 19.2, 95% CI 9.9 to 37.2, for sanctioned vs legal tackles). Tacklers who received cards (n=4 out of 96 tackler HIAs) were 24.7 times more likely to require HIA1 removal than tacklers who made legal tackles.

Figure 3 shows the odds of a concussion to either player as sanction severity increases in a sequential manner, with the OR of each sanction relative to the odds from a legal tackle shown on the graph. The odds of concussion increased with a dose-response relationship as sanction severity increased sequentially from legal tackle to RC (p<0.001). The odds of a concussion were 457.4 (200.3 to 1044) times greater after a red-carded tackle than a legal tackle.

DISCUSSION

This study explored the likelihood of concussion and HIA1 removal as a function of tackle sanction outcome. We show that concussion and HIA1 removal were significantly more likely after sanctioned high than legal tackles, that risk increases as sanction severity increases in a dose-response manner, and that the magnitude of this risk increase is large; red-carded tackles were 272 times more likely to cause concussions than legal tackles, with any sanctioned high tackle 56 times more likely to result in a concussion. We also show that concussion and HIA1 risk are higher for both the tackler and ball carrier following sanctioned high tackles.

Given that the sanction decision is guided by an HCP (figure 1) that considers degree of danger and presence of mitigating factors, our findings support that the tackle characteristics currently considered important for the sanction decision are indeed associated in an appropriate manner with the likelihood of head injury in the tackle.^{6 14} For example, an upright tackler informs the assessment of foul play, while tackle force (a function of speed, acceleration and tackle type), contacting body part, and tackle type inform the match official's assessment of the degree of danger (figure 1).

Tackler and ball carrier risk

The increase in the concussion and HIA1 risk as sanction severity increased was observed in both tacklers and ball carriers (table 1). Concussion sample sizes from red-carded and yellow-carded tackles are small when tacklers and ball carriers are considered separately, so specific relative risks should not be overinterpreted, but if collectively grouped as sanctioned high tackles, tackler concussion propensity is 28.5-fold higher (95% CI 13.5 to 59.9) when making a tackle that meets the criteria for sanction in the HCP (table 1). For the ball carrier, the risk of concussion from a sanctioned high tackle is 134-fold greater than from a legal tackle (51.6 concussions per 1000 illegal tackles vs 0.4 concussions per 1000 legal tackles, propensity ratio 133.7, 65.5 to 272.8, table 1). The relative difference in risk from illegal tackles is thus disproportionately higher for the ball carrier, which is

Table 1 Tackle, concussion and HIA removal numbers, and calculated propensities for a range of sanction severities to tacklers and ball carriers

	Legal tackle	Penalty only	Yellow card	Red card	Any sanctioned high tackle
Tackler					
Total tackles of each type	46640	165	60	27	252
Concussions	52	5	1	2	8
Concussion propensity (per 1000 of such tackle)	1.1 (0.9 to 1.5)	30.3 (12.6 to 72.8)	16.7 (2.4 to 118.3)	74.1 (18.5 to 296.2)	31.8 (15.9 to 63.5)
Tackler concussion propensity ratio (relative to legal)	-	27.2 (10.9 to 68.1)	14.9 (2.1 to 108.1)	66.4 (16.2 to 272.8)	28.5 (13.5 to 59.9)
HIA1 removals	87	5	2	2	9
Tackler HIA1 removal propensity (per 1000 of such tackle)	1.9 (1.5 to 2.3)	30.3 (12.6 to 72.8)	33.3 (8.3 to 133.3)	74.1 (18.5 to 296.2)	35.7 (18.6 to 68.6)
HIA1 propensity ratio (relative to legal)	-	16.3 (6.6 to 40.0)	17.9 (4.4 to 72.6)	39.7 (9.8 to 161.3)	19.2 (9.6 to 38.0)
Ball carrier					
Total tackles of each type	46640	165	60	27	252
Concussions	18	1	3	9	13
Concussion propensity (per 1000 of such tackle)	0.4 (0.2 to 0.6)	6.1 (0.9 to 43.0)	50.0 (16.1 to 155.0)	333.3 (173.4 to 640.7)	51.6 (30.0 to 88.8)
Ball carrier concussion propensity ratio (relative to legal)	-	15.7 (2.1 to 117.6)	129.6 (38.2 to 439.8)	863.7 (388.0 to 1922.5)	133.7 (65.5 to 272.8)
HIA1 removals	31	4	11	15	30
HIA1 removal propensity (per 1000 of such tackle)	0.7 (0.5 to 1.0)	24.2 (9.1 to 64.6)	183.3 (101.5 to 331.1)	555.6 (334.9 to 921.5)	119.1 (83.2 to 170.3)
Ball carrier HIA1 propensity ratio (relative to legal)	-	36.5 (12.9 to 103.3)	275.8 (138.6 to 548.8)	835.8 (451.2 to 1548.2)	179.1 (108.4 to 295.6)
HIA, head injury assessment:					

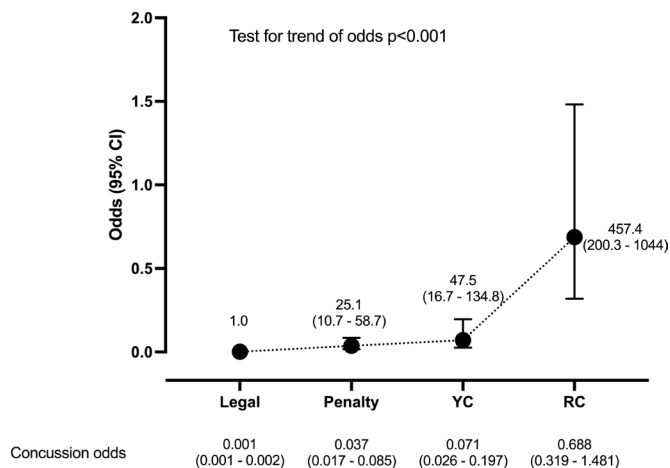


Figure 3 Odds of a concussion for sequential increases in sanction severity. The odds for each sanction type are shown below the graph, while the calculated OR, relative to legal tackles, is indicated adjacent to each symbol.

unsurprising, since ball carriers are almost exclusively concussed as a result of direct contact to their heads, which is, by definition, foul play (table 1).

In contrast, tacklers' heads are almost always in close proximity and thus at risk of contact with some part of the ball carrier's body, and so the risk increase when making illegal tackles is relatively smaller. That there is an elevated risk from illegal tackles reflects that when tacklers make higher contact tackles, which place their own heads near the heads and shoulders of ball carriers, their risk also increases. This is important, as it confirms that higher contact tackles also increase risk to the player who initiates the illegal tackle, as has been shown previously for both legal and illegal tackles in both Rugby Union and Rugby League, in both men and women.^{6 7 15 16}

The implication of these findings is that if high tackle numbers are reduced, both tacklers and ball carriers will be relatively protected and concussion and HIA incidence should decrease. Since illegal tackles are defined by the HCP, it may be inferred that if tackles causing head contact to the ball carrier, deemed to be the result of foul play, and in particular with high danger and no mitigation, then fewer head injuries will occur, both to the ball carrier and to the tackler.

The injury prevention principle employed and examined in this study is an attempt to change behaviour by more harshly sanctioning already illegal tackles, rather than to change the height of the tackle in law. The latter approach has also been tested, with mixed results. In one study in elite players, tackler concussion risk increased when the legal tackle height was reduced to the armpit, though the study was short, and the trial introduced midway through a season, which may have negated learning and adaptation time.¹⁷

In contrast, a study in amateur level players found that lowering the legal tackle height to the armpit resulted in fewer upright tackles, suggesting player behaviour

change, but a non-significant reduction in concussion incidence.^{18 19}

This suggests that time and significant stakeholder engagement are required for effective implementation and adaptation, though further studies are required in this regard. Furthermore, the additive effect of other preventative measures such as improved tackler and ball-carrier technique training needs to be considered.^{20 21} Whether the sanctioning approach can achieve the same effect on player behaviour as a direct law change also requires investigation. One consideration is whether player behaviour will necessarily change in response to sanction, since harsh sanctions in particular remain relatively rare. In the current cohort, for instance, an RC sanction occurred every 9.1 matches in the current cohort, which is in agreement with global data from World Rugby's referee audit where an RC is currently awarded approximately every 14 matches.

Limitations

One factor that must be considered a confounder is that the sanction outcome may be influenced by clear and obvious signs of concussion to the ball carrier. That is, match officials will in some instances observe clear and obvious concussion indicators (loss of consciousness, ataxia) after illegal tackles, and sanction the inciting event more severely than if the tackled player shows no such signs. This is likely in part responsible for the size of the increase in concussion and HIA1 removal propensity for RCs compared with YCs, as evidenced by the large increase in odds shown in figure 3. Put simply, a concussion outcome is likely to bias a referee towards an RC, rather than the HCP detecting the contributing factors that result in concussions when RCs are warranted, and this increases the odds of concussion for RCs. However, this cannot be the sole explanation for the increase, because match officials are more often unaware of the diagnosis of concussion, which is made only at the HIA2 and HIA3 assessment stages 2 hours and 48 hours after matches, respectively. Only when clear on-field signs are visible can the concussion diagnosis be known prior to these assessments, and potentially influence the decision.

However, within the HCP framework, match officials almost certainly consider the tackle outcome (player clearly injured) as part of their assessment of the degree of danger, and this will contribute to the magnitude of the relative increase in injury propensity we describe for illegal tackles.

We also do not have the ability to assess whether degree of danger affects concussion and HIA1 risk independent of the presence of mitigation when YCs are awarded. That is, in the HPC, a YC sanction may occur for two tackle scenarios. The first involves a tackle deemed high in danger, but with the presence of mitigating factors. The second is when degree of danger is assessed as low, but mitigation is absent (figure 1). Consequently, YCs may be given for both low-danger and high-danger tackles. Our analysis considered only the final sanction (YC),

and not the specific path taken to reach that decision. This is primarily a function of the very low sample size of YCs (n=60), particularly those resulting in concussion (n=4, table 1). It would be of interest for future studies to compare concussion and HIA1 risk as a function of the high versus low danger distinction, independent of, and when factoring in, the mitigating factor assessment.

Finally, in the present analysis, an illegal high tackle was identified on the basis of whether the match officials sanctioned the tackle. Since not every high tackle resulting from foul play is seen by match officials, there will be tackle events currently counted as 'legal tackles' in our analysis, but that should be sanctioned, and that increase the risk of concussion. The number of these instances is not known, but they would be counted as concussions in the legal tackle group that should be allocated to the sanctioned tackle groups. In theory, this adjustment would increase the calculated concussion propensity from high tackles even more, while reducing that of legal tackles, since fewer truly legal tackles would result in concussion. Future analysis may refine the relative risks of head injuries by auditing referee sanction decisions, such that currently unsanctioned tackles are included in the illegal high tackle group, and some sanctions may be either increased or decreased on review.

CONCLUSION

The risk of both concussion and HIA1 removal increases in a dose-response relationship with sanction severity, and this increase in risk exists for both the tackler and ball carrier. Red-carded tackles are 272 times more likely to result in concussion than legal tackles, and 6 times more likely to cause concussion than yellow-carded tackles. Given that cards can be defined by a sequence of characteristics that consider the degree of danger and presence of mitigating factors, these findings support that what the current law considers to be tackle behaviours and characteristics that create head injury risk do indeed increase the risk of concussion outcomes. Collectively, these findings support the conceptual value of the HCP as a framework that identifies and then sanctions foul play in proportion to its risk of causing injury and removal from play following significant head impacts.

X Ross Tucker @Scienceofsport and Sharief Hendricks @Sharief_H

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Contributors RT conceived the study. RT and BH designed the study. BH conducted the video analysis. RT performed the analysis and drafted the article, and all other authors revised it critically for important intellectual content. RT is the guarantor. All authors had full access to all the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

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Competing interests RT is employed in a consulting role with World Rugby, the governing body for the sport of Rugby Union globally. JB receives research funding from and manages the global concussion monitoring system for WR. SH has received research funding from World Rugby for other research studies on

the sport. BH is employed as a video analyst with World Rugby. ECF is the Chief Medical Officer of World Rugby.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Consent obtained directly from patient(s).

Ethics approval This study involves human participants and was approved by World Rugby Ethics Committee. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. Data may be provided upon request, where such data are not in the public domain and do not reveal medical information of any players.

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ORCID iDs

Ross Tucker <http://orcid.org/0000-0002-4294-4822>

Sharief Hendricks <http://orcid.org/0000-0002-3416-6266>

James Brown <http://orcid.org/0000-0002-7778-7783>

Éanna C Falvey <http://orcid.org/0000-0003-3961-1805>

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