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Original research

Tackling the tackle 2: Evaluation of referee and player behavioural change as measures of implementation of a law variation in community-level male amateur rugby union

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ABSTRACT

Objectives: To evaluate player and referee behaviour during a lower tackle height law variation trial in community rugby union ('rugby').
Design: Prospective observational cohort study.
Methods: In a law variation trial in male amateur community rugby, coded match video surveillance data were analysed. Referee (sanctioning rate) and player (tackler body position) behaviour changes over one season (under the lowered, armpit-level maximum legal tackle height condition) were analysed in three approximately equal periods of the season. Secondarily, an independent professional referee reviewed illegal high tackle sanctioning data.
Results: Overall, 108 matches with 14,780 tackles were filmed and coded. Sanctioned illegal high tackle propensity was significantly higher in the mid-season (41 sanctioned high tackles/1000 tackle events; 95 % CI: 35–47), compared with first and last periods. Upright tacklers in tackles decreased significantly in the final vs. middle period of the season (rate ratio: 0.69; 95 % CI: 0.54–0.88; $p < 0.01$). Of all the coder-determined high tackles also assessed as high under the new law by the independent referee, 51 % were sanctioned by the on-field referee.
Conclusions: Positive player and referee behavioural changes were observed during a lowered legal tackle height law variation in this community rugby setting. Increased mid-phase high tackle sanctioning by referees was followed by fewer tackles with upright tacklers in the subsequent (last) phase of the season. Encouraging positive behaviour changes of this nature, particularly if sustained (beyond trial study periods), may contribute to overall injury risk reduction, and hold considerable importance to inform future injury prevention strategies in rugby.

Practical implications

- Positive player and referee behaviour was observed following the implementation of a lowered legal tackle height law variation in this amateur community cohort.
- Increased sanctioning was followed by fewer tackles with upright tacklers.

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- Law trials have the potential to cause significant wider system effects that may contribute substantially to an intervention's ultimate ability to reduce injury risk.
- A safe tackle technique training intervention should form part of future law variation trials to enhance law variation outcomes.
- The findings of this study represent important considerations to inform future injury prevention policies.

1. Introduction

Concussion in sport is a serious public health concern.[1,2] Research in elite and community rugby union (rugby),[3–5] identified the tackle event as the primary cause of injury in the sport.[4,6,7] The tackle is a physical-technical contest where the defending tackler(s) brings the attacking ball-carrier from the opposing team, to ground.[8] This contest causes more than half of all injuries in rugby[8,9] and is the most frequent cause of concussion,[4,10,11] with an incidence of 4–9 concussions per 1000 match hours and a propensity of 0.3 concussions per 1000 tackles in community rugby.[10,12–14] Tackle-related risk factors for head injury include tackler (and ball carrier) body position in the tackle, the tackler's level of contact with the ball carrier's body (i.e. higher risk when contact is above the level of the ball carrier's armpit, compared with below), players' relative speeds into the tackle, and tackle type.[4] The tackler is at higher risk for head injury than the ball carrier.[4] High contact in the tackle (i.e. at the level of the ball carrier's shoulder and above) has ~4.5-fold increased odds of an HIA (i.e. risk for head injury) and an upright tackler, compared with a bent-at-the-waist tackler, has a 1.4-fold higher risk of head injury.[4]

Injury and concussion prevention strategies, based on this empirical evidence, aim to 'nudge' tacklers into lower body positions and to lower the tackler's point of contact on the ball carrier, to reduce the frequency that tacklers' and ball carriers' heads share proximity. This can be achieved by an increased sanctioning focus (stricter application of the law with harsher penalties) to reduce illegal head contact[15,16] and lowering the maximum legal tackle height through law variations.[8] However, research describing the role of focussed sanctioning on safe player behaviour to reduce concussion risk is lacking. Furthermore, only two lowered legal tackle height law trials have been reported in the literature – one in professional rugby[17] and one in community rugby (a study that we previously reported on).[12] In both these studies, despite the intervention being based on sound empirical evidence, there was no effect on concussion incidence. Thus, the effective implementation of these interventions requires deeper evaluation to gain an understanding of the observed lack of reported epidemiological effect.

Authors have proposed the need for a socioecological systems approach to address the complexities of concussion in rugby.[18,19] The primary socioecological actors responsible for the implementation of a lowered maximum legal tackle height law variation are the target-level actors, i.e. match officials (referees) and players. How the actors respond, or change behaviour, after an injury prevention strategy implementation such as a tackle law variation, provides important information in terms of evaluating the intervention's implementation. Behaviour change following implementation of an active injury prevention measure is a prerequisite for injury reduction.[20,21] In terms of the Transtheoretical Model of Health Behaviour Change, the introduction of an intervention is followed by a lag period, during which time individuals adjust to the change (i.e. progress through various stages of changes), followed by adaptation (maintenance stage of behaviour change).[22] Thus, when implementing a tackle height law variation trial, we hypothesise that the enforcement of the new law may fluctuate based on the stage of the season, e.g. referees may poorly enforce the high tackle law variation in the early part of the season. However, this may change as the season progresses and the referees and players adjust to the new law. These temporal changes in referee and player behaviour after the implementation of a tackle height law variation trial are unknown.

Therefore, as key implementers of an injury prevention intervention, i.e. a lowered maximum legal tackle height law variation, the primary aim of this study was to investigate player and referee behaviour changes to evaluate the intervention's implementation across a season of amateur community rugby played under the lowered (armpit) legal tackle height condition. On-field referee decisions may also be influenced by subjective referee interpretation of the law variation; therefore, a secondary aim of the study was to examine on-field referee sanctioning decisions of illegal high tackles.

2. Methods

This study formed a secondary analysis of an overarching cross-sectional analytical study.[12] The overarching study investigated concussion incidence following the implementation of a lowered maximum legal tackle height law variation, i.e. lowering the maximum legal height from shoulder level to armpit level. The first year of the study was conducted using the standard shoulder-level legal tackle height.[13] The lowered, armpit-level legal tackle height was enforced in the second year of the study.[12] Briefly, to address these study objectives, referee behaviour (propensity of sanctioning rate) and player behaviour (propensity of upright tacklers) were compared between three periods of the season. On-field referee decisions were examined by comparing the on-field sanctioning decisions to those of an independent professional referee. Ethical approval for this study was granted by the Health Research Ethics Council of Stellenbosch University (reference number N20/02/017).

The study was conducted in the university rugby club's four-league, inter-residence competition comprising ~42 teams that is played annually from April to October.[23] Fixtures occur weekly. Each league's matches are played on the same weekday on adjacent rugby fields. First league is the highest league, whereas fourth league is the lowest league. Matches last 60 (1st–3rd leagues) or 50 min (4th league), compared to the standard match duration of 80 min, due to the recreational level of play. All registered (as is required by the rugby club) players taking part in the residence competition provided consent and were thus eligible for the study. Players were registered university students aged 18 years and older. Sixteen referees from the South African Referees Academy acted as match officials during the competition. The referees had 4 ($\pm$2) mean years of experience at collegiate-level rugby. Key stakeholder (coaches, players, and referees) engagement started six weeks prior to study onset through an awareness campaign that included numerous presentations and Q & A sessions (tailored to stakeholder group; some sessions facilitated by World Rugby representatives), and a digital marketing campaign.

In the second year of the larger study, matches were filmed via 1) a videographer-operated wide-view camera from dedicated scaffolding between fields and 2) close-up footage from a standard head strap mounted GoPro camera (Version 7, with image stabilisation technology) worn by the match referee. Eight matches had no video surveillance data due to technical or logistical limitations.

A secure, centralised data repository was used to store captured video files. A coder was assigned to each of the four leagues and coding was performed with NacSport Basic (NacSport, Las Palmas de Gran Canaria). Coder preference determined whether GoPro or wide-angle video was primarily used for coding, whilst cross-referencing the other video angle as needed if the primary source was unclear. The coding framework was developed in collaboration with a Rugby Football Union working group and subject-expert co-authors.[24] The coders had prior coding experience, having conducted coding as central elements of post-graduate studies under the instruction of a co-author (WK), an experienced coder, who also oversaw the coding function in this study. Inter- and intra-coder reliability was tested using the Kappa statistic that is commonly used in rugby video analyses studies[25] and provides an indication of the level of agreement between raters.[26] This was achieved by

randomly selecting one half of a match that each coder had to code on two separate occasions at least one week apart. Kappa provides a value from 0 to 1 to represent agreement, with different values indicating agreement categories that range from slight to almost perfect.[26] Intra-coder Kappa values ranged between 0.95 and 0.97 and inter-coder values ranged between 0.95 and 0.98. Therefore, the reliability between the four coders was deemed to be 'almost perfect'. The coding framework is attached as supplementary materials (Supplementary 1).

Exported data were parsed through custom-built scripts (based on the logical flow of the coding framework) to flag any illogical coding descriptor combinations and address technical database organisational limitations (e.g. tackler detail from two separate tackles occurring within 2 s of each other assigned to a single tackle). This process was performed by a research data scientist and compared to raw video data and coding data by RvT.

Statistical comparison between three periods of the season was performed to examine potential rates of change in player and referee behaviour. The season was divided into three approximately equal periods that coincided with the first, middle and last periods of the season (1060, 1205, and 1150 match hours respectively). Each period corresponds to a period spanning 3–4 weeks of competition, interspersed with university examination and holiday periods. This division was based on total match exposure, avoiding fractions of matches, or separating a day into two periods. Match exposure was calculated as the number of matches per league multiplied by the number of players exposed (30), multiplied by the time exposed (leagues 1–3: 1 h, 60 min; league 4: 0.83 h, 50 min).

Relevant to this study, coders recorded whenever they judged a tackle event to be a 'high tackle under new law', whether a 'high tackle under new law' was sanctioned by the on-field referee or not, and the tackler's body position on contact in the tackle event. Player and referee behaviour changes were evaluated by calculating propensities, i.e. the number of event occurrences per 1000 tackles, for each of the three periods of the season. Poisson regression was used to determine rates of change (rate ratios) in propensity between periods.

First, the normalised fractions of all coded tackles that the coders identified as 'high tackle under the new law' were calculated for each period:

The fraction of all coded tackles that the coders identified as high tackles

$$\left(\frac{\#\text{total coder} - \text{determined high tackles per period}}{\#\text{total number of tackles per period}}\right) \times 1000$$

Second, for player behaviour, the normalised propensity calculations are represented by the following equations:

1) The fraction of upright tacklers in coder identified high tackles

$$\left(\frac{\#\text{upright tacklers in coder} - \text{determined high tackles per period}}{\#\text{total coder} - \text{determined high tackles per period}}\right) \times 1000$$

2) The fraction of upright tacklers in all coded tackles

$$\left(\frac{\#\text{upright tacklers in coder} - \text{determined high tackles per period}}{\#\text{total number of tackles per period}}\right) \times 1000$$

For referee behaviour, the following equations describe the normalised propensity calculations:

1) The fraction of coder identified high tackles that received on-field sanction

$$\left(\frac{\#\text{on} - \text{field sanctioned coder} - \text{determined high tackles per period}}{\#\text{total coder} - \text{determined high tackles per period}}\right) \times 1000$$

2) The fraction of all coded tackles that received on-field sanctions

$$\left(\frac{\#\text{on} - \text{field sanctioned coder} - \text{determined high tackles per period}}{\#\text{total number of tackles per period}}\right) \times 1000$$

The remaining propensities (e.g. for on-field sanctioned high-tackles in relation to independent referee assessment of coder-determined high-tackles) were calculated in a similar fashion.

All tackle events were assessed by the coders as high under the law variation when a tackler made any initial contact with the ball carrier's body at or above the level of the armpit (i.e. first point of contact at the ball carrier's shoulder- or head-and-neck level deemed high tackle by definition). An evaluation of on-field referee sanctioning was performed by a professional South African Rugby Union (SARU) international-level referee who independently assessed video clips of all tackle events that had been coded as high under the law variation. The purpose of this evaluation was to improve current knowledge of and gain a broader understanding of the challenges and complexities experienced by on-field referees during the dynamic, real-time application of a tackle height law variation. The referee categorised these tackles as either 'high tackle under new law', 'not a high tackle under new law', or 'unclear'. The independent referee assessment was based on the interpretation and application of the law that an international level referee would normally apply, i.e. if he were the on-field referee, would he have sanctioned the tackle, or not, given a lowered armpit-level maximum legal tackle height and considering the match contextual situation of the tackle event. The independent referee was able to review video clips multiple times and in slow motion. The Kappa value was calculated to determine the level of agreement between the on-field referee sanctioning decisions of coder-determined high tackles and independent referee review of the same coder-determined high tackles. The Kappa value for the full season was 0.39, i.e. 'fair' agreement.

Descriptive statistics (mean ± SD, median and range, frequency, proportions) were used to report data. Additional data analyses, including propensity calculations and Poisson regressions with 95 % confidence intervals and the level of significance set at $p = 0.05$ were performed using Stata (StataCorp. 2021. *Stata Statistical Software: Release 12*. College Station, TX: StataCorp LLC) and R statistical software.[27]

3. Results

Overall, 108 matches were filmed and coded, yielding 14,780 total coded tackles. There were 137 (±30) mean and 137 (119–156) median tackles per match. One hundred and forty-six high tackles were not assessed due to unclear video footage; therefore, these tackles were excluded from further analyses.

3.1. Temporal tackle count change, and player and referee behaviour change over the season (Table 1)

The propensities for coder- and independently determined high tackles followed a similar pattern with a significant increase in the mid-period of the season (Fig. 1a).

The propensity of upright tacklers in tackles was significantly lower in the final period of the season compared with the first or second (middle) periods of the season. There was an increase in upright tacklers involved in high tackles from the first to the second period, but this increase was not statistically significant (Fig. 1b).

The propensity of on-field sanctioned high tackles was significantly greater in the second period compared to the first period, and significantly lower in the third period compared to the second period of the season (Fig. 1b).

Non-significant changes were observed for upright tacklers and sanctioned high tackles, based on coder-determined and independently-determined high tackle propensity calculations (Fig. 1c and d).

Table 1
Propensities of high tackles, sanctioned tackles, and upright tacklers per 1000 events under the new law.[a]

	P 1		P 2		P 3	
	n	95 % CI	n	95 % CI	n	95 % CI
Per 1000 tackles						
Coder-determined high tackles	96	88–105	116	107–126	73	65–81
Independently determined high tackles	50	44–56	63	56–71	43	37–49
Sanctioned high tackles	28	23–33	41	35–47	24	20–28
Coder-determined upright tacklers	32	27–37	35	30–40	24	20–29
Per 1000 coder-determined high tackles						
Sanctioned tackles	288	243–339	352	304–405	326	268–392
Coder-determined upright tacklers	332	283–387	299	254–348	329	271–395
Per 1000 independently-determined high tackles						
Coder-determined upright tacklers	641	547–746	547	466–638	556	459–668
Sanctioned tackles	463	384–554	550	469–641	502	410–609

P, period; n, propensity per 1000 events; CI, confidence interval.
[a] Excluding 'unclear' tackles not assessed independently.

3.2. Independent referee review of on-field sanctioning of coder-determined high tackles (Table 2)

The overall average sanctioning proportion of coder-determined high tackles was low (33 %, 509 of 1539; range 22–47 %). An independent professional SARU referee assessed 1539 coder-determined high tackles. Several tackles (n = 146; 9 % of 1539) were excluded due to unclear video, i.e. could not be assessed as either 'high tackle under new law' or 'not a high tackle under new law', leaving a total of 1393 'high tackle under new law' events that could be analysed (Table 2).

The independent referee assessed that only 55 % (n = 762 of 1393) of coder-determined high tackles were 'high tackle under new law'. Of these 762 coder-determined high tackles assessed as 'high tackle under new law' by the independent referee, 51 % (n = 387) were sanctioned by the on-field referee. In contrast, 90 % (n = 569) of coder-determined high tackles assessed by the independent referee as 'not a high tackle under new law', were not sanctioned by the on-field referee.

According to coded data of on-field referee decisions, 449 (32 % of 1393) coder-determined high tackles were sanctioned. The majority (n = 387, 86 % vs. n = 62, 14 %) of coder-determined high tackles sanctioned by the on-field referee (n = 449) were assessed as 'high tackle under new law' according to independent referee review. Similarly, the majority (n = 569, 60 % vs. n = 375, 40 %) of coder-determined high tackles not sanctioned by the on-field referee (n = 944) were assessed as 'not a high tackle under new law' by the independent referee.

4. Discussion

This study aimed to investigate the implementation of lowering the maximum legal tackle height from shoulder to armpit level as an injury prevention strategy in amateur, community-level rugby. The implementation was assessed by evaluating the behaviour of two key implementing stakeholders: players and referees.

We found significantly fewer upright tacklers in tackles in the last phase of the season, compared with the first and middle periods, and a significantly greater sanctioning rate in the mid-phase of the season, compared with the first and last periods of the season (Fig. 1b). These findings suggest that both players and referees exhibited positive on-field behaviour change observed across a season conducted under the lowered law variation condition.

The tackle causes most concussions in rugby and therefore, it is targeted for interventions to reduce concussion incidence. Tackle technique training[8] and a system approach to reduce tackle-related injury risk[19] represent measures to reduce injury risk in rugby. Two important factors frequently proposed to reduce tackle-related concussion incidence are focussed sanctioning of high tackles and lowering the body position of the tackler going into a tackle event, through an increased, or stricter, sanctioning of (illegal) high tackles[15] and law variations.[12,17]

This study found that, compared to the first and middle periods, there was a significant reduction in upright tacklers in tackle events in the last period of the season. Data from this law variation trial (not reported here, as outside the aims of this study) indicate that an upright tackler had the highest odds (~3.4×) of being associated with a high tackle (any tackle event where the tackler contacts the ball carrier above armpit level) of all factors investigated. In the only other law variation trial published to date by Stokes et al.,[17] the propensity of upright tacklers (and ball carriers) in tackle events was compared between the standard (shoulder level) maximum legal tackle height condition and the lowered (armpit) maximum legal tackle height condition in an elite cohort. The study did not aim to investigate the rate of change in the propensity of upright tacklers in tackle events over a period of time under the same maximum legal tackle height condition as we did in the present study. Nonetheless, positive player behaviour change was reported as an important finding during the lowered legal tackle height condition. These player behaviour changes included fewer tackle events where the tackler contacted the ball carrier above armpit level or with the ball carrier's shoulder or head, and fewer tackle events with upright tacklers (and ball carriers). Our findings, in an amateur community cohort, therefore, seem to emulate the findings of Stokes et al.[17] It should be noted that the measurement of the propensity of factors associated with high (i.e. unsafe) tackles occurred at different times in these studies, that is, before and after lowering the legal tackle height in the elite cohort, and at different time periods within the same (lowered) tackle height condition in the amateur cohort. Measuring the propensity at different time points within the same tackle height setting enables the measurement of the rate of change. Therefore, despite the differences in the timing of statistical outcome measurements, this indicates that law variation trials may likely have significant beneficial behaviour change effects (i.e. lowering the body position of the tackler in the tackle event), independent of whether the findings stem from an elite or amateur cohort. This bears significant importance regarding scientific conclusions that may be drawn from current and future tackle law variation trials.

An independent professional rugby union referee reviewed video footage of all coder-determined high tackles. Considering only those high tackles that were assessed by the independent referee to be a 'high tackle under new law', the on-field sanctioning rate equals 51 % (n = 387 of 762). In terms of real-life outcomes, i.e. taking into consideration nuanced law interpretation and real-time enforcement by the on-field referee, and not adherence to a strict coding framework definition, this figure is likely more representative of the actual on-field sanctioning rate of illegal high tackles during the competition. The Kappa value of agreement between on-field sanctioning and independent referee review of coder-determined high tackles indicates limited agreement. Speculatively, this may indicate the difficulty faced by the on-field referees (non-professional and relatively less experienced than the independent professional referee, with an average of 4 years'

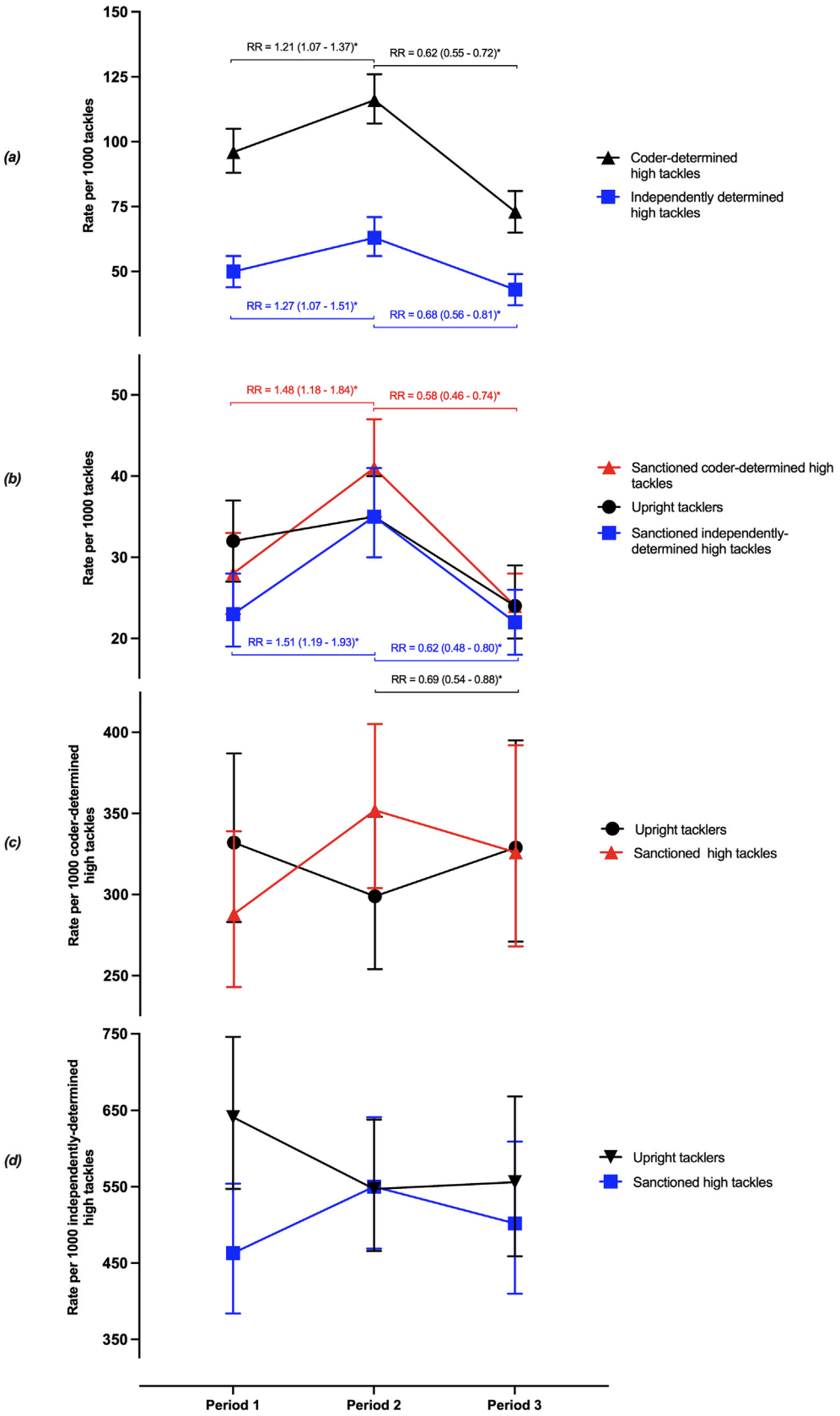

Fig. 1. Comparison of rates of sanctioning and upright tacklers per period. RR indicates rate ratios (95% confidence intervals). Significant rate ratios (*, $p < 0.05$) are shown. (a) The propensity of coder- and independently determined high tackles per 1000 tackles. (b) The propensity of upright tacklers and sanctioned coder- and independently determined high tackles per 1000 tackles. (c) The propensity of upright tacklers and sanctioned high tackles per 1000 coder-determined high tackles. (d) The propensity of upright tacklers and sanctioned high tackles per 1000 independently-determined high tackles.

Table 2
On-field referee sanctioning of coder-determined high tackles in relation to independent referee assessment of all coder-determined high tackles under the new law.[a]

	P 1	P 2	P 3	Total	%
Independent Referee Review = high	259 (34 %)	298 (39 %)	205 (27 %)	762	55 % of 1393
Sanctioned	120 (31 %)	164 (42 %)	103 (27 %)	387	51 % of 762
Not sanctioned	139 (37 %)	134 (36 %)	102 (27 %)	375	49 % of 762
Independent Referee Review = not high	241 (38 %)	248 (39 %)	142 (23 %)	631	45 % of 1393
Sanctioned	24 (39 %)	28 (45 %)	10 (16 %)	62	10 % of 631
Not sanctioned	217 (38 %)	220 (39 %)	132 (23 %)	569	90 % of 631
Upright tacklers[b]	166 (37 %)	163 (37 %)	114 (26 %)	443	
On-field sanctioned high tackles	144 (32 %)	192 (43 %)	113 (25 %)	449	
Coder-determined high tackles	500 (36 %)	546 (39 %)	347 (25 %)	1393	
Total tackles	5204 (35 %)	4703 (32 %)	4772 (33 %)	14,679	

P, period; %, proportion.
[a] Excluding 'unclear' tackles not assessed independently.
[b] In coder-determined high tackle.

refereeing experience at senior amateur level rugby) in applying the high tackle law variation in real-time. This aspect may present additional opportunities to induce greater behaviour change as increased referee education prior to the implementation of a law variation as in this study, may further enhance positive outcomes. An attempt to compare agreement between coders and referees is likely of little value (nor possible to calculate the kappa statistic of agreement), considering the distinctly different strict coding framework application by coders and nuanced, interpretive dynamic law application by referees.

The propensity of on-field referee sanctioning of high tackles was significantly higher in the middle period of the season, compared to the first and last periods of the season. A similar pattern was observed whether based on coder-determined or independent referee-determined high tackles (Fig. 1a and b). This represents an important finding as it suggests that the rate of change in the observed on-field referee implementation of the law variation remained similar, whether in relation to either coder-determined or independent referee-determined high tackles. Prior studies have only reported overall sanctioning proportions of high tackles,[16,28] or compared changes in overall sanctioning proportions under different maximum tackle height conditions[17] and not investigated changes in the rates of sanctioning under the same maximum tackle height condition. In the elite-level law variation trial, compared to the standard shoulder-level tackle height phase, the authors report a 4-fold increase in sanctions for high tackles in the lowered, armpit-level tackle height phase of the study, although the lowered law variation phase only constituted approximately a quarter of matches in the study.[17] This study at the elite level also reported fewer tackles with upright tacklers and ball carriers, and lower initial contact points on the ball carrier in the lowered tackle height phase.[17] This may seem contradictory, as one would expect fewer sanctions when there are fewer tackles with upright tacklers and lower initial contact points on ball carriers, and therefore, fewer illegal high tackles to be sanctioned.

Our a priori hypothesis was that a 'lag period' is likely to occur following the introduction of the law variation until the study environment adjusts to the new conditions. Sanctioning increased in the mid-season and a reduction in the number of upright tacklers in tackles in the subsequent (last) period of the season was observed. The observed player behaviour change (fewer upright tacklers in high tackles) is associated with a concomitant reduction in sanctioning observed in the final period of the season. Speculatively, the observed player behaviour change may have been a response to stricter sanctioning in the mid-season, but a definitive finding in this regard was not the aim of this study and would necessitate a different study design (quasi-experimental study). Logically, one would expect fewer sanctioned high tackles when there are fewer tackles with upright tacklers. In this sense, the findings in this study seem to differ from the findings in the elite-level law variation trial, although, as described previously, the measurement of sanctioning occurred at different times and under different tackle height conditions. This places a limitation on meaningful comparison between the studies' findings.

The overall average sanctioning proportion of coder-determined high tackles (at or above the level of the armpit, regardless of ball carrier body position) is low (33 %, 509 of 1539; range 22–47 %). This sanctioning rate is lower than that achieved by professional referees-in-training at South African elite youth rugby tournaments (41 %, 46 of 113).[16] However, it should be noted that this sanctioning rate is substantially better than the sanctioning rate of high tackles reported in a study from the English Premiership rugby competition between 2003 and 2006 (6 %, 14 out of 238), which used professional referees and the standard regulation tackle height law at the time.[28] It is important to reiterate that the coders purely coded high tackles in terms of the initial point of contact by the tackler on the ball-carrier, irrespective of ball-carrier behaviour, as per the study's predefined coding framework. Thus, based on independent referee determined high tackles, the on-field sanctioning proportion of 51 % compares favourably with the rate of 41 % reported by Brown et al.[16]

Despite sound empirical evidence, in the only two reported tackle law variation trials in which the maximum legal tackle height was lowered from shoulder to armpit level, the desired reduction in concussion incidence was not achieved.[12,17] In the cohort in which the present study was conducted, a concussion incidence between 6 and 9 concussions per 1000 match hours had previously been observed.[12,13] In fact, whilst the observed overall concussion incidence rate ratio was 0.69 (8.9 to 6.1 concussions per 1000 match hours), the tackle-related concussion incidence rate ratio in this cohort was 0.99.[12] Therefore, the notion that these injury prevention interventions did not achieve their desired outcomes, warrants deeper examination. It is likely that adopting a narrow view and focusing solely on incidence numbers does not fully account for the complexity of injury prevention, particularly related to concussion.[29] Various injury prevention models have been proposed since Van Mechelen published his sequence of prevention.[30] Increasingly, these subsequent models aimed to incorporate the complexity of at least some degree of requisite, sustained behaviour change, often for extended periods, that underpins the success of any injury prevention strategy and precedes traditional, quantitatively measured changes in injury rates.[20,21] Therefore, we evaluated changes in behaviour of the players and referees as the primary intervention implementers in this study to gain a deeper understanding of the wider, system effects that an injury prevention intervention may cause. It should also be noted that the behaviour change expected of the players is an acquired skill. Therefore, the addition of some form of tackle training intervention may be an important additional consideration in future studies.[19]

The COVID-19 pandemic was the biggest study limitation: the 2020 rugby season was cancelled and therefore we could not collect a second season of video surveillance data to allow for more robust data comparison under the lowered law variation trial conditions, nor determine whether the observed player and referee behaviour change is sustainable. Match duration in this study (50–60 min) is a factor that requires careful consideration, as injuries and concussions are known to occur

more frequently towards the end of matches which are usually 80 min in duration, due to physical and mental fatigue.[31–34] Not all matches could be filmed due to technical and logistical limitations. In this study, the data were generated by collating the output of four different coders. This introduces a measure of subjectivity, in spite of reliability testing between coders, that may influence the accuracy of coding data output. The completeness of the dataset was also affected by database organisational limitations imposed by the coding software that was employed. Therefore, custom parsing scripts were necessary to address these software-imposed limitations. Finally, the coding of a tackle is an inherently difficult task, as the tackle represents a very dynamic activity. Therefore, it is often difficult to discern exact interactions between the ball carrier and tackler. This could lead to potential further subjective interpretive differences between coders.

5. Conclusion

We evaluated the implementation of an injury prevention intervention by investigating changes in referee and player behaviour during the implementation of a lowered maximum legal tackle height law variation trial in amateur community-level rugby. Positive changes in player and referee behaviour were observed, with significantly fewer upright tacklers in tackle events in the final phase of the season, most likely following more focussed and stricter referee sanctioning of high tackles in the preceding mid-phase of the season. These findings represent important intended behaviour change outcomes of the intervention. Furthermore, we found fair (limited) agreement between on-field sanctioning and independent referee review of coder-determined high tackles, with an overall on-field sanctioning proportion of 51 % based on independent referee review. The implementation of injury prevention strategies may lead to wider socioecological system outcomes, which could significantly contribute to reducing overall injury incidence in rugby, particularly if sustained beyond trial study periods, by promoting positive behaviour change in individual-level actors. This is an important consideration for future injury prevention strategies in rugby. Unfortunately, the cancellation of the intended subsequent season of this study prevented a more robust determination of the sustainability of the observed positive changes in player and referee behaviour beyond the law variation trial. Therefore, these encouraging positive findings require further study and emphasise the importance of continued efforts to inform tackle-related injury prevention.

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Confirmation of ethical compliance

Stellenbosch University Health Research Ethics Committee approval was granted (N20/02/017) for this study.

CRediT authorship contribution statement

Riaan van Tonder: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Project administration. **Sharief Hendricks:** Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing – review & editing, Supervision. **Lindsay Starling:** Conceptualization, Methodology, Investigation, Data curation, Writing – review & editing, Project administration. **Sean Surmon:** Conceptualization, Resources, Writing – review & editing. **Pierre Viviers:** Conceptualization, Methodology, Investigation, Writing – review & editing. **Wilbur Kraak:** Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing – review & editing. **Keith A. Stokes:** Conceptualization, Methodology, Software, Writing – review & editing, Supervision. **Wayne Derman:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision. **James Craig Brown:** Conceptualization, Methodology, Resources, Validation, Formal analysis, Investigation, Data curation, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of interest statement

KS is employed by the Rugby Football Union, the national governing body for rugby union in England. LS is employed by World Rugby, the world governing body for rugby union; however, this appointment only started once data collection for this study had concluded. SH is a JSAMS editorial board member. The other authors have no competing interests to declare.

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