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Association of ground hardness with injuries in rugby union

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Background: Ground hardness is considered one of the possible risk factors associated with rugby injuries. **Objectives:** To examine the contribution of ground hardness, rainfall and evapotranspiration to the incidence of injury, and to investigate seasonal injury bias throughout one full season of rugby union.

Methods: A prospective epidemiological study of rugby injuries was performed on 271 players from rugby union teams involved in the premier grade rugby competition in Dunedin, New Zealand. Ground hardness was measured before each match over 20 rounds with an industrial penetrometer, and local weather information was collected through the National Institute of Weather and Atmospheric Research and the Otago Regional Council. Poisson mixed models were used to describe injury incidence as a function of ground hardness throughout the season.

Results: The overall injury incidence during the season was 52 injuries per 1000 match player-hours (95% CI 42 to 65). Although injury incidence decreased gradually by round with a rate ratio of 0.98 (95% CI 0.96 to 0.99) ($p=0.036$), and the hardness of match grounds decreased significantly over the season (0.16 MPa/round, 95% CI 0.12 to 0.21, $p<0.001$), a non-significant association was demonstrated between injury incidence and ground hardness. Injury incidence was not associated with a combination of ground hardness, rainfall and evapotranspiration on the day of the match or cumulative rainfall and evapotranspiration before each match.

Conclusions: Seasonal change in ground hardness and an early-season bias of injuries was demonstrated. Although the contribution of ground hardness to injury incidence was not statistically significant, match round and injury incidence were highly correlated, confirming a seasonal bias, which may confound the relationship of injury to ground condition.

Rugby union is a collision sport with a high incidence of injury to players, but epidemiological studies have demonstrated a decline in injury incidence throughout the playing season.^{1–3} This phenomenon has been seen both in the northern and southern hemispheres, despite the different months in which rugby is played, and therefore the change of ground condition that occurs from autumn to late winter or early spring has been considered a contributor to this observation.⁴

Environmental factors such as weather and ground conditions have been historically cited as potential extrinsic risk factors for sports injuries.^{5–7} Other studies have investigated the relationship between ground condition and the incidence of injury,^{8–12} but few of these studies are relevant to injuries encountered on natural turf where rugby union football is usually played. Because of the nature of rugby union, ground hardness is considered to be a major contributor to injury. Ground hardness is a combination of soil structure, soil compaction and grass type, all of which can be moderated by weather conditions and usage. Generally, rainfall reduces ground hardness, whereas evapotranspiration, which is a combination of radiation, wind speed, temperature and humidity, tends to dry out grounds and increase their hardness.¹³

Orchard established that the risk for non-contact anterior cruciate ligament (ACL) injury tended to increase on harder grounds and, conversely, the relative risk of ACL injury decreased when softer grounds were prepared in the Australian Football League (AFL).¹⁴ Only one study has systematically investigated the relationship between ground condition and injury occurrence in rugby union. Lee and Garraway found that injury incidence in Scotland was higher on harder surfaces than on heavier (softer) pitches, when using qualitative measures to identify the condition of the rugby field.²

A major epidemiological study of rugby injuries, the Rugby Injury and Performance Project, proposed, as one of 23 recommendations, that the relationship between ground condition and injury incidence be investigated as a possible means to prevent rugby injuries.¹⁵ Our current study aimed at examining the contribution of ground hardness, rainfall and evapotranspiration to injury incidence in premier grade club rugby union. In addition, observed seasonal trends of injury incidence and ground condition throughout one season were examined.

METHODS

A prospective epidemiological study of match injuries was conducted on 271 registered rugby union players who participated in the Dunedin premier grade competition throughout the 2002 season. The weekend competition began in late March (early autumn) and concluded in late July (mid-winter). Each team played 18 matches over the season, and teams that qualified for the final play-offs (rounds 19–20) completed an extra one or two matches. Each round of the competition consisted of five matches and exposure was calculated on the basis of 15 players competing for 80 minutes, which equated to 20 player-hours per team or 40 player-hours per match.

For the purpose of this study, an injury was defined as any physical event that required medical attention, or subsequently caused a player to miss at least one scheduled game or team training session.¹⁶ Players were excluded from the study if they could not train or play rugby for the entire season because of an injury sustained during the pre-season. Return to play was defined as the injured player being able to play or train without

Abbreviations: ACL, anterior cruciate ligament; AFL, Australian Football League

Table 1 Injury incidence and exposure as a function of round

Round	Injuries (events)	Exposure (hours)	Incidence (/1000 player-hours) (95% CI)
1	11	140	79 (43 to 144)
2	9	160	56 (29 to 110)
3	7	160	44 (20 to 94)
4	7	160	44 (20 to 94)
5	23	160	144 (92 to 225)
6	7	160	44 (20 to 94)
7	8	160	50 (25 to 102)
8	12	160	75 (42 to 134)
9	7	160	44 (20 to 94)
10	8	160	50 (25 to 102)
11	4	160	25 (9 to 68)
12	11	160	69 (37 to 126)
13	9	160	56 (29 to 110)
14	5	160	31 (13 to 77)
15	4	160	25 (9 to 68)
16	5	160	31 (13 to 77)
17	12	160	75 (42 to 134)
18	9	160	56 (29 to 110)
19	2	160	13 (3 to 52)
20	4	120	33 (12 to 91)
Total	164	3140	52 (42 to 65)

restriction. The Orchard Sports Injury Classification System was used to classify injuries to the entire body.¹⁷

Injury surveillance was undertaken by a physiotherapist and/or sports medic associated with each team, who attended each match at the weekend and was in contact with the players at training during the week. When a player sustained an injury, report forms were completed that included subject demographic information, the place, date and timing of the injury, and the nature of injury (including type, site and previous history). Subsequent information on the player's participation in, or return to, rugby after the injury was also acquired from team management and match sheets. All forms were collected weekly from the physiotherapists or sports medics, or both, and verified by the researchers.

Ground hardness was measured using an industry standard penetrometer (Eijkelpamp, model 06.01; Giesbeek, Netherlands), which is routinely used in soil science, agriculture and civil engineering to measure ground strength.¹⁸ An appropriately sized cone-tip with standard angle (60°) was selected, depending on soil conditions. To calculate the average ground hardness at each match venue, 15 areas were identified and standardised on a grid pattern across each playing field. Penetration measures were performed at a constant speed (approx 2 cm/s) to a depth of 50 mm from the ground surface and were repeated three times at adjacent points in each area. Maximum ground penetration force (kN) was recorded through an analogue scale and converted to megapascals (MPa), the International System of Units for pressure. The same researcher (MT) took all ground hardness measurements an average of 2 hours before each match at the designated rugby grounds throughout the 20-week season.

Daily precipitation (mm) and Penman Potential Evapotranspiration (mm) data were obtained before and throughout the rugby season from local weather stations, the National Institute of Weather and Atmospheric Research and the Otago Regional Council. The Penman Potential Evapotranspiration measure describes water evaporation from soil and plants and is a function of radiation, wind speed, temperature and humidity.¹³

Total amounts of rainfall and evapotranspiration on the day of the match, and at intervals before each match, were

determined. A composite of rainfall and evaporation variables is considered potentially to have more effect on ground conditions than each individual variable alone, and has previously been used when examining the relationship between ground hardness and injury occurrence.^{19–21}

Statistical analysis

Injury incidence for each competition round and over the whole season was calculated on the basis of 1000 player-hours.^{22–23} We explored the relationships between injury incidence rate as a function of the possible covariates of ground hardness, round (time) and cumulative rainfall and evapotranspiration at 0, 7, 10, 14, 30, 60, 90, 120 and 180 days before each match. Predictors of ground hardness were also investigated. These data are correlated, in that all matches in a round are played on the same weekend, and there are a limited number of venues. To account for these correlations, statistical analyses were carried out at round level, using mean values, and match level, using mixed models.

Using mean values, we performed univariate analyses, including Poisson regression,²⁴ simple linear regression and correlation. Graphical methods, including a pairwise scatterplot of relevant variables with a Lowess smoother, were also used.²⁵

Two multivariate Poisson mixed models²⁶ for the outcome measure of injury incidence were considered, using ground as a random effect. The first model examined injury incidence as a function of round, ground hardness, evapotranspiration and rainfall on the day of the match (day 0). Backwards selection was used to determine the best model. The second model explored the best historical weather predictors (rainfall and evapotranspiration) of injury incidence.

Deviance²⁶ was used to determine which of the rainfall and evapotranspiration variables gave the most statistical information on incidence. This was done by comparing deviance for nine models, each of which included match, ground hardness, and rainfall and evapotranspiration measures at day *i*; where *i* = 0, 7, 10, 14, 30, 60, 90, 120 and 180 days before the match. Similarly, normal mixed models were used to model ground hardness, with the best historical predictors determined by comparing *R*². Normality assumptions were found to be satisfactory. All statistical analyses were performed using the statistical software SAS (v 8).²⁷

The study was approved by the University of Otago Human Ethics Committee.

RESULTS

Injury surveillance data were completed for 96 of the 99 matches during the season. Two of the 10 teams did not comply with the injury surveillance phase of the study and therefore the three matches involving both these teams were excluded from the analysis. All players subsequently injured in the remaining cohort agreed to participate in the study.

A series of 94 ground hardness measurements were taken from a total of 13 separate rugby fields. Two matches were twice held at the same field on the same day during the season, and data from these matches were included in the study as a single set of measurements.

A total match exposure time of 3140 player-hours was recorded for the eight teams across the competition season (table 1). Rounds 1 and 20 have lower exposure hours than the other rounds owing to incomplete data from one team and the competition finals, respectively, during these rounds.

Injury and ground hardness data were obtained from a total of 92 matches, which were then used to examine the association of ground hardness with injury incidence. However, round 5 of the competition had an extremely high and atypical injury rate (144 injuries/1000 player-hours) and was therefore excluded from the Poisson mixed models, as

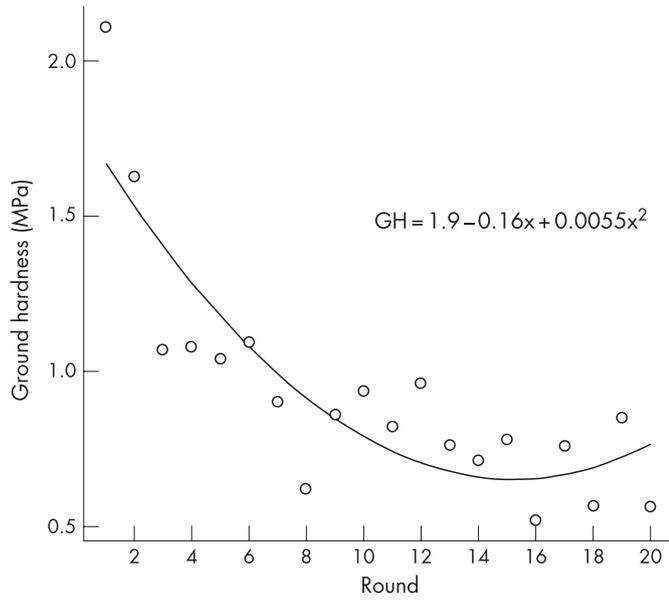


Figure 1 Trends of ground hardness (GH) throughout the playing season. $x = \text{round}$.

regression diagnostics showed it was an excessively influential point. There was no obvious reason for this single, outstanding result. This reduced the final number of matches analysed to 87.

Injury incidence

A total of 164 injuries from 108 injured players were recorded. Injury incidence and exposure for each round and throughout

the season is included in table 1 and demonstrates an overall incidence rate of 52 injuries per 1000 player-hours (95% CI 42 to 65).

Ground hardness

Ground hardness (GH) decreased throughout the season as a function of round (fig 1); rapidly at first, then levelling out, as shown by the fitted quadratic model: $GH = 1.9 - 0.16 \times \text{round} + 0.0055 \times \text{round}^2$. Both coefficients were highly significant ($p < 0.001$).

Ground hardness and weather conditions

Ground hardness was best modelled using historical weather data (cumulative rainfall and evapotranspiration) from 14 days before the round. The coefficient for evapotranspiration was positive ($p < 0.001$) and for rainfall, negative ($p = 0.002$), indicating that ground hardness increased with evapotranspiration and decreased with rainfall. However, when round was included in this model, it was not significant ($p = 0.458$), but ground hardness was still significantly associated with both evapotranspiration (positively) and rainfall (negatively). This may indicate that these variables have a stronger effect than round, or it may be a function of the high degree of correlation among each of the variables, as shown by fig 2.

Injury incidence, ground hardness and round

Poisson regression demonstrated a significant decrease in injury incidence as a function of round when round was modelled continuously, with a rate ratio of 0.98 (95% CI 0.96 to 0.99; $p = 0.036$). This implies that the rate of injury decreased by 2% with each successive round, as illustrated in fig 2. Univariate modelling of injury incidence as a function of

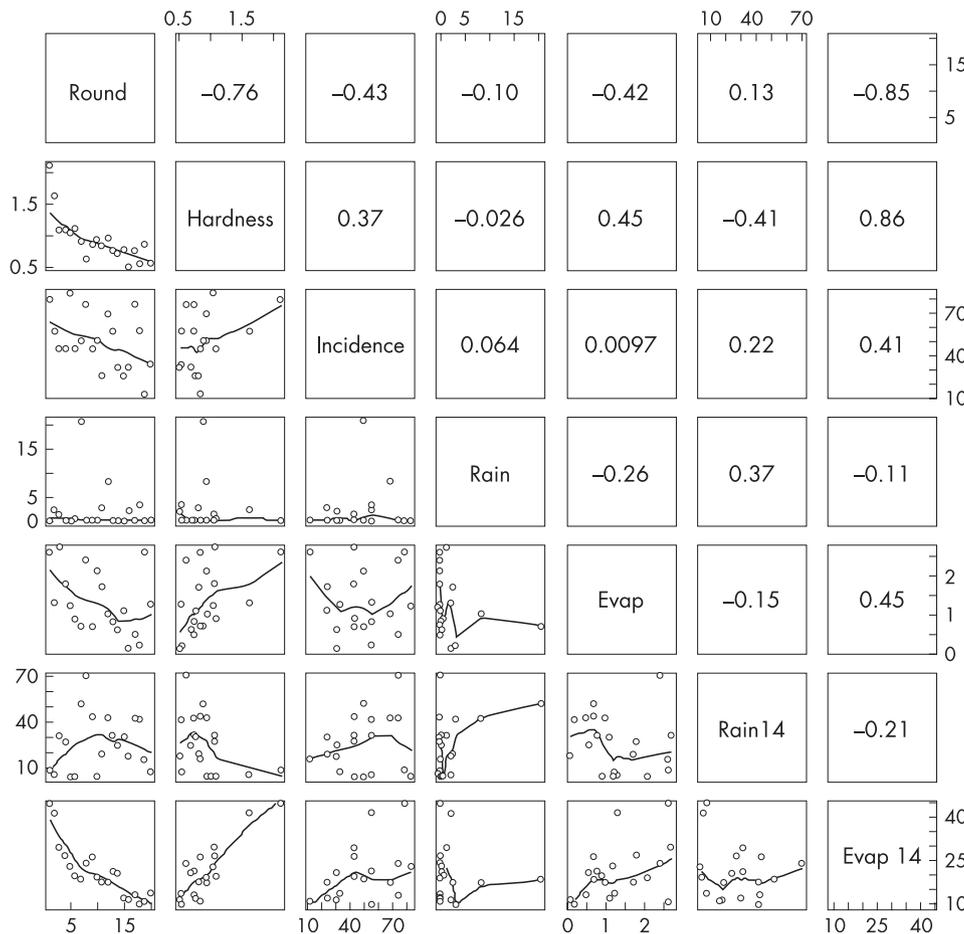


Figure 2 Scatterplot relationship between variables. The upper right panels show correlations between each pair, and the lower left panels show scatter plots with a Lowess smoother. Rain14 and Evap14 refer to rain and evapotranspiration 14 days previous.

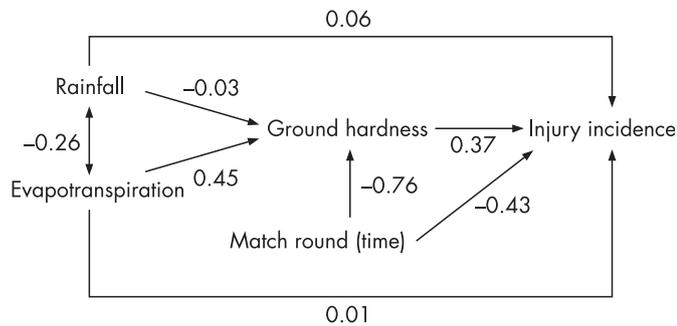


Figure 3 Summary of the correlations between injury incidence and ground hardness. Rainfall and evapotranspiration refer to match day values.

ground hardness demonstrated no association ($p = 0.961$) (fig 2).

Injury incidence and weather conditions

A backwards selection model for the outcome injury incidence, starting with the variables rainfall and evapotranspiration on the day of the match, ground hardness and round, resulted in no variables being retained in the model. None of the historical weather variables appeared to out-perform any of the others in explaining injury incidence in a model that included round or evapotranspiration and rainfall at a given day (0, 7, 10, 14, 30, 60, 120, 180).

Summary of the relationship between variables

The relationships between the study variables were complicated, with multiple interactions. The relationships between injury incidence, ground hardness, round, rainfall and evapotranspiration on the weekend of the round are best shown in figs 2 and 3.

DISCUSSION

An injury incidence of 52 injuries per 1000 player-hours in premier grade rugby was recorded in this study. Injury incidence in first-grade club rugby has been previously reported in Australia,^{28, 29} South Africa,³⁰ New Zealand,¹⁶ and Croatia,³¹ and varied considerably in these studies (17–105 injuries/1000 player-hours), primarily owing to different injury definition and incidence calculation methods.

One study that used similar methodology to this research monitored a professional team in the Super 12 rugby competition and reported 120 injuries per 1000 player-hours over a full season.²³ The comparatively high incidence in Targett's study is consistent with the findings of Bird *et al*, who demonstrated that injury incidence increased as the competition grade advanced,¹⁶ and Bathgate *et al* who reported that professional level rugby (International, Super 14 competition) now has the highest injury rate of all levels of competitions.³² All three authors suggested that in more senior grades, higher levels of skill, fitness, experience and game intensity resulted in a higher rate of injury.

Ground hardness decreased significantly throughout the rugby season in Dunedin, especially during the first half of the competition. This finding is consistent with that of Orchard, who found that the ground was harder in the early part of the season (autumn) than in late winter and early spring at AFL grounds in Australia, despite climatic differences (temperate-subtropical) between the geographical location of matches.¹⁴ It is not clear, however, whether ground hardness follows the same pattern each year owing to annual climate variation, as in the South Pacific, the El Niño Southern Oscillation is a

significant source of seasonal and year-to-year climate variability.³³

This study demonstrated an early-season injury bias in premier rugby union in New Zealand, consistent with other studies.^{1–3} However, most studies that have investigated this phenomenon categorised the rugby playing period into several stages to compare injury incidence in the early season with that in the late season. Only one study examined weekly trends of injury incidence throughout the season and showed that injury incidence significantly decreased by an average of 2.5%/week as the season progressed.¹ In the present study, there was also a significant decrease in injuries (2%/week) as a function of round, which resulted in almost twice as many injuries reported in the first half of the season as in the second half.

There are several reasons why seasonal bias exists in rugby union injuries,⁴ including attrition of an injury-prone cohort early in the season,¹ more enthusiastic play owing to greater motivation in the early season,^{1, 34} a lack of enthusiasm in reporting injuries in the late season^{1, 34} and inadequate match physical fitness.^{3, 28, 34–36} These reasons are all plausible and yet to be fully investigated, although Alsop *et al* reported that a lower fitness level in the early part of the season did not seem to affect how quickly the injury rate deteriorated.¹ Changes in ground condition have also been suggested as one of the primary reasons why early seasonal bias exists in rugby union injuries.^{4, 34}

Apart from physical contact with the surface, ground hardness might be an important indirect factor in rugby union injuries owing to its influence on running speed and consequent impact force. Although it is recognised that a hard ground provides greater external force directly to the body when a player falls, a harder sports ground also produces faster and quicker movements,³⁷ probably because of increased traction and less force attenuation.

Orchard reported an increase in non-contact injuries in the AFL when the grounds were harder.¹⁴ However, the present study was unable to examine the effect of ground hardness on contact injury in relation to non-contact injury, as the number of reported non-contact injuries was low. Rugby union is differentiated from many contact sports by its high prevalence of collision-related injuries and further research is therefore required on the mechanism of injury to substantiate the influence of ground hardness on indirect (non-contact) injury.

In the present study, the incidence of injury in premier grade rugby declined as ground hardness decreased throughout the season. However, previous studies in New Zealand and Ireland reported that over half of all injuries in rugby union occurred on softer sports grounds.^{38, 39} Conversely, a more recent and detailed epidemiological study demonstrated an increased injury incidence on harder grounds,² although this study only classified ground hardness qualitatively.

Environmental and weather factors such as rainfall and evapotranspiration have been suggested to affect injury incidence through a change in ground hardness.^{4, 14, 40} Ground hardness was best modelled in the current study using historical weather data from 14 days before each round, which suggests a delayed or cumulative effect. Although these results were quite strong, care should be taken in interpreting them. It is likely that the composition of the soil has a direct relationship to ground hardness in its ability to retain moisture from precipitation, lose it through evaporation and therefore determine its consistency and compaction value. Grass type and structural characteristics may also affect ground hardness measurements, and the type or species of grass sown on stadium fields has been recently reported to show a stronger association with non-contact ACL injury incidence in the AFL than the hardness of the ground.⁴¹ Soil composition,⁴² moisture

What is already known

- A seasonal injury bias has been identified in rugby union and the change in ground condition due to environmental and weather factors has been suggested as a contributor to this phenomenon.
- An association between ground hardness and injury incidence using qualitative measures has previously been identified.

What this study adds

- This is the first study to measure quantitatively ground hardness in rugby union.
- The contribution of ground hardness to injury incidence was more driven by the time of the season than environmental factors.
- It remains unclear whether seasonal injury bias can be directly attributed to ground condition.

content⁴³⁻⁴⁴ and grass species⁴¹ could therefore be considered as interactive factors associated with ground hardness when the relationship between ground hardness and injury occurrence is examined. This association warrants further investigation.

As far as we know, this is the first study to measure ground hardness quantitatively throughout one season of rugby union. Previous studies have relied on subjective assessment of hardness, and have not quantified ground hardness changes throughout a full playing season. Despite some debate over the relative merits of ground hardness measurement devices,¹⁴ the penetrometer remains a practical tool for measuring ground hardness in a sports environment.

The fact that ground hardness significantly decreased as the season progressed, as did injury rate, suggested that ground hardness and injury rate may be associated. However, when round was included in the regression model, injury incidence as a function of ground hardness showed no association, confirming that the "round" was the influential variable. The high incidence of injury in the early rounds, often termed early seasonal bias, may therefore be a confounding factor when investigating injury incidence in rugby union, possibly masking the effect of ground hardness or other factors associated with injury.

CONCLUSIONS

This study investigated the relationship between injury incidence and ground hardness in premier club rugby union throughout a playing season. Although the results of this study demonstrated a seasonal change of ground hardness and provided evidence of a seasonal bias on injury incidence, the contribution of ground hardness to injury incidence was more driven by the time of the season than by environmental factors. No single variable showed a sufficiently strong relationship with injury incidence to identify it clearly as the cause of the increased injury incidence in the early part of the season.

Rugby union is a collision sport with most injuries occurring in the tackle phase where players come into contact with each other or the ground, or both. Although ground hardness is a possible direct contributing factor for rugby injuries, it may also be an indirect factor through providing increased traction, acceleration and ultimately, greater collision forces. It remains

unclear whether the seasonal injury bias often reported in rugby union can be directly attributed to ground condition or to other factors and therefore further research into seasonal bias is warranted.

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Conflict of interest: None declared.

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COMMENTARY

This study is another to demonstrate the early-season bias for injuries in rugby union, with a unique analysis of the variable, ground hardness, long thought to be a possible explanation for the early-season increase in injuries. The results show that in southern New Zealand there is a definite decrease in ground hardness over the course of the season, roughly corresponding to the decrease in injury rate. However, as the authors point out, “round” itself is a better predictor of injury than ground hardness, suggesting that confounders are at work. Further study is needed to differentiate between other ground-related variables (such as shoe-surface traction and grass type), intrinsic factors (such as player fitness) and methodological artefacts. Nevertheless, this study confirms the early-season bias for injury as one which is critical for an understanding of injury prevention in rugby.

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