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A global perspective on collision and non-collision match characteristics in male rugby union: Comparisons by age and playing standard

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ABSTRACT

This study quantified and compared the collision and non-collision match characteristics across age categories (i.e. U12, U14, U16, U18, Senior) for both amateur and elite playing standards from Tier 1 rugby union nations (i.e. England, South Africa, New Zealand). Two-hundred and one male matches (5911 min ball-in-play) were coded using computerised notational analysis, including 193,708 match characteristics (e.g. 83,688 collisions, 33,052 tackles, 13,299 rucks, 1006 mauls, 2681 scrums, 2923 lineouts, 44,879 passes, 5568 kicks). Generalised linear mixed models with *post-hoc* comparisons and cluster analysis compared the match characteristics by age category and playing standard. Overall significant differences ($p < 0.001$) between age category and playing standard were found for the frequency of match characteristics, and tackle and ruck activity. The frequency of characteristics increased with age category and playing standard except for scrums and tries that were the lowest at the senior level. For the tackle, the percentage of successful tackles, frequency of active shoulder, sequential and simultaneous tackles increased with age and playing standard. For ruck activity, the number of attackers and defenders were lower in U18 and senior than younger age categories. Cluster analysis demonstrated clear differences in all and collision match characteristics and activity by age category and playing standard. These findings provide the most comprehensive quantification and comparison of collision and non-collision activity in rugby union demonstrating increased frequency and type of collision activity with increasing age and playing standard. These findings have implications for policy to ensure the safe development of rugby union players throughout the world.

Highlights

- The safety of rugby union, especially the tackle, has previously been questioned but limited data are available to understand the collision and non-collision match characteristics between different age categories and playing standards.
- The frequency of collision and non-collision match characteristics increase with age and playing standard except for the frequency of scrums and tries which are lowest at the Senior Elite level. The activity of the tackle and ruck are also different between age categories and playing standards.
- Hierarchical cluster analysis demonstrated clear differences in all and collision match characteristics between junior (i.e. U12, U14, U16), and amateur (i.e. U18 and senior) and elite (i.e. U18 and senior) playing levels.
- Governing bodies and practitioners should be aware of the differences in collision and non-collision match characteristics by age and playing standard, when reviewing future versions of rugby union.

KEYWORDS
Tackle; ruck; scrum; player development; policy

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Introduction

Rugby union is amongst the most played and watched sports in the world, with an estimated 9.6 million participants across 124 countries (Till et al., 2020). Participation occurs across youth and senior levels, and amateur and elite standards is characterised by both collision (e.g. tackle, ruck, maul, scrum, lineout) and non-collision events (e.g. pass, kick, ball running; Till et al., 2020). Collision events involve physical engagement between opposing players to compete for possession of the ball and prevent their opponents from scoring points (Hendricks et al., 2018). Both collision and non-collision events are fundamental to rugby union and successful performance of these events has been associated with team success (Bennett et al., 2019; Jones et al., 2014). However, collision events, primarily the tackle, have been identified as the greatest injury risk within rugby union (Fuller et al., 2007; Williams et al., 2013). Given this risk of injury, the safety of the tackle for youth players has been questioned (Pollock et al., 2017). However, most research in rugby union has been conducted in senior elite standards (Burger et al., 2020), and as such, further research is required across multiple playing levels.

To increase player safety and improve performance in rugby union, video analysis research has been recommended to quantify key match characteristics (den Hollander et al., 2018). To date, study sample sizes range from small (e.g. under ten; Bishop & Barnes, 2013) to large (e.g. over 300; Vaz et al., 2010). However, studies which use large sample sizes typically utilise data from commercially available datasets, limiting the information presented due to the characteristics that have already been collected and analysed. Furthermore, to date, more recent video analysis studies within rugby union have solely focussed upon the tackle (Hendricks et al., 2017) including tackle rates (Hendricks et al., 2018), outcomes (van Rooyen et al., 2014), technique (Tierney et al., 2018) and associations with injury (Quarrie & Hopkins, 2008), and concussion (Tierney et al., 2016). Rugby union match-play includes other collision and non-collision events, yet these have been explored to a lesser extent despite being fundamental to the characteristics of the sport. These include the ruck (Hendricks et al., 2018), maul (Schoeman & Schall, 2019), scrum (Bradley et al., 2020) and lineout (Schoeman & Schall, 2019) alongside other non-collision characteristics (e.g. catching, passing, kicking). As such, limited research exists quantifying and comparing the collision and non-collision match characteristics across different rugby union age categories and playing standards (Tucker et al., 2016).

The sport of rugby union at the senior elite standard appears collision dominant. However, the limited data available from age-group match-play may suggest otherwise (McIntosh et al., 2010). In Australian rugby union, McIntosh and colleagues (2010) used technique analysis on the tackle, showing a lower frequency of active shoulder tackles at the U15 level compared to senior players (McIntosh et al., 2010). In England, Read et al. (2018) analysed microsensor technology to examine match-play physical characteristics, demonstrating greater running and less collisions were observed in U16-U18 compared to senior players (Read et al., 2018). These findings suggest that the collision characteristics and activity of youth amateur rugby union may be different to senior elite rugby, which may occur due to the rules applied. However, limited research is available particularly focusing upon a broader age range and the inclusion of multiple nations.

Therefore, this study aimed to quantify and compare the collision and non-collision match characteristics across age categories (i.e. U12, U14, U16, U18, Senior) for both amateur and elite playing standards from Tier 1 rugby nations (i.e. England, South Africa, New Zealand). A large-scale study of this nature would address this research gap, helping understand rugby union match characteristics across multiple playing levels whilst potentially informing training strategies, long-term player development, as well as both policy and law modification debates.

Materials and methods

Study design

The study collected and analysed video footage from 201 male rugby union matches across five age categories (i.e. U12, U14, U16, U18, Senior) and two playing standards (i.e. Amateur, Elite) within England, New Zealand and South Africa. Amateur playing standards included education (i.e. competitive match-played between two teams where players represent their school or university) and community (i.e. competitive match-played between two teams at an amateur standard where players are not paid to play) rugby union matches. Elite playing standards included international (i.e. competitive match-played between two international teams) or professional (i.e. a competitive match-played between two teams at the highest standard where players are paid to play) rugby union matches. This resulted in seven independent playing groups (i.e. U12 Amateur, $n = 19$ matches; U14 Amateur, $n = 25$; U16 Amateur, $n = 30$; U18 Amateur $n = 24$; U18 Elite n = 38; Senior Amateur, $n = 25$; Senior

Elite, $n = 40$). It should be acknowledged that player numbers (e.g. U12 = 12-a-side vs. U14 = 15-a-side), pitch size (e.g. U12 = 70 × 50 m vs. U14 = full size), playing duration (e.g. U12 = 40 mins vs. Senior = 80 mins) and playing rules (e.g. U12 = uncontested scrums, U14 = uncontested lineouts) were not the same for each playing group. However, even though such differences were apparent, to achieve the study aim of quantifying and comparing the match characteristics, data were reported in absolute terms (i.e. number of events), consistent with other research (McIntosh et al., 2010), with some characteristics (e.g. tackle type) considered as a percentage of the total activity. Such reporting of data allowed an understanding of total frequency of match characteristics and relative contribution of activity type.

Protocols

All analyses were performed at the match level with no coding of individual players. All matches were competitive and played between 2017 and 2019, adopting the laws of World Rugby at the time. Matches were screened for suitability to meet the criteria (i.e. complete match, appropriate age category and playing standard within England, New Zealand and South Africa). All video recordings of matches were obtained from a principal investigator from each of the three countries and it was their responsibility to source the video footage of matches from existing recorded matches or by filming matches prospectively. All match footages were screened for completeness and quality by the lead analyst. The quality of the video footage was considered suitable when match events were clearly visible and interpretable. Match footage was predominantly filmed from an elevated side position at the halfway line. This allowed the camera to follow the ball during play and zoom in on specific match events. Match footage was excluded if the angle of the footage was too wide, too high, or unclear to accurately code. Insufficient footage quality contributed to a lower sample size at the U12 and U14 levels as factors such as camera position restricted the clarity of match events. Ethics approval was obtained for the filming and analysis of matches in line with Helsinki international ethics. Consent for the use of the videos and analysis was provided by the national governing bodies and a representative from each team.

Match video footage was analysed using Sports Code Elite Version 14 (Sportstec), using an Apple iMac or Macbook (Apple Inc., Cupertino, CA, USA). The analysis software allowed control over the speed at which each movement could be viewed and the recording and saving of each coded instance into a database. During the analyses, the analyst could pause, rewind and watch the footage in slow motion. The highest frame frequency the analyst could slow down the motion of the footage was to 25 frames per second. Match characteristics were coded by nine video analysts based on two laboratories ($n = 4$ Leeds, England; $n = 5$ Cape Town, South Africa). To enhance consistency between analysts, the lead analyst from the two video analysis laboratories collaboratively reviewed a full match examining each match characteristic and their associated definitions (Appendix 1). During the training process, each match characteristic was replayed at 25 frames per second to facilitate a clear distinguishment between coding criteria. The initial training process lasted approximately six hours with 15-minute breaks incorporated every hour. The lead analysts repeated this process with the remaining seven analysts from their respective video analysis laboratories until each analyst understood the coding process for each variable. If an analyst was unclear on the coding process for a match event, an online meeting was arranged between the video analysis laboratories until a resolution was established.

Once each analyst indicated they understood the variables and definitions, they were tested for intra- and inter-rater reliability. Half of a randomly selected match at each playing standard was coded for reliability using the descriptors and definitions described in appendix 1. For intra-rater reliability, the same half was coded twice separated by at least one week (Wheeler et al., 2010). The first round of coded halves was used to determine the inter-rater reliability of all nine analysts. Cohen's Kappa statistics (κ) were used to evaluate intra- and inter-rater reliability for each analyst (James et al., 2007). Kappa statistics were calculated separately for total match variables, tackle variables, ruck variables, scrum variables, line-out variables and maul variables. Kappa values of 0.01–0.2, 0.21–0.4, 0.41–0.6, 0.61–0.8, 0.81–0.99, and 1.0 represent *slight*, *fair*, *moderate*, *substantial*, *almost perfect* and *perfect,* respectively (James et al., 2007). The mean and 95% confidence intervals (CI) intra- and inter-reliability of the nine analysts for total match characteristics and each contact activity are reported in appendix 2. For the ruck and maul activity, which had a moderate agreement, differences in understanding and coding of these contact variables were clarified between analysts and it was decided a second round of inter-reliability testing for these variables was not required.

Match characteristics were coded using the definitions established by the Rugby Union Video Analysis Consensus group (Appendix 1; Hendricks et al., 2020). The match characteristics coded were the ball-in-play

time, total collisions, the tackle (i.e. frequency, number of players per tackle, tackle outcome, tackle type, tackle direction, tackle point of contact, tackle sequence, attacking intention and penalty against the defender), the ruck (i.e. frequency, time in ruck, number of defenders and attackers, activity and outcome), the maul (i.e. frequency, number of defenders and attackers, and outcome), the scrum (i.e. frequency, and outcome), the lineout (i.e. frequency and outcome) and the frequency of passes, kicks, catches, tries, conversions and freekicks.

Statistical analysis

Generalised linear models and generalised linear mixed models were constructed to identify differences between the seven playing groups (i.e. U12 Amateur, U14 Amateur, U16 Amateur, U18 Amateur, U18 Elite, Senior Amateur, Senior Elite). Ball-in-play time and frequency of match characteristics were analysed at a match level using generalised linear models with playing group as the independent variable. When analysing action-level events (e.g. number of defenders in a tackle) generalised linear mixed models were constructed to account for clustering, with match added as a random effect. In the case where data were not normally distributed and followed a Poisson distribution, a log link function was used with the results back transformed for reporting. The residuals of each model were evaluated visually through Q-Q plots. Estimated means (± standard error) were reported, in addition to the Chi-squared statistic to identify an overall group effect. The subsequent pairwise analysis identified between group differences with a Bonferroni adjustment to account for multiple comparisons. Statistical analyses were conducted in R (R Core Team) using the lme4 (Bates et al., 2014) and emmeans (Lenth et al., 2018) packages.

To reduce the complexity of comparisons between playing groups (i.e. due to the number of characteristics analysed and compared), three hierarchical cluster analyses were performed to identify similarities in (1) all match characteristics, (2) tackle characteristics only and (3) ruck, maul, scrum, and lineout characteristics excluding tackles. Hierarchical cluster analyses allowed the formation of discrete groups using multiple data sources to present overall similarities between playing groups. Playing groups that are similar are joined by clades, the joints that form the discrete groups. The most similar playing groups are therefore identified at the first clade, with higher level clades indicating newly added groups that are more similar than any other. Such analyses were deemed appropriate to help understand similarities between playing groups based on the overall data structure rather than individual variables. All data were mean centred and scaled to 1 standard deviation (SD) prior to analysis to prevent data with greater variability disproportionately influencing the clustering. All match characteristics analysed were included within the cluster analysis. Wards method, an agglomerative clustering approach, was used (Murtagh & Legendre, 2014). This method placed each group into its own cluster then grouped them until a single cluster was reached. Analysis and visualisation of the clusters was conducted in R.

Results

The analysis of the 201 rugby union matches resulted in the coding of 5911 min of ball-in-play time and 193,708 match characteristics including 83,688 collisions, 33,052 tackles, 13,299 rucks, 1006 mauls, 2681 scrums, 2923 lineouts, 44,879 passes, 5568 kicks, 4136 catches, 1398 tries, 806 conversions and 272 free kicks. Ball-in-play time was 22 ± 1 mins for U12, 24 ± 1 mins for U14, 27 ± 1 mins for U16, 31 ± 1 mins for U18 amateur, 30 ± 1 mins for U18 elite, 34 ± 1 mins for senior amateur and 35 ± 1 mins for senior elite.

Match characteristics

Table 1 presents the frequency of match characteristics according to the seven playing groups. Overall, significant differences (all $p < 0.001$) were found for the frequency of each match characteristic. Generally, ball-in-play time and the frequency of each match characteristic increased with age. For rucks, U18 Elite were significantly lower than U18 Amateur, and Senior Amateur and Elite levels. For scrums, Senior Elite level had the same frequency of scrums as U12, which was significantly lower than the U18 groups and Senior Amateur levels. Passes, catches and kicks were significantly greatest at the Senior Elite level but tries were lower than the other levels.

Tackle characteristics

Table 2 presents the tackle characteristics and differences between playing groups. Figure 1 presents the relative proportion of tackle characteristics per playing group. Overall significant differences between playing groups were observed for all tackle characteristics, except for the leg lift tackle type.

The mean number of defenders at all age categories and playing standards was two defenders per tackle. The frequency of successful tackles generally increased with age. Unsuccessful tackles were significantly greater

Table 1. Frequency (events per match) for each match characteristic by age category and playing standard.

	Amateur					Elite			
	U12	U14[a]	U16[b]	U18[c]	Senior [d]	U18[e]	Senior [f]	X^2	*P*
Ball-in-play (mins)	22 ± 1 [c,d,e,f]	24 ± 1 [c,d,e,f]	27 ± 1 [e,f]	31 ± 1 [d,f]	34 ± 1 [e]	30 ± 1[f]	35 ± 1	132.2	<0.001
Collisions (*n*)	228 ± 3 [a,b,c,d,e,f]	268 ± 3 [c,d,e,f]	263 ± 4 [c,d,e,f]	332 ± 4 [f]	346 ± 4 [e]	326 ± 3 [f]	357 ± 3	1140.8	<0.001
Tackles (*n*)	155 ± 3 [a,b,c,d,e,f]	173 ± 3 [c,d,e,f]	170 ± 3 [c,d,e,f]	204 ± 3 [f]	211 ± 3	206 ± 3 [f]	221 ± 3	459.7	<0.001
Rucks (*n*)	53 ± 2[a,b,c,d,e,f]	74 ± 2[c,d,e,f]	67 ± 2[c,d,e,f]	87 ± 2 [e]	85 ± 2 [e]	76 ± 2 [f]	90 ± 2	306.6	<0.001
Mauls (*n*)	4 ± 1 [d,e,f]	4 ± 0 [d,e,f]	4 ± 0 [d,e,f]	5 ± 0 [f]	7 ± 1[f]	7 ± 1[f]	9 ± 1	98.9	<0.001
Scrums (*n*)	13 ± 1 [c,d,e]	14 ± 1 [c,d]	16 ± 1	19 ± 1[f]	19 ± 1[f]	17 ± 1[f]	13 ± 1	58.0	<0.001
Lineouts (*n*)	8 ± 1[b,c,d,e,f]	11 ± 1 [c,d,e,f]	14 ± 1 [c,d,e,f]	18 ± 1 [d,f]	24 ± 1	20 ± 1 [d,f]	24 ± 1	279.3	<0.001
Catches (*n*)	14 ± 1 [c,d,e,f]	14 ± 1 [c,d,e,f]	12 ± 1 [c,d,e,f]	20 ± 1[f]	22 ± 1 [f]	23 ± 1[f]	33 ± 1	398.2	<0.001
Passes (*n*)	155 ± 11 [c,d,e,f]	165 ± 10 [c,d,e,f]	189 ± 11[d,e,f]	219 ± 10	248 ± 10[f]	247 ± 9 [f]	293 ± 9	150.6	<0.001
Kicks (*n*)	12 ± 1 [b,c,d,e,f]	16 ± 1 [b,c,d,e,f]	21 ± 1[d,e,f]	25 ± 1[d,e,f]	34 ± 1[f]	29 ± 1[f]	44 ± 1	679.0	<0.001
Tries (*n*)	10 ± 1 [a,b,c,d,f]	8 ± 1[f]	6 ± 1 [e]	6 ± 1	7 ± 1 [f]	8 ± 1 [f]	5 ± 1	56.3	<0.001
Conversions (*n*)	2 ± 0 [a,d,e]	4 ± 0	3 ± 0[d,e]	3 ± 0[e]	5 ± 0	5 ± 0	4 ± 0	45.9	<0.001
Free Kicks (*n*)	1 ± 0	1 ± 0[f]	1 ± 0	1 ± 0	1 ± 0	1 ± 0	2 ± 0	19.7	<0.001

Notes: [a] Significantly different to Under 14; [b] Significantly different to Under 16, [c] Significantly different to Under 18 Amateur; [d] Significantly different to Senior Amateur; [e] Significantly different to Under 18 Elite; [f] Significantly different to Senior Elite. Data presented are based upon log transformed data.

at U12 age category compared to all other playing groups. Senior Amateur (although not significant) and Elite ($p < 0.001$) groups had a lower frequency of unsuccessful tackles compared to the other playing groups.

For tackle type, active shoulder tackles increased with age and playing standard. The frequency of active shoulder tackles was greater in U18 and Senior Elite compared to Amateur standards. For the smother tackle, Elite standards (U18 and Senior) had greater frequency than Amateur. However, for arm tackles, Amateur standards had greater frequency compared to Elite. For tackle proportions (Figure 1), U12 Amateur had a greater proportion of arm tackles, and lower proportion of shoulder (active and passive) tackles

Table 2. Frequency of tackle activity in male rugby union by age category and playing standard.

	Amateur					Elite			
	U12	U14[a]	U16[b]	U18[c]	Senior [d]	U18[e]	Senior [f]	X^2	*P*
Tackles (*n*)	155 ± 3 [a,b,c,d,e,f]	173 ± 3 [c,d,e,f]	170 ± 3 [c,d,e,f]	204 ± 3 [f]	211 ± 3	206 ± 3 [f]	221 ± 3	459.7	<0.001
Number of players (*n*)	2 ± 0	2 ± 0 [b]	2 ± 0	2 ± 0	2 ± 0	2 ± 0	2 ± 0	15.6	0.01
Outcome (*n*)									
Successful	89 ± 2 [a,b,c,d,e,f]	121 ± 2 [c,d,e,f]	119 ± 3 [c,d,e,f]	152 ± 3 [d,f]	165 ± 3 [e,f]	151 ± 2 [f]	179 ± 2	996.9	<0.001
Unsuccessful	66 ± 2 [a,b,c,d,e,f]	51 ± 1 [f]	52 ± 2 [f]	51 ± 1 [f]	46 ± 1 [e]	55 ± 1 [f]	43 ± 1	153.4	<0.001
Tackle Type (*n*)									
Arm	99 ± 2 [e,f]	104 ± 2 [b,e,f]	91 ± 2 [c,d,e,f]	107 ± 2 [e,f]	102 ± 2 [e,f]	77 ± 2	72 ± 2	353.5	<0.001
Collision	1 ± 0 [f]	1 ± 0	2 ± 1	2 ± 0	2 ± 0	2 ± 0	3 ± 0	23.2	<0.001
Jersey	10 ± 1 [f]	10 ± 1 [f]	8 ± 1	8 ± 1	8 ± 1 [e]	11 ± 1 [f]	7 ± 0	31.5	<0.001
Lift	1 ± 0	2 ± 0	1 ± 0	2 ± 0	2 ± 0	2 ± 0	1 ± 0	1.1	0.98
Shoulder Active	15 ± 1 [a,b,c,d,e,f]	20 ± 1 [b,c,d,e,f]	27 ± 1 [c,d,e,f]	38 ± 1 [e,f]	37 ± 1 [e,f]	52 ± 1 [f]	59 ± 1	1128.7	<0.001
Shoulder Passive	20 ± 1 [b,c,d,e,f]	23 ± 1 [b,c,d,e,f]	33 ± 1 [d,f]	33 ± 1 [d,f]	48 ± 1 [e]	37 ± 1 [f]	48 ± 1	504.7	<0.001
Smother	10 ± 1 [c,d,e,f]	13 ± 1 [e,f]	11 ± 1 [c,e,f]	16 ± 1 [e,f]	14 ± 1 [e,f]	25 ± 1 [f]	30 ± 1	482.3	<0.001
Tap	4 ± 1 [a]	1 ± 0 [e]	2 ± 0	2 ± 0	2 ± 0	3 ± 0	2 ± 0	20.5	0.002
Tackle Direction (*n*)									
Behind	24 ± 1 [b,c]	21 ± 1 [e]	17 ± 1 [e,f]	18 ± 1 [e,f]	20 ± 1 [e]	28 ± 1 [f]	23 ± 1	92.0	<0.001
Front	60 ± 2 [a,b,c,d,e,f]	86 ± 2 [c,d,e,f]	90 ± 2 [c,d,e,f]	114 ± 2 [e]	117 ± 2 [e]	97 ± 2 [f]	106 ± 2	574.1	<0.001
Oblique	8 ± 1 [d,e,f]	8 ± 1 [d,e,f]	6 ± 1 [d,e,f]	9 ± 1 [d,e,f]	12 ± 1 [e,f]	19 ± 1 [f]	27 ± 1	629.3	<0.001
Side	18 ± 1 [a,e,f]	22 ± 1 [b,e,f]	15 ± 1 [c,d,e,f]	21 ± 1 [e,f]	20 ± 1 [e,f]	32 ± 1	34 ± 1	338.7	<0.001
Point of Contact (*n*)									
Head and neck	1 ± 0 [d,e,f]	3 ± 0 [e,f]	3 ± 1 [f]	2 ± 0 [e,f]	4 ± 0 [f]	5 ± 1	6 ± 1	66.6	<0.001
Leg	26 ± 1 [a,b,c,d,e,f]	32 ± 1 [c,e,f]	32 ± 1 [c,e,f]	39 ± 1 [d,e,f]	33 ± 1 [e,f]	47 ± 1	48 ± 1	278.3	<0.001
Mid-torso	58 ± 2 [a,b,c,d,e,f]	50 ± 1 [b,c,d,e,f]	68 ± 2 [d,e,f]	73 ± 2 [d,e,f]	83 ± 2	85 ± 2	86 ± 2	418.1	<0.001
Shoulder	71 ± 2 [a,c,d,f]	88 ± 2 [b,c,d,e]	69 ± 2 [c,d,f]	91 ± 2 [e,f]	93 ± 2 [e,f]	72 ± 2 [f]	82 ± 2	168.6	<0.001
Sequencing (*n*)									
Attacking sequential	2 ± 0 [b,c,d,e,f]	4 ± 1 [d,e,f]	6 ± 1 [d,e,f]	6 ± 1 [d,e,f]	13 ± 1 [e]	9 ± 1 [f]	13 ± 1	227.4	<0.001
One-on-one	91 ± 2	86 ± 2 [d,e,f]	95 ± 2	94 ± 2	99 ± 2	99 ± 2	100 ± 2	40.4	<0.001
Sequential	59 ± 2 [a,c,d,e,f]	73 ± 2 [b,c,d,e,f]	65 ± 2 [c,d,e,f]	91 ± [e]	89 ± 2 [e]	81 ± 2 [f]	93 ± 2	318.4	<0.001
Simultaneous	5 ± 1 [a,b,c,d,e,f]	12 ± 1 [b,e,f]	7 ± 1 [c,d,e,f]	15 ± 1	14 ± 1 [e]	17 ± 1	17 ± 1	240.9	<0.001
Attacking intention (*n*)									
Arcing run	5 ± 1 [d,e,f]	6 ± 1 [d,e,f]	5 ± 1 [d,e,f]	7 ± 1	9 ± 1	9 ± 1	9 ± 1	53.8	<0.001
Diagonal run	76 ± 2 [c,d,f]	80 ± 2 [c,d,f]	73 ± 2 [c,d,f]	89 ± 2 [e,f]	92 ± 2 [e,f]	81 ± 2 [f]	69 ± 2	127.9	<0.001
Lateral run	17 ± 1 [d,e,f]	14 ± 1	15 ± 1 [f]	14 ± 1	13 ± 1	12 ± 1	12 ± 1	37.0	<0.001
Side step	18 ± 1 [a,e,f]	22 ± 1 [b,e,f]	15 ± 1 [c,d,e,f]	21 ± 1 [e,f]	20 ± 1 [e,f]	32 ± 1	34 ± 1	338.7	<0.001
Straight	41 ± 1 [a,b,c,d,e,f]	53 ± 1 [b,c,d,e,f]	64 ± 2 [c,d,e,f]	74 ± 2 [f]	79 ± 2 [f]	73 ± 2 [f]	98 ± 2	755.6	<0.001
Penalty Against Defence (*n*)	1 ± 0 [a,c,d,e,f]	2 ± 0	1 ± 0	2 ± 0	2 ± 0	2 ± 0	2 ± 0	27.3	<0.001

Notes: [a] Significantly different to Under 14; [b] Significantly different to Under 16, [c] Significantly different to Under 18 Amateur; [d] Significantly different to Senior Amateur; [e] Significantly different to Under 18 Elite; [f] Significantly different to Senior Elite. Data presented are based upon log transformed data.

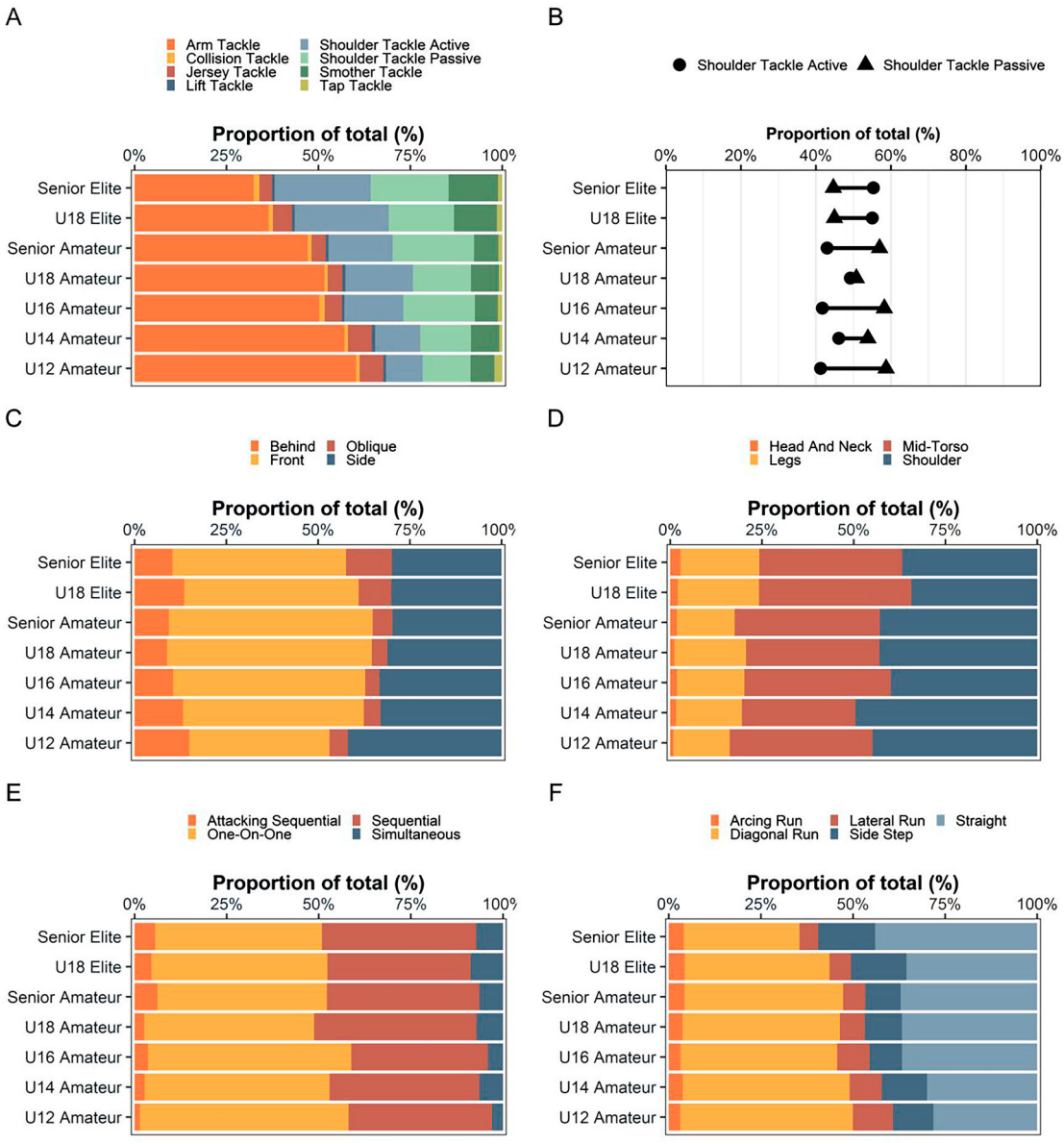

Figure 1. Proportion of tackle characteristics by age category and playing standard; (A) Tackle type, (B) Active vs Passive Shoulder tackles, (C) Tackle Direction, (D) Point of Contact, (E) Sequencing, and (F) Attacker Intention.

compared to Senior Elite and U18 Elite who had a greater proportion of shoulder and smother tackles. U18 and Senior Elite standards had a greater proportion of active vs. passive shoulder tackles. Whilst all other playing levels had a greater proportion of passive vs. active shoulder tackles.

For tackle direction, significant overall effects were shown for side, front, oblique and from behind tackles. Whilst tackle direction frequencies were generally higher at U18 and Senior age categories, the differences for frequencies and proportions were less clear. However, a greater frequency and proportion of side and oblique tackles were found at Elite standards.

There was a greater frequency of the point of contact with the head and neck at U18 and Senior Elite levels whilst the point of contact with the legs, torso and shoulder generally increased with age. However, at the elite standard, the proportion of tackles that contacted the shoulder were lower.

Although an overall significant difference was observed for one-on-one tackles, it was only the U14 age groups who were significantly lower than all other playing groups. No significant differences were found between U12 and Senior groups. Attacking sequential, sequential and simultaneous tackle frequency generally increased with playing group.

For attacker intention, running straight, arcing run and side step frequency increased with age category and playing level. Lateral run frequency declined with age category. U12 Amateur had significantly less

Table 3. Frequency of ruck, maul, scrum and lineout activity by age category and playing standard.

	Amateur					Elite			
	U12	U14[a]	U16[b]	U18[c]	Senior [d]	U18[e]	Senior [f]	X^2	*P*
Ruck									
No. of Attackers (*n*)	3 ± 0 [d,e,f]	3 ± 0 [c,d,e,f]	3 ± 0	3 ± 0	2 ± 0	2 ± 0	2 ± 0	57.0	<0.001
No. of Defenders (*n*)	2 ± 0[b,c,d,e,f]	2 ± 0[b,c,d,e,f]	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	119.2	<0.001
Attacker Activity (*n*)									
Clearing	11 ± 1 [c,d,e,f]	10 ± 1[c,d,e,f]	12 ± 1[d,e,f]	14 ± 1[d,e,f]	22 ± 1[f]	22 ± 1[f]	30 ± 1	466.6	<0.001
Clearing and protecting	12 ± 1[a,b,c,d,e,f]	21 ± 1 [c,d,e,f]	24 ± 1[d,e,f]	28 ± 1 [d,f]	34 ± 1	30 ± 1 [f]	35 ± 1	363.4	<0.001
Protecting	28 ± 1[a,c,e,f]	39 ± 1[b,d,e,f]	27 ± 1[c,e,f]	42 ± 1[d,e,f]	27 ±1[e,f]	22 ± 1	21 ± 1	322.2	<0.001
Protecting and clearing	2 ± 0[f]	2 ± 0 [f]	2 ± 0 [f]	2 ± 0 [f]	3 ± 0 [f]	3 ± 0 [f]	4 ± 0	32.9	<0.001
Defender Activity (*n*)									
Clearing	10 ± 1 [e,f]	13 ± 1 [c,e,f]	11 ± 1[e,f]	10 ± 1[e,f]	12 ± 1[e,f]	20 ± 1[f]	34 ± 2	631.7	<0.001
Clearing and protecting	2 ± 0[c,e]	3 ± 0[c,e]	2 ± 0[e,f]	1 ± 0[d,f]	3 ± 1[e]	1 ± 0[f]	4 ± 1	90.2	<0.001
Protecting	36 ± 3 [a,b,c,d,e,f]	51 ± 3 [c,d]	50 ± 4 [c,d]	70 ± 5 [e,f]	66 ± 4 [e,f]	50 ± 3	48 ± 3	336.9	<0.001
Protecting and clearing	4 ± 1	6 ± 1	4 ± 1	5 ± 1	4 ± 1	5 ± 1	4 ± 1	11.8	0.07
Turnovers (*n*)	9 ± 1[f]	8 ± 1	7 ± 1	7 ± 1	7 ± 1	7 ± 1	6 ± 0	14.4	0.03
Penalty against Attack (*n*)	2 ± 0 [c]	3 ± 0	4 ± 1	4 ± 0	3 ± 0	3 ± 0	3 ± 0	14.3	0.03
Penalty against Defence (*n*)	4 ± 0	4 ± 0	5 ± 1	5 ± 1	5 ± 1	4 ± 0	4 ± 0	3.5	0.74
Maul									
Number of Attackers (*n*)	6 ± 0	6 ± 0	6 ± 0	6 ± 0	6 ± 0	6 ± 0	7 ± 0	15.4	0.02
Number of Defenders (*n*)	5 ± 0	5 ± 0	5 ± 0	5 ± 0	5 ± 0	5 ± 0	5 ± 0	10.4	0.11
Turnover (*n*)	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	9.1	0.17
Penalty against Attack (*n*)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	6.1	0.40
Penalty against Defence (*n*)	1 ± 0	1 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	22.1	0.001
Scrum									
Engagement (*n*)	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	5.4	0.49
Collapse (*n*)	1 ± 0	1 ± 0	1 ± 0 [d]	1 ± 0	2 ± 0	1 ± 0	1 ± 0	19.4	0.004
Turnover (*n*)	2 ± 0	2 ± 0	3 ± 0	2 ± 0	2 ± 0	1 ± 0	1 ± 0	11.7	0.07
Penalty against Attack (*n*)	0 ± 0[f]	0 ± 0[f]	0 ± 0[f]	0 ± 0	1 ± 0	0 ± 0	1 ± 0	42.4	<0.001
Penalty against Defence (*n*)	0 ± 0[d,f]	0 ± 0[c,d,e,f]	1 ± 0[d,f]	1 ± 0[d,f]	2 ± 0[e]	1 ± 0[f]	2 ± 0	87.0	<0.001
Lineout									
Turnovers (*n*)	2 ± 0 [c,d,e]	3 ± 0 [c,d,e]	3 ± 0 [c,d,e]	5 ± 0 [f]	5 ± 0 [f]	5 ± 0 [f]	3 ± 0	41.7	<0.001

Notes: [a] Significantly different to Under 14; [b] Significantly different to Under 16, [c] Significantly different to Under 18 Amateur; [d] Significantly different to Senior Amateur; [e] Significantly different to Under 18 Elite; [f] Significantly different to Senior Elite. Data presented are based upon log transformed data.

penalties against the defence than all other playing levels.

Ruck, maul, scrum and lineout characteristics

Table 3 presents the frequency of ruck, maul and scrum characteristics according to the playing groups. Significant differences ($p < 0.001$) were found across both age category and playing standard for the number of attackers and defenders in a ruck, attacker and defender ruck activity and frequency of turnovers. For the number of attackers and defenders, greater numbers of players were involved in ruck activity at the younger (i.e. U12, U14) age categories. For ruck attack activity, less clearing and clearing and protecting was evident at the younger age categories with the Senior Elite level demonstrating the most clearing activity. Greater protecting activity occurred at the younger age categories with the highest protecting activity at U14 and U18 Amateur. Protect and clear activity was greatest at Senior Elite. For ruck defence activity, U18 and Senior Elite had greater clearing activity. Senior Amateur and Elite had the greatest clearing and protecting activity but both U18 Amateur and Elite only had one frequency per match. Protecting activity was greatest at U18 and Senior Amateur levels. Turnovers were lower in Senior Elite than U12 matches. No significant differences were found between age categories and playing standard for penalties against attack and defence.

For the maul, although overall significant differences were identified for the number of attackers and penalty against defence, no *post-hoc* comparisons were found between age category and level. For scrum activity, no overall significant differences were found for frequency of engagements and turnovers. The greatest scrum collapses were at the senior amateur level. For penalty attack and defence, significant differences were apparent which increased with age. Lineout turnovers were higher at U18 Amateur and Elite and Senior Amateur levels than U12, U14, U16 and Senior Elite.

Hierarchical cluster analysis; overall similarities and differences

The hierarchical cluster analysis (Figure 2) identified similarities between playing groups for (1) all match (Figure 2(A)), (2) tackle (Figure 2(B)) and (3) ruck, maul, scrum and lineout (Figure 2(C)) characteristics. For all match characteristics, playing groups were clustered

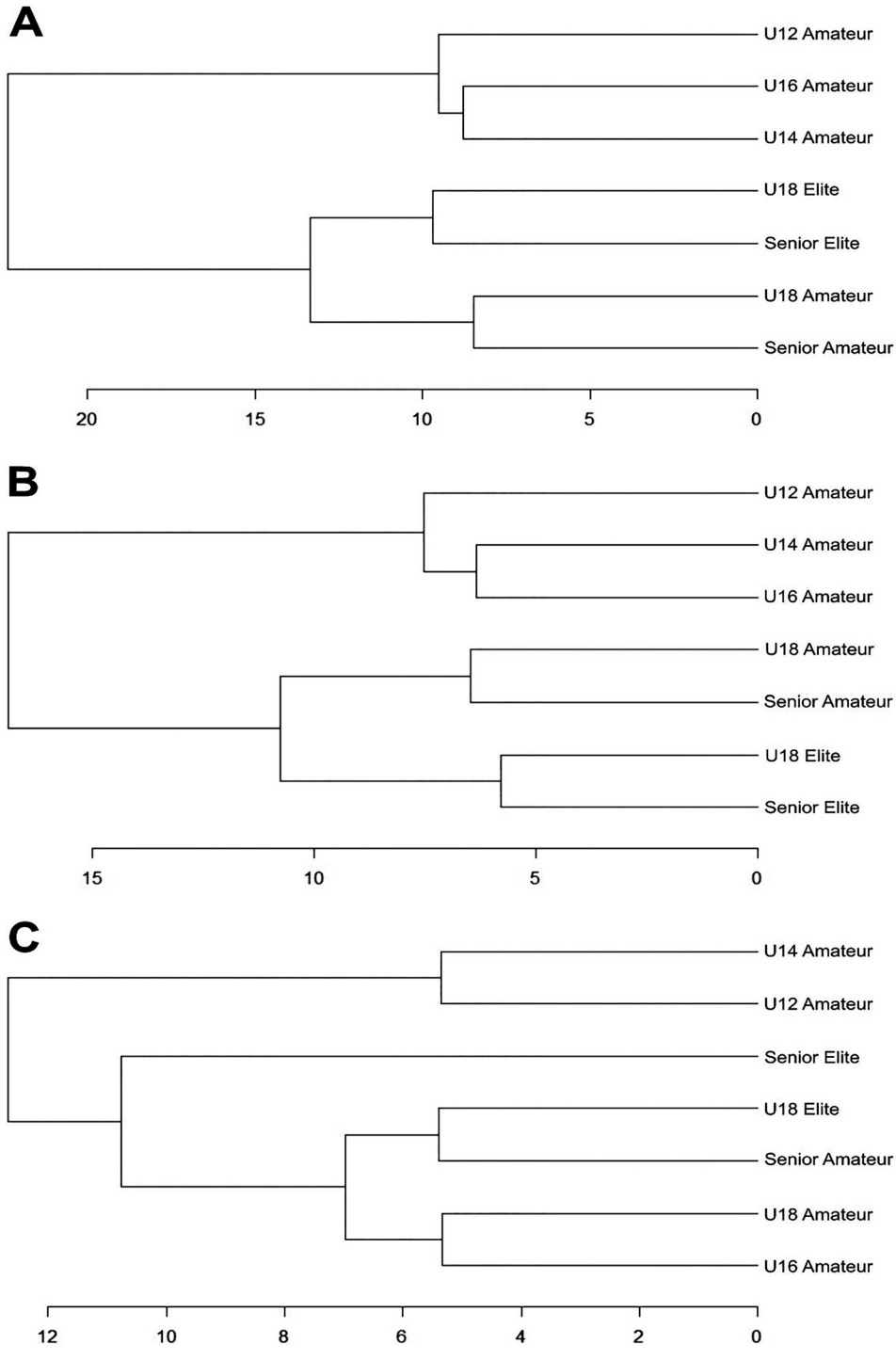

Figure 2. Hierarchical cluster analysis for (A) all match characteristics, (B) tackle characteristics and (C) ruck, maul, scrum and lineout characteristics, demonstration the overall differences and similarities of age categories and playing standards.

Notes: The discrete grouping of playing groups is indicated by the point at which they join, with the horizontal length of the line indicating the degree of difference. For example, in Figure 2A, U18 and Senior Amateur are grouped and U18 and Senior Elite are grouped showing differences. At the next level, these 4 playing groups differ from the U12, U14 and U16 Amateur level.

into two main categories, age grade Amateur (U12, U14, U16) and Senior Amateur and Elite (U18 and Senior). The Amateur age grade cluster is divided into two subgroups with younger (U12) and older (U14 and U16) age grade match characteristics displaying similarities. In the other cluster, Elite (U18 and Senior) and Amateur (U18 and Senior) were clustered as subgroups. These same clusters were identified for the tackle activity (Figure 2(B)). For ruck, maul, scrum and lineout characteristics, two main clusters were identified, which

included young (U12 and U14) and older (U16, U18 and Senior) playing groups. U12 and U14 Amateur groups were clustered together. For the older groups, Senor Elite was one sub cluster, U18 Elite and Senior Amateur were a second sub cluster and U16 and U18 Amateur were the third sub cluster.

Discussion

To our knowledge, this study is the largest video analysis study undertaken to quantify and compare the collision and non-collision match characteristics of male rugby union, across multiple age categories and playing standards within three major playing nations. The findings, based on the analysis of 193,708 collision and non-collision characteristics from 201 matches, showed an increase in the frequency of collisions, tackles, rucks, mauls, passes, catches and kicks into senior rugby union age categories and elite playing standards. However, the frequency of scrums and tries were lowest at the Senior Elite level. Differences were also apparent in the tackle and ruck activity characteristics. For the tackle, differences in tackle outcome, type, direction, point of contact, sequencing and attacker intention were apparent between age categories and playing standards. For ruck activity, a greater number of attackers and defenders were apparent at the younger age categories where more attacker protecting activity occurred. Hierarchical cluster analysis identified two main groups for match and tackle characteristics, which included U12, U14 and U16, and U18 and Senior Amateur, and Elite. For ruck, maul, scrum and lineout activities (Figure 2(C)), U12 and U14 were clustered together (i.e. similar) and differed from the other playing groups who formed a second cluster. These results demonstrate the differences in the frequency and activity of rugby union match characteristics between playing levels. This is most notable in collision activities of the tackle and ruck between youth and Senior Elite levels.

Ball-in-play time and the frequency of collisions, tackles, rucks, mauls, lineouts, passes, catches and kicks significantly differed across age categories and playing standards with the highest frequency of activities found at the Senior Elite standard. This most likely occurred due to the increased ball-in-play time (due to an increased playing duration) in older age categories with collisions per ball-in-play time approximately equivalent to 10 per minute across all playing groups. However, it was deemed important to report the absolute frequency of events to fully understand the characteristics of rugby union match-play due to the increased playing and ball-in-play time at older and elite playing levels. However, the frequency of scrums and tries did not follow the same trend as other characteristics, with the frequency of these match characteristics the same (or lower for tries) at Senior Elite levels as the U12 age category. The reduction in errors at the Senior Elite level or fewer opportunities to score tries due to improved defensive systems, may explain these findings.

The frequency of tackles reported per match (i.e. U12 = 155; Senior Elite = 221) were generally greater than studies reporting tackle rates in rugby union match-play across the senior elite or international standards (Schoeman & Schall, 2019; Vaz et al., 2010). Furthermore, tackle frequency increasing with age and playing standard was inconsistent with previous findings (McIntosh et al., 2010) whereby an increased tackle rate was found in U18 and U20 age categories in Australia compared to international and senior players. This finding suggests that tackle frequency within rugby union match-play has large variability that may impact upon the comparisons of frequency of match events. For the frequency of rucks, mauls, scrums and lineouts, the comparisons with recent research studies were inconsistent. For example, frequencies for each collision event in the current study were generally higher (Schoeman & Schall, 2019) and lower (Hendricks et al., 2018; Kraak & Welman, 2014) than those reported in previous work. These findings may be apparent due to the different coding criteria applied across the current literature suggesting the use of the definitions established by the Rugby Union Video Analysis Consensus group (Hendricks et al., 2020) used within this study, is required in future video analysis studies.

For the tackle, the frequency of successful tackles and the relative proportion of successful vs unsuccessful tackles was highest in older age categories and elite playing standards, consistent with previous research (McIntosh et al., 2010). This could be explained by greater technical tackle performance at older and higher playing standards, which has recently been assessed using a tackle proficiency drill (den Hollander et al., 2019). Aligned to a greater tackle technique, the frequency and proportion of active shoulder and smoother tackles increased with age and standard whilst arm tackles decreased. Older and Elite standards had more contact with the head and neck, higher frequency of sequential, attacking sequential and simultaneous tackle sequencing and more attacker intention (e.g. side step, arching run) to defend. Interestingly, there was no difference in one-on-one tackles between Senior Elite and U12 levels. These findings provide empirical evidence that the tackle, based upon frequency and proportion of tackle activity, is different between playing standards and age categories.

For the ruck, the number of attackers and defenders were greater at the younger age categories who demonstrated more protecting type activity. At the senior levels, clearing was the most frequent activity in attack and defence, demonstrating a more attacking ruck strategy. However, the frequency of turnovers at the ruck was greatest at U12, which may be apparent because of the greater technical ruck proficiency as demonstrated in senior than academy rugby union players (den Hollander et al., 2019). Therefore, the ability to develop effective ruck technique at lower playing standards and younger age categories may be an important consideration for player development, building upon the recent work of Hendricks et al. (2017). Significant overall differences were also apparent for mauls and scrums. Maul frequency increased from U12 (4 ± 1) to Senior Elite (9 ± 1) but activity did not differ across age category or playing standard with mauls typically including 6 attackers and 5 defenders with 1 turnover and no penalties occurring per game. For scrums, frequency increased with age in the amateur playing standard between U12 and Senior. However, within the Elite standard, scrum frequency was significantly lower at Senior Elite standard (13 ± 1), which was the same frequency as U12. At younger age categories, this could suggest a large amount of playing time could be undertaken by scrum activity, which may limit player development opportunities from a skill perspective. Although not significant, scrum turnover decreased with age and playing standard but the number of penalties for attackers and defenders increased, which may be because of limited pushing at scrums in younger age groups. Such findings may have implications for the frequency of scrum activity within younger playing levels.

Whilst analysis by individual match characteristics was able to identify differences between age categories and playing standards, the hierarchical cluster analysis identified similarities between two main categories: (1) younger age grade amateur (U12, U14, U16) and (2) U18 and Senior Amateur and Elite. This showed that overall, differences in the frequency and type of activity within age-grade Amateur and Elite U18 and Senior rugby were apparent, demonstrating that the match characteristics of rugby union is not consistent across all playing levels. Therefore, this study showed that age-grade amateur rugby union within the matches analysed is not convergent with the elite and senior levels. Such findings demonstrate the need for further research and insight across all age categories, playing standards and rugby union contexts to understand the sport of rugby union and inform future interventions, especially related to injury risk (Quarrie et al., 2017).

Whilst this study advances our understanding of rugby union match-play across multiple playing levels, limitations still exist. Firstly, the quantity of games analysed was higher for senior vs. youth match-play (e.g. U12, $n = 19$; Senior Elite $n = 40$) due to the access and quality of video footage. A second limitation was that all analysis was performed at a match level, rather than an individual player level. Whilst analysing 193,708 match characteristics was a strength of this study, match only analysis failed to understand other factors (e.g. playing position) that may impact upon collision and non-collision match characteristics and activity. Furthermore, differing contexts and rules (e.g. playing duration, number of players) of rugby union match-play across different age groups and playing standards does make comparisons more difficult. Furthermore, future research is required to understand the relationships between match events and health considerations (e.g. injury, concussion) across all age groups and playing levels to deem the appropriateness of generalising findings across age groups and playing levels in rugby union. Furthermore, this study only includes male participants, thus future research should also include female cohorts, given the significant increases in participation numbers, and general lack of research in female rugby (Emmonds et al., 2019).

Conclusion

This study identified that the collision and non-collision characteristics of rugby union match-play differ by age categories (i.e. U12 to Senior) and playing standards (i.e. Amateur vs. Elite) across male rugby union in Tier 1 playing nations. The frequency of characteristics, except the scrum and tries scored, increased with age and playing standard. Furthermore, tackle and ruck activity also differentiate by age category and playing standard, especially tackle type and active vs. passive shoulder tackles. These findings provide the most comprehensive insight into the characteristics and activity of rugby union match-play and demonstrate that characteristics of the Elite Senior rugby union differ from younger age categories. Future research should continue to evaluate the injury risk vs benefit (e.g. health and belonging) of rugby union, based on the match characteristics, whilst policy and practitioners can use these data to inform their player development strategies, considering the frequency and activity of the collision and non-collision characteristics.

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References

Bates, D., Mächler, M., Bolker, B ., & Walker, S. (2014). *Fitting linear mixed-effects models using lme4.* arXiv preprint arXiv:1406.5823.

Bennett, M., Bezodis, N., Shearer, D. A., Locke, D., & Kilduff, L. P. (2019). Descriptive conversion of performance indicators in rugby union. *Journal of Science and Medicine in Sport*, *22* (3), 330–334. https://doi.org/10.1016/j.jsams.2018.08.008

Bishop, L., & Barnes, A. (2013). Performance indicators that discriminate winning and losing in the knockout stages of the 2011 Rugby World Cup. *International Journal of Performance Analysis in Sport*, *13*(1), 149–159. https://doi.org/10.1080/24748668.2013.11868638

Bradley, E. J., Board, L., Hogg, B., & Archer, D. T. (2020). Quantification of movement characteristics in women's English Premier elite domestic rugby union. *Journal of Human Kinetics*, *72*(1), 185–194. https://doi.org/10.2478/hukin-2019-0104

Burger, N., Lambert, M., & Hendricks, S. (2020). Lay of the land: Narrative synthesis of tackle research in rugby union and rugby sevens. *BMJ Open Sport & Exercise Medicine*, *6*(1), e000645. https://doi.org/10.1136/bmjsem-2019-000645

den Hollander, S., Jones, B., Lambert, M., & Hendricks, S. (2018). The what and how of video analysis research in rugby union: A critical review. *Sports Medicine - Open*, *4*(1), 1–14. https://doi.org/10.1186/s40798-018-0142-3

den Hollander, S., Lambert, M., Jones, B., & Hendricks, S. (2019). Tackle and ruck technique proficiency within academy and senior club rugby union. *Journal of Sports Sciences*, *37*(22), 2578–2587. https://doi.org/10.1080/02640414.2019.1648121

Emmonds, S., Heyward, O., & Jones, B. (2019). The challenge of applying and undertaking research in female sport. *Sports Medicine - Open*, *5*(1), 1–4. https://doi.org/10.1186/s40798-019-0224-x

Fuller, C. W., Brooks, J. H. M., Cancea, R. J., Hall, J., & Kemp, S. P. T. (2007). Contact events in rugby union and their propensity to cause injury. *British Journal of Sports Medicine*, *41* (12), 862–867. https://doi.org/10.1136/bjsm.2007.037499

Hendricks, S., Till, K., Brown, J. C., & Jones, B. (2017). Rugby union needs a contact skill-training programme. *British Journal of Sports Medicine*, *51*(10), 829–830. https://doi.org/10.1136/bjsports-2016-096347

Hendricks, S., Till, K., den Hollander, S., Savage, T. N., Roberts, S. P., Tierney, G., Burger, N., Kerr, H., Kemp, S., Cross, M., Patricios, J., McKune, A. J., Bennet, M., Rock, A., Stokes, K. A., Ross, A., Readhead, C., Quarrie, K. L., Tucker, R., & Jones, B. (2020). Consensus on a video analysis framework of descriptors and definitions by the Rugby Union Video Analysis Consensus group. *British Journal of Sports Medicine*, *54*(10), 566–572. https://doi.org/10.1136/bjsports-2019-101293

Hendricks, S., van Niekerk, T., Sin, D. W., Lambert, M., den Hollander, S., Brown, J., Maree, W., Treu, P., Till, K., & Jones, B. (2018). Technical determinants of tackle and ruck performance in International rugby union. *Journal of Sports Sciences*, *36*(5), 522–528. https://doi.org/10.1080/02640414.2017.1322216

James, N., Taylor, J., & Stanley, S. (2007). Reliability procedures for categorical data in performance analysis. *International Journal of Performance Analysis in Sport*, *7*(1), 1–11. https://doi.org/10.1080/24748668.2007.11868382

Jones, M. R., West, D. J., Harrington, B. J., Cook, C. J., Bracken, R. M., Shearer, D. A., & Kilduff, L. P. (2014). Match play performance characteristics that predict post-match creatine kinase responses in professional rugby union players. *BMC Sports Science, Medicine and Rehabilitation*, *6*(1), 38. https://doi.org/10.1186/2052-1847-6-38

Kraak, W. J., & Welman, K. E. (2014). Ruck-play as performance indicator during the 2010 Six Nations Championship. *International Journal of Sports Science & Coaching*, *9*(3), 525–537. https://doi.org/10.1260/1747-9541.9.3.525

Lenth, R. V., Buerkner, P., Giné-Vázquez, L., Herve, M., Jung, M., Love, J., Miguez, F., Riebl, H., & Singmann, H. (2018). Emmeans: Estimated marginal means, aka least-squares means. *R Package Version*, *1*(1), 3.

McIntosh, A. S., Savage, T. N., McCrory, P., Fréchède, B. O., & Wolfe, R. (2010). Tackle characteristics and injury in a cross section of rugby union football. *Medicine & Science in Sports & Exercise*, *42*(5), 977–984. https://doi.org/10.1249/MSS.0b013e3181c07b5b

Murtagh, F., & Legendre, P. (2014). Ward's hierarchical agglomerative clustering method: Which algorithms implement Ward's criterion? *Journal of Classification*, *31*(3), 274–295. https://doi.org/10.1007/s00357-014-9161-z

Pollock, A. M., White, A. J., & Kirkwood, G. (2017). Evidence in support of the call to ban the tackle and harmful contact

in school rugby: A response to World Rugby. *British Journal of Sports Medicine*, *51*(15), 1113–1117. https://doi.org/10.1136/bjsports-2016-096996

Quarrie, K. L., Brooks, J. H. M., Burger, N., Hume, P. A., & Jackson, S. (2017). Facts and values: On the acceptability of risks in children's sport using the example of rugby — A narrative review. *British Journal of Sports Medicine*, *51*(15), 1134–1139. https://doi.org/10.1136/bjsports-2017-098013

Quarrie, K. L., & Hopkins, W. G. (2008). Tackle injuries in professional rugby union. *The American Journal of Sports Medicine*, *36*(9), 1705–1716. https://doi.org/10.1177/0363546508316768

Read, D. B., Jones, B., Phibbs, P. J., Roe, G. A. B., Darrall-Jones, J., Weakley, J. J. S., & Till, K. (2018). The physical characteristics of match-play in English schoolboy and academy rugby union. *Journal of Sports Sciences*, *36*(6), 645–650. https://doi.org/10.1080/02640414.2017.1329546

Schoeman, R., & Schall, R. (2019). Comparison of match-related performance indicators between major professional rugby competitions. *International Journal of Sports Science & Coaching*, *14*(3), 344–354. https://doi.org/10.1177/1747954119848419

Tierney, G. J., Denvir, K., Farrell, G., & Simms, C. K. (2018). The effect of technique on tackle gainline success outcomes in elite level rugby union. *International Journal of Sports Science & Coaching*, *13*(1), 16–25. https://doi.org/10.1177/1747954117711866

Tierney, G. J., Lawler, J., Denvir, K., McQuilkin, K., & Simms, C. K. (2016). Risks associated with significant head impact events in elite rugby union. *Brain Injury*, *30*(11), 1350–1361. https://doi.org/10.1080/02699052.2016.1193630

Till, K., Weakley, J., Read, D. B., Phibbs, P., Darrall-Jones, J., Roe, G., Chantler, S., Mellalieu, S., Hislop, M., Stokes, K., Rock, A., & Jones, B. (2020). Applied sport science for male age-grade rugby union in England. *Sports Medicine - Open*, *6*(1), 1–20. https://doi.org/10.1186/s40798-020-0236-6

Tucker, R., Raftery, M., & Verhagen, E. (2016). Injury risk and a tackle ban in youth Rugby Union: Reviewing the evidence and searching for targeted, effective interventions. A critical review. *British Journal of Sports Medicine*, *50*(15), 921–925. https://doi.org/10.1136/bjsports-2016-096322

van Rooyen, M., Yasin, N., & Viljoen, W. (2014). Characteristics of an 'effective' tackle outcome in Six Nations rugby. *European Journal of Sport Science*, *14*(2), 123–129. https://doi.org/10.1080/17461391.2012.738710

Vaz, L., Van Rooyen, M., & Sampaio, J. (2010). Rugby game-related statistics that discriminate between winning and losing teams in IRB and Super Twelve close games. *Journal of Sports Science & Medicine*, *9*(1), 51.

Wheeler, K. W., Askew, C. D., & Sayers, M. G. (2010). Effective attacking strategies in rugby union. *European Journal of Sport Science*, *10*(4), 237–242. https://doi.org/10.1080/17461391.2010.482595

Williams, S., Trewartha, G., Kemp, S., & Stokes, K. (2013). A meta-analysis of injuries in senior men's professional Rugby Union. *Sports Medicine*, *43*(10), 1043–1055. https://doi.org/10.1007/s40279-013-0078-1

Appendices

Appendix 1

Variables	Definition
Match variables	
Ball in Play	The amount of time the ball is in the possession of any of the players or is in a position where either team can contest the ball. Time when play has been stopped by the referee is considered out of play and does not contribute to ball in play time.
Collisions	Total tackle, ruck, scrum, maul and lineout count.
Tackle	An event where one or more tacklers (player or players making the tackle) attempted to stop or impede the ball-carrier (player carrying the ball) whether or not the ball-carrier was brought to ground.
Ruck	A ruck is formed when at least one player from each team is in contact, on their feet and over the ball, which is on the ground. Once a ruck is formed, additional players joining the ruck to compete for the ball, without being guilty of foul play, are considered rucking.
Maul	A maul begins when a player carrying the ball is held by one or more opponents, and one or more of the ball-carrier's team mates bind on the ball-carrier. A maul therefore consists, when it begins, of at least three players, all on their feet; the ball-carrier and one player from each team.
Scrum	A scrum is formed in the field of play when eight players from each team, bound together in three rows for each team, engage with their opponents so that the heads of the front rows are interlocked. Scrum engagement occurs when the front-row of each team make contact with each other.
Lineouts	A lineout is formed on the mark of touch. Each team forms a single line parallel to and half a metre from the mark of touch on their side of the lineout between the 5 and 15 m lines. A minimum of two players from each team are required to form a lineout. A quick line-out (quick throw) can take place before a line-out is formed and is observed when a player whose feet are both outside the field of play throws the ball parallel to or towards the thrower's own goal line, between the mark of touch and the thrower's own goal line, so that it reaches the 5 m line before it touches the ground or makes contact with a player.
Catches	Count of times the ball is received following a kick.
Passes	Count of times the ball is transferred between attacking players
Kicks	The number of times the ball is kicked out of hand by a player, irrespective of whether it went into touch or not.
Tries	Count of tries by the attacking and defensive teams during the matches
Conversations	Count of successfully converted conversion by the attacking and defensive teams during the match
Free Kicks	Count of free-kick indicated by the referee
Tackle variables	
Tackle frequency	Count of tackle events during match play.
Number of players	Number of player in the tackle event.
Outcomes	Successful Unsuccessful
Tackle Type	Arm Tackle Tackler impedes ball-carrier with upper limbs. Collision Tackle Tackler impedes ball-carrier without the use of the arms. Jersey Tackle Tackler holds ball-carrier's jersey. Lift Tackle Tackler raises ball-carrier's hips above ball-carrier's head. Shoulder Active Tackle First contact is with the tackler's shoulder, and the tackler drives or attempts to drive the ball-carrier backwards. Shoulder Passive Tackle First contact is with the tackler's shoulder, and the tackler does not drive or attempts to drive the ball-carrier backwards. Smother Tackle Tackler uses chest and wraps both arms around ball-carrier. Tap Tackle Tackler trips ball-carrier with hand on lower limb below the knee.
Tackle Direction	Behind Tackler makes contact with the ball-carrier's from behind. Front Tackler makes contact with the front of the ball-carrier. Oblique Tackler makes contact with ball-carrier at an angle Side Tackler makes contact with the ball-carrier's side.
Point of (first) Contact	Head and neck Above the shoulder (shirt/neck) with any connection with the head/neck during the course of the tackle. Leg Area below the hips (shorts line) Mid-torso Above the ball-carrier's hip level (shorts line) to the level of the ball-carrier's arm pit. Shoulder From the ball-carrier's arm pit level to the shoulder.
Sequencing	Attacking sequential One attacker contacts one defender, followed by a second attacker joining the contact situation. One-on-one

(*Continued*)

Continued.

Variables	Definition
	One defender contacts one attacker.
	Sequential
	One defender contacts one attacker, followed by a second defender joining the contact situation. (can be coded as a separate tackle)
	Simultaneous
	Two defenders contact one attacker at the same time (coded as separate tackles)
Attacking intention	Arcing run
	ball-carrier performs an arcing run.
	Diagonal run
	ball-carrier runs at an angle, instead of straight at the tackler.
	Lateral run
	ball-carrier performed a run from touchline to touchline.
	Side step
	ball-carrier performed an evasive step initiated by either leg before contact.
	Straight
	ball-carrier ran straight at the defence.
Penalty Against Defence	Penalty awarded against defender.
Ruck variables	
Ruck	A ruck is formed when at least one player from each team is in contact, on their feet and over the ball, which is on the ground. Once a ruck is formed, additional players joining the ruck to compete for the ball, without being guilty of foul play, are considered rucking.
No. of Attackers	Count of attackers actively engaged in ruck.
No. of Defenders	Count of defenders actively engaged in ruck.
Attacker Activity	Clearing attackers are actively pushing and/or driving opponents off the ball, either on their own or binding to team members.
	Clearing and protecting attackers actively clear the ruck first, before protecting the ball.
	Protecting attackers are positioned over the ball to prevent access to the opponents.
	Protecting and clearing attackers actively protect the ball first, before clearing the ruck.
Defender Activity	Clearing
	Defenders are actively pushing and/or driving opponents off the ball, either on their own or binding to team members.
	Clearing and protecting
	Defenders actively clear the ruck first, before protecting the ball.
	Protecting
	Defenders are positioned over the ball to prevent access to the opponents.
	Protecting and clearing
	Defenders actively protect the ball first, before clearing the ruck.
Turnovers	Change in ball-possession to the opposing team.
Penalty against Attack	Penalty awarded against attacker.
Penalty against Defence	Penalty awarded against defender.
Scrum variables	
Scrum	A scrum is formed in the field of play when eight players from each team, bound together in three rows for each team, engage with their opponents so that the heads of the front rows are interlocked.
	Scrum engagement occurs when the front-row of each team make contact with each other.
Engagement	Count of engagements and re-engagements (resets) before the scrum was considered contestable.
Collapse	Count of collapsed scrums indicated by the referee
Turnover	Change in ball-possession to the opposing team.
Penalty against Attack	Penalty awarded against attacker.
Penalty against Defence	Penalty awarded against defender.
Maul variables	
Maul	A maul begins when a player carrying the ball is held by one or more opponents, and one or more of the ball-carrier's team mates bind on the ball-carrier. A maul therefore consists, when it begins, of at least three players, all on their feet; the ball-carrier and one player from each team.
Number of Attackers	Total number of players from the attacking team, including the player carrying the ball in the maul, involved when the maul ended.
Number of Defenders	Number of players from the defending team.
Turnover	Change in ball-possession to the opposing team.
Penalty against Attack	Penalty awarded against attacker
Penalty against Defence	Penalty awarded against defender.
Lineout	
Turnover	Change in ball-possession to the opposing team.

Appendix 2. Kappa statistics for video analysis

	Mean Intra-Reliability Kappa Scores	95% CI	Interpretation	Mean Inter-Reliability Kappa Scores	95% CI	Interpretation
Match Variables	0.95	0.94–0.97	Almost Perfect Agreement	0.93	0.91–0.94	Almost Perfect Agreement
Tackle Variables	0.80	0.73–0.88	Substantial Agreement	0.70	0.68–0.73	Substantial Agreement
Ruck Variables	0.69	0.81–0.89	Substantial Agreement	0.50	0.43–0.57	Moderate Agreement
Scrum Variables	0.85	0.81–0.89	Almost Perfect Agreement	0.74	0.69–0.79	Substantial Agreement
Maul Variables	0.68	0.59–0.77	Substantial Agreement	0.51	0.48–0.55	Moderate Agreement
Line-out Variables	0.95	0.86–1.00	Almost Perfect Agreement	0.91	0.89–0.93	Almost Perfect Agreement