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Research Article

Does Playing Away From Home Influence the Number and Severity of Impacts in Amateur Rugby Union Players: Analyses by Home/Away, Won/Lost and First/Second Season Halves

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Keywords

- Head impact
- Acceleration

Abstract

Objectives: To determine head impact characteristics for amateur rugby union players.

Design: Descriptive cohort study.

Methods: A total of 20,687 head impacts greater than 10*g* over a 2013 amateur senior rugby union season of matches for one team of 38 players. Analyses by matches home/away, won/lost and first/second season halves. Additional analyses by player position and head impact position.

Results: There were more significantly impacts for matches played away (124 ± 218), matches won (111 ±178) and matches in the first half of the competition season (147 ± 220). Front-row forwards (FRF) recorded more impacts to the head at away games (RR: 1.5 [95% CI: 1.5-1.6]; $p<0.0001$) compared with home games. The front of the head recorded a longer impact duration ($t_{(2158)}=11.2$; $p<0.0001$; $d=0.38$), and had a higher resultant PLA*g* ($\chi^2_{(1)}=86.6$; $p<0.0001$; z=-9.7; $p<0.0001$; $d=0.20$), PRA(rad/s^2) ($\chi^2_{(1)}=62.4$; $p<0.0001$; z=-8.4; $p<0.0001$; $d=0.80$) and RWE_{CP} ($\chi^2_{(1)}=60.3$; $p<0.0001$; z=-7.6; $p<0.0001$; $d=0.09$) in games won when compared with games lost.

Conclusion: The nature of matches affected head impacts measured by an instrumented mouthguard in amateur rugby union players with more frequent and greater magnitude impacts for away, won and first half season of matches. The finding that there were far more impacts experienced by players during the first half of the season compared to the second half of the season could be related to the players level of fitness level. There were more impacts recorded to the side of the head in matches won and the first half of the season.

INTRODUCTION

Amateur rugby competitions are commonly played on a home and away basis where one week one team plays at their home ground (advantage) and the next week they play at their opposition team's home ground (disadvantage). To gain insight into whether matches played away from home affect head impact data, analysis of a prior data set [1], from a season of amateur rugby union matches for one team of 38 players was conducted. Prior analysis has shown that there is an average of 95 ±133 impacts per-player per-match and that the mean resultant peak linear and rotational accelerations were higher than some [2,3], but not all sports [4,5]. The aim was to re-assess the data recorded to determine any differences in matches between home and away, won and lost, and first or second half of the rugby season.

METHODS

Ethics

The researchers' university ethics committee approved all procedures in the study (AUTEC 12/156) and all players gave written informed consent prior to participating. The study recruited 38 male players (mean ± SD age; 22 ± 4 y) who were considered amateur as they received no remuneration for participating in rugby union activities. The matches were played under the rules and regulations of the New Zealand Rugby Union.

Data set

A review was undertaken of data obtained from a previous study [1], reporting on head impacts in an amateur senior rugby union team over the 2013 season of competition matches in Wellington, New Zealand. Players were grouped into four positional groups [6], front row forwards (FRF: player numbers 1, 3, 4 and 5), back row forwards (BRF: 2, 6, 7 and 8), inside backs (ISB: 9, 10, 12, 13) and outside backs (OSB: 11, 14, 15). The hooker (player no. 2) was included in the back-row forwards based on their roving style of play, whilst the scrum half (player no. 9) was included in the inside backs due to being the link between the forwards and the backs.[6] Data were extracted and assessed for games played at the clubs home venue and played away; games won and lost, and by first and second half of the season.

Instrumented mouthguard

Players were fitted with a moulded instrumented mouthguard (XGuard; X2Biosystems, Inc., Seattle, WA, USA) sampling at 1,000 Hz, prior to the start of the season. Containing a low-power, high *g* tri-axial accelerometer (H3LIS331DL) with 200*g* maximum per axis, and a tri-axial angular rate gyroscope (L3G4200D; ST Microelectronics, Geneva, Switzerland; www.st.com),[7] the mouthguards were similar to those used in a previous study[7] and more detailed validity and performance characteristics of the XGuard have been previously reported.[1] Impacts were identified as any linear acceleration above 10*g* measured at the mouthguard.[1] These impacts could be a result of a direct blow to the head, face, neck or elsewhere on the body with an 'impulsive' acceleration transmitted to the head. Each recorded impact was categorised into four general locations (front, side, back and top) [1,8].

Impacts <10*g* of linear acceleration were considered negligible in regards to impact biomechanical features and to eliminate head accelerations from non-impact events such as jumping and running [9]. Head impact exposure including frequency, magnitude and location of impacts was quantified using previously established methods [8,10]. All matches were videotaped (Sony HDR-PJ540 Camcorder) to enable verification of the impacts recorded.

Data were analysed by impact location (front, back, side, top), and player groups. For the impact to be recorded, a total of 100 ms of data were stored, including 25 ms prior to, and 75 ms following, the impact. Software provided by X2Biosystems calculated the peak linear acceleration (PLA*g*), peak rotational acceleration (PRA (rad/s^2)) (x-axis and y-axis angular accelerations), impact location, Head Impact Criterion (HIC) [11], Gadd Severity Index (GSI) [12], Head Impact Telemetry severity profile (HIT_{SP}) [13], and date and time stamp for later download and analyses. After downloading the data, a logistic regression equation and regression coefficient of injury risk prediction of an injury occurring termed Risk Weighted Exposure combined (linear and rotational) probability (RWE_{CP}) [3], were conducted. The RWE_{CP} is utilised to elucidate individual player and team-based head impact exposure

Before the statistical analysis was conducted, the raw data were reduced as follows. Data contained on the XGuard were uploaded to the Impact Management System (IMS) provided by X2Biosystems. The data were then downloaded and filtered through the IMS to remove any spurious linear acceleration that did not meet the proprietary algorithm for a head impact [14]. This method utilised various parameters (time above 10*g* data acquisition limit, ratio of PLA to area under curve, filtered/unfiltered PLA ratio, PLA vs. number of points above data acquisition limit) to assess waveform characteristics of the aggregate of the various features of the acceleration waveform to determine an impact vs a 'clack'. The exact X2Biosystems proprietary algorithm is unavailable. The data underwent a second filtering waveform parameter proprietary algorithm during data exporting to remove spurious linear acceleration data with additional layers of analysis [14]. This included cross-correlation pattern matching (with configurable cross-correlation coefficient) by comparing the impact form to a Gaussian-like reference waveform, looking for a cross-correlation coefficient above a configurable data acquisition limit (0.90 is the default i.e. 90% match). It has been reported [15], that approximately 80% of the impacts recorded may have been removed through the analysis that X2Biosystems provide as part of the IMS program. This may be similar for the current study; however, the authors were unable to obtain the details of the proprietary algorithm or the raw data. Impact location variables were also computed as part of the IMS and were reported as azimuth and elevation angles relative to the centre of gravity (CG), of the head centred on the mid-sagittal plane [16].

All data collected were entered on a Microsoft Excel 2016 spreadsheet for visual examination. The data were then reviewed by impact time stamps (hr:min:s) to identify identical and sequential patterns for each player. Time stamps with multiple (≥ 2) linear accelerations having the same hr:min:sec time stamp in quick succession milliseconds after the preceding impact were removed. These were removed by the authors utilising Microsoft Excel conditional formatting and duplicate values to screen for linear accelerations with the same hr:min:s time stamp in quick succession. The data were then screened for player number and if there were any duplicate impacts on the hr:min:s time stamp with the same player number these were removed. No incidence of this was identified in the final screening of the data prior to analysis.

Statistical analyses

All filtered data on the Microsoft Excel spreadsheet were analysed with SPSS V.25.0.0.0 (IBM Corp, Released 2017. IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp). To test for normality, one-sample Kolmogorov-Smirnov and one sample *t*-test were conducted. If the tolerances were not met, the equivalent non-parametric tests were utilised. Comparison of the number of impacts and the impact duration were compared with a paired samples *t*-test. Data for these groups are reported as means and standard deviation (± SD). To compare between player groups and impact locations risk ratios (RR) were used. The RRs were presumed to be significant at $p<0.05$. Data that were shown to be non-parametric (PLA; PRA; RWE_{CP}), were analysed with a Friedman repeated measures ANOVA on ranks. If any notable differences were observed, a Wilcoxon signed-rank post-hoc test was conducted with a Bonferroni correction applied. Data for these groups were reported as median with 25th to 75th interquartile range [IQR].

Total frequency impact burden per-match were analysed using a Kruskal-Wallis one-way ANOVA with a Dunn's post-hoc test for all pairwise comparisons with player positions. Although there is no accepted method to quantify total frequency impact burden [17], the sum of linear and rotational accelerations associated with each individual head impact per-match over the course of the study was calculated for all of these parameters. The total sum of the resultant peak linear and the peak rotational accelerations recorded was undertaken for each match half, total match, player role, player position and for the duration of the study. Head impact exposure including impact duration, frequency, magnitude and location of impacts were quantified using previously established methods [8,10]. Cohen's effect size (d) were utilised to calculate practically meaningful differences. Effect sizes of <0.19, 0.20-0.60, 0.61-1.20 and >1.20 were considered trivial, small, moderate, and large, respectively [18]. The level of significance was set at $p \leq 0.05$.

RESULTS

There were 20,687 head impacts >10g over the season of 20 matches in the 38 players (Table 1). Players in the first half of the season of competition matches recorded more impacts per-player per-match ($t_{(9)}$=4.9; p=0.0008) and the impact duration was longer ($t_{(6850)}$=21.2; p<0.0001) when compared with the second half of the season of competition matches.

Front-row forwards (FRF) recorded more impacts to the head at away games (RR: 1.5 [95% CI: 1.5-1.6]; p<0.0001) compared with home games (Table 2). Back-row forwards recorded more impacts to the head in games won (RR: 1.3 [95% CI: 1.2-1.3; p<0.0001) when compared with games lost. Outside backs recorded a longer impact duration in the first- ($t_{(847)}$=5.9; p<0.0001 d=0.29),when compared with the second-half of the season.

Although the side of the head sustained more impacts in home compared with away games this was not significant (RR: 1.0 [95% CI: 0.9-1.0]; p=0.2727) (Table 3). However, the side of the head recorded a longer impact duration ($t_{(3116)}$=-6.6; p<0.0001; d=0.19), and had a higher resultant PLAg ($\chi^2_{(1)}$=91.9; p<0.0001; z=-8.5; p<0.0001; d=0.10), PRA(rad/s^2) ($\chi^2_{(1)}$=65.0; p<0.0001; z=-6.5; p<0.0001; d=0.11) and RWE$_{CP}$ ($\chi^2_{(1)}$=50.2; p<0.0001; z=-4.0; p=0.0001; d=0.03) in home compared with away games. The front of the head recorded a longer impact duration ($t_{(2158)}$=11.2; p<0.0001; d=0.38), and had a higher resultant PLAg ($\chi^2_{(1)}$=86.6; p<0.0001; z=-9.7; p<0.0001; d=0.20), PRA(rad/s^2) ($\chi^2_{(1)}$=62.4; p<0.0001; z=-8.4; p<0.0001; d=0.80) and RWE$_{CP}$ ($\chi^2_{(1)}$=60.3; p<0.0001; z=-7.6; p<0.0001; d=0.09) in games won when compared with games lost.

DISCUSSION

Expanding on a previous study [1], matches played at away venues, won, and in the first half of the competition season recorded notably more impacts to the head with a greater magnitude. An interesting finding of this study was that there were more impacts per-player per-match recorded during matches played away (1,417 vs. 1,014), when compared with matches played at home. In addition to this, matches played away had a higher resultant median PLA (15.0 g vs. 13.7 g), but similar resultant median PRA (2,183 rad/s^2 vs. 2,143 rad/s^2). Interestingly, the team won 62.5% of away matches and 90% of home matches. This finding may be reflective of the players mental and physical preparation when competing in matches played at the home field. It has been previously reported [19], that players have a lower state anxiety level, higher self-confidence and more positive mood profiles at matches played at home when compared with matches played away. If this was the case with the current cohort then reducing state anxiety and providing a more positive pre-match environment may assist with the reduction of the impacts to the head during matches played away. Further research is warranted to evaluate the impact of pre-match player state anxiety and self-confidence on the frequency and magnitude of impacts to the head.

More impacts (14,510 vs. 6,177) were recorded for games won with a higher median PLAg (14.5g vs. 14.1g), and PRA(rad/

Table 1: Summary of 20,687 head impacts >10g (for total impacts recorded, impact duration, resultant peak linear and rotational accelerations and risk weighted exposure combined probability over a season of matches) in New Zealand senior amateur rugby union for games played on home and away grounds, games won and lost and first and second half of the season.

	Impacts >10g				Resultant Peak Linear Acceleration, g			Resultant Peak Rotational Acceleration, rad/s^2			Risk Weighted Exposure Combined Probability, RWE$_{CP}$	
	Total Recorded n=	No. per Match Mean ±SD	No. per-player per-match Mean ±SD	Duration, ms Mean ±SD	Median [IQR]	95%	Total Impacts Frequency Burden*	Median [IQR]	95%	Total Impacts Frequency Burden*	Median [IQR]	95%
Home games	8,886[f]	1,014 ±269	89 ±119	7.0 ±5.2[f]	13.7 [11.3-19.8][b]	43.9	165,962	2,143 [1,045-4,030][b]	8,980	26,735,226	0.0005 [0.0002-0.0027][b]	0.2783
Away games	11,801[e]	1,417 ±1,050	124 ±218	8.0 ±6.0[e]	15.0 [11.8-22.3][a]	46.7	237,099	2,183 [1,155-3,943][a]	9,646	37,099,263	0.0005 [0.0002-0.0027][a]	0.3995
Games won	14,510[d]	1,421 ±675[d]	111 ±178	7.9 ±6.0[d]	14.5 [11.6-21.6][d]	46.8	287,667	2,252 [1,131-4,134][d]	9,707	46,451,852[d]	0.0005 [0.0002-0.0032][d]	0.4323
Games lost	6,177[c]	857 ±881[c]	95 ±168	6.9 ±4.9[c]	14.1 [11.6-20.3][c]	42	115,394	1,991 [1,046-3,606][c]	8,536	17,382,637[c]	0.0004 [0.0002-0.0019][c]	0.1724
First half season	13,836[b]	1,674 ±834[f]	147 ±220	8.0 ±6.1[b]	15.2 [11.8-22.4][f]	46.8	280,686[b]	2,141 [1,125-3,818][f]	9,417	42,182,220	0.0000 [0.0005-0.0002][f]	0.0025
Second half season	6,851[a]	703 ±377[e]	65 ±105	6.9 ±4.8[a]	13.2 [11.2-18.3][e]	42.1	122,375[a]	2,231 [1,068-4,301][e]	9,349	21,652,269	0.0000 [0.0005-0.0002][e]	0.0034

SD = Standard Deviation; IQR = interquartile [25th to 75th] range;95% = 95th percentile; * = The total impact frequency burden is the sum of all the impacts by linear and rotational accelerations; Significant difference (p<0.05) than (a) = Home games; (b) = Away games; (c) = Games won; (d) = Games lost; (e) = First half season; (f) = Second half season

Table 2: Player positional group analyses for the 20,687 head impacts >10*g* (for total impacts recorded, impact duration, resultant peak linear and rotational accelerations and risk weighted exposure combined probability over a season of matches) in New Zealand senior amateur rugby union for games played on home and away grounds, games won and lost and first and second half of the season.

		Impacts >10*g*		Resultant Peak Linear Acceleration, *g*			Resultant Peak Rotational Acceleration, rad/s^2			Risk Weighted Exposure Combined Probability (RWE_{CP})	
		Total n=	**duration (ms) Mean ±SD**	Median [IQR]	95th	**Total Impacts Frequency Burdena**	Median [IQR]	95th	**Total Impacts Frequency Burdena**	Median [IQR]	95th
Home Games											
	FRF	2,311[bcdf]	7.7 ±5.3[bcdf]	13.8 [11.4-20.2][df]	42.2	43,596[bcd]	2,838 [1,162-5,320][bf]	10,602	8,644,584	0.0009 [0.0002-0.0086][bcf]	0.5488
	BRF	3,448[acdf]	6.7 ±4.9[acdf]	13.5 [11.3-19.1][df]	42.7	63,253[ac]	1,961 [1,011-3,562][af]	8,320	9,452,042	0.0004 [0.0002-0.0017][acdf]	0.1753
	ISB	2,125[abdf]	6.9 ±5.2[abdf]	14.0 [11.3-20.0][f]	46.4	40,400[ab]	1,949 [944-3,578][d]	8,247	5,778,878	0.0004 [0.0001-0.0019][abd]	0.1986
	OSB	1,003[abcf]	7.0 ±5.4[abc]	14.0 [11.6-20.7][ab]	45.9	19,057[a]	2,189 [1,134-3,710][cf]	8,409	2,859,723	0.0005 [0.0002-0.0022][bcf]	0.1925
Away Games											
	FRF	4,690[bcde]	8.8 ±6.7[bcde]	15.4 [11.7-23.7][de]	47.2	96,665[bd]	2,323 [1,164-4,553] [bcde]	11,525	16,788,648	0.0006 [0.0002-0.0047][bcde]	0.7826
	BRF	3,084[acde]	7.7 ±5.6[ade]	14.9 [11.9-21.9][de]	47.1	61,762[a]	2,158 [1,141-3,625][ace]	7,862	8,759,370	0.0005 [0.0002-0.0021][ace]	0.1131
	ISB	2,352[abde]	7.7 ±5.7[ade]	15.1 [11.9-21.6][de]	48.2	47,407	1,924 [1,063-3,417] [abde]	7,568	6,216,904[d]	0.0004 [0.0002-0.0017][ab]	0.1052
	OSB	1,674[abce]	7.2 ±5.2[abc]	14.1 [11.6-20.2] [abc]	41.8	31,265[a]	2,266 [1,271-3,995][ac]	9,247	5,334,342[c]	0.0005 [0.0002-0.0028][ae]	0.3149
Games Won											
	FRF	4,960[cd]	9.1 ±6.7[bcdh]	15.2 [11.8-23.4] [bdh]	47.8	102,713[ch]	2,820 [1,357-5,657][bch]	12,011	20,218,910	0.0009 [0.0002-0.0126][bc]	0.8471
	BRF	4,890[cdf]	7.2 ±5.3[a]	14.1 [11.5-20.4] [acd]	45.3	93,637[ch]	1,970 [1,021-3,481] [acdh]	7,804	13,049,780	0.0004 [0.0002-0.0017][acdh]	0.1182
	ISB	3,103[abd]	7.5 ±5.7[ah]	14.6 [11.5-21.2][bd]	48.5	61,802[ab]	2,026 [1,050-3,622][abh]	8,247	8,635,622	0.0004 [0.0002-0.0021][abh]	0.2011
	OSB	1,557[abcf]	7.4 ±5.6[ah]	14.2 [11.6-20.8] [abc]	43.6	29,515	2,212 [1,205-3,745][b]	8,360	4,547,541	0.0005 [0.0002-0.0023][b]	0.1887
Games Lost											
	FRF	2,041[bcd]	6.8 ±5.0[dg]	14.0 [11.2-20.6] [bdg]	39.7	37,205[g]	1,791 [840-3,314][bcg]	7,861	5,214,322	0.0004 [0.0001-0.0015][b]	0.1237
	BRF	1,642[acde]	7.0 ±5.0	14.1 [11.7-20.8][a]	45.4	31,776[g]	2,270 [1,254-4,082][acg]	8,844	5,161,631	0.0005 [0.0002-0.0031][acdg]	0.2253
	ISB	1,374[abd]	6.9 ±4.8[dg]	14.6 [11.9-20.3][d]	42.5	26,005	1,735 [994-3,134][abdg]	7,052	3,360,160	0.0003 [0.0002-0.0014][bdg]	0.0524
	OSB	1,120[abce]	6.7 ±4.7[acg]	13.9 [11.6-19.4][ac]	43.5	20,807	2,259 [1,242-4,168][c]	9,758	3,646,524	0.0005 [0.0002-0.0032][bc]	0.3883
First Half Season											
	FRF	4,347[bcdf]	9.0 ±6.8[bcdj]	16.0 [12.2-24.6] [bch]	47.2	92,041	2,472 [1,306-4,825] [bcdj]	11,716	16,362,435	0.0007 [0.0002-0.0060][bcdj]	0.8156
	BRF	4,075[acdf]	7.5 ±5.5[aj]	14.6 [11.6-21.7][ah]	46.5	80,337	1,975 [9820-3,393][adj]	7,451	10,675,765	0.0004 [0.0002-0.0017][adj]	0.0986
	ISB	3,585[abdf]	7.5 ±5.7[a]	15.0 [11.7-21.5][ah]	47.9	72,054	1,901 [1,030-3,418][ad]	7,974	9,528,321	0.0004 [0.0002-0.0017][ad]	0.1605
	OSB	1,829[abc]	7.6 ±5.7[aj]	14.8 [11.9-21.7][h]	45.2	36,254	2,296 [1,250-3,855] [abcj]	9,042	5,615,699	0.0006 [0.0002-0.0025][abcj]	0.2693
Second Half Season											
	FRF	2,654[bcde]	7.4 ±5.2[bi]	13.0 [10.9-19.1] [cdg]	42.3	47,877[bcd]	2,469 [739-4,990][bdi]	10,291	9,070,797	0.0006 [0.0001-0.0061][bi]	0.4931
	BRF	2,457[acde]	6.7 ±4.6[ai]	13.5 [11.5-18.2][g]	43.1	44,678[ad]	2,200 [1,194-3,996][adi]	8,827	7,535,646	0.0005 [0.0002-0.0027][adi]	0.2525
	ISB	892[abe]	6.4 ±4.6	13.1 [11.3-17.7] [adg]	42.8	15,753[ad]	2,041 [1,011-3,832]	8,144	2,467,461	0.0004 [0.0001-0.0020]	0.1288
	OSB	848[ab]	6.2 ±3.9[i]	12.8 [11.3-17.0] [acg]	36	14,068[abc]	2,093 [1,161-3,930][abi]	9,147	2,578,366	0.0004 [0.0002-0.0027][bi]	0.2246

SD = Standard Deviation; ms = milliseconds; IQR = Interquartile [25th to 75th] Range; * = The total impact frequency burden is the sum of all the impacts by linear and rotational accelerations; FRF = Front Row Forwards; BRF = Back Rowe Forwards; ISB = Inside Backs; OSB = Outside Backs; rad/s2 = radians per second per second; Significant ($p<0.05$) difference than (a) = FRF; (b) = BRF; (c) = ISB (d) = OSB; (e) = Home games; (f) = Away games; (g) = Games won; (h) = Games lost; (i) = First half season; (j) = Second half season

Table 3: Head impact position analyses for the 20,687 head impacts >10*g* (for total impacts recorded, impact duration, resultant peak linear and rotational accelerations and risk weighted exposure combined probability over a season of matches) in New Zealand senior amateur rugby union for games played on home and away grounds, games won and lost and first and second half of the season.

	Impacts >10*g*		Resultant Peak Linear Acceleration, *g*			Resultant Peak Rotational Acceleration, rad/s^2			Risk Weighted Exposure Combined Probability (RWE_{CP})	
	Total n=	**duration (ms) Mean ±SD**			**Total Impacts Frequency Burdena**			**Total Impacts Frequency Burdena**		
			Median [IQR]	**95th**	**Burden^{a}**	**Median [IQR]**	**95th**	**Burden^{a}**	**Median [IQR]**	**95th**
Home Games										
Front	2,923^{bcd}	7.0 ±5.0^{bcdf}	13.5 [11.5-19.2]^{bcf}	40.9	52,964	2,272 [1,146-4,280]^{bcdf}	9,425	9,410,221	0.0005 [0.0002-0.0035]^{bcdf}	0.3535
Back	2,479^{acdf}	7.5 ±5.4^{acdf}	14.9 [12.0-21.6]^{acd}	47.8	49,152	3,029 [1,765-5,149]^{acdf}	10,180	9,690,495	0.0010 [0.0003-0.0076]^{acdf}	0.5163
Side	3,117^{abd}	6.8 ±5.1^{abf}	13.0 [10.9-18.7]^{abf}	44.7	56,840	1,507 [437-2,884]^{abf}	7,297	6,684,389	0.0003 [0.0001-0.0010]^{abf}	0.0829
Top	368^{abcf}	6.6 ±4.7^{abf}	13.4 [11.6-19.3]^{bf}	42.3	7,005	1,319 [778-3,219]^{abf}	8,663	950,120	0.0002 [0.0001-0.0014]^{abf}	0.2092
Away Games										
Front	3,757^{bcd}	7.2 ±5.1^{bce}	13.6 [11.2-19.4]^{bce}	40.5	67,845^{d}	1,887 [925-3,431]^{be}	8,014	10,001,184	0.0004 [0.0001-0.0017]^{bce}	0.1279
Back	3,448^{acde}	9.3 ±7.1^{ace}	16.8 [12.7-26.5]^{ac}	54.2	79,112	3,327 [1,802-6,194]^{acde}	13,159	15,852,228	0.0014 [0.0003-0.0202]^{ace}	0.9479
Side	4,248^{abc}	7.8 ±5.6^{abde}	14.9 [11.8-21.7]^{abde}	44.1	83,227	1,866 [1,038-3,028]^{bde}	6,728	10,199,106	0.0004 [0.0002-0.0013]^{abe}	0.049
Top	347^{abce}	8.1 ±6.4^{ce}	14.9 [11.7-22.2]^{ce}	45.3	6,916^{a}	1,735 [956-4,147]^{bce}	9,596	1,046,745	0.0004 [0.0001-0.0035]^{ce}	0.465
Games Won										
Front	4,521^{bcdh}	7.7 ±5.5^{bch}	14.1 [11.6-20.5]^{bdh}	42.6	85,419^{d}	2,256 [1,147-4,056]^{bch}	8,929	14,067,081	0.0005 [0.0002-0.0029]^{bch}	0.2524
Back	4,057^{acdh}	8.8 ±7.0^{acdh}	15.8 [12.3-25.0]^{ach}	54	89,186	3,336 [1,894-6,084]^{acdh}	12,515	18,394,488	0.0014 [0.0004-0.0182]^{acdh}	0.8918
Side	5,393^{abdh}	7.5 ±5.5^{abh}	13.9 [11.2-20.6]^{b}	44.7	102,342	1,725 [800-3,006]^{abdh}	7,027	12,441,600	0.0003 [0.0001-0.0012]^{abd}	0.0755
Top	540^{abch}	7.5 ±5.9^{b}	13.9 [11.6-21.4]^{a}	43.9	10,719^{a}	1,501 [837-4,080]^{bch}	9,379	1,548,683	0.0003 [0.0001-0.0032]^{bch}	0.4844
Games Lost										
Front	2,157^{bcdg}	5.9 ±3.9^{bcg}	12.6 [11.0-17.0]^{bcg}	34.8	35,389	1,606 [860-3,171]^{bch}	7,919	5,344,325	0.0003 [0.0001-0.0012]^{bg}	0.104
Back	1,871^{adeg}	7.8 ±5.4^{acg}	15.9 [12.5-24.1]^{acdg}	48.2	39,078	2,889 [1,622-5,019]^{acdh}	10,193	7,148,236	0.0010 [0.0003-0.0073]^{acdg}	0.5374
Side	1,973^{adg}	7.0 ±5.2^{abdg}	14.4 [11.7-21.1]^{ad}	43.6	37,757	1,735 [935-2,925]^{abdh}	6,288	4,457,731	0.0003 [0.0002-0.0011]^{bd}	0.0352
Top	175^{acg}	6.7 ±4.8^{c}	13.8 [11.7-19.9]^{b}	37	3,202	1,497 [902-3,505]^{bch}	8,827	448,181	0.0002 [0.0001-0.0018]^{bcg}	0.2246
First Half Season										
Front	3,654^{bcdj}	7.6 ±5.5^{bcj}	14.8 [11.9-21.3]^{bcj}	42.6	70,852	2,182 [1,139-3,716]^{bcj}	8,357	10,771,959	0.0005 [0.0002-0.0022]^{bcj}	0.1658
Back	3,970^{acd}	9.2 ±7.1^{acj}	16.8 [12.6-26.3]^{acj}	54.2	90,548	3,063 [1,709-5,724]^{acj}	12,772	17,334,703	0.0012 [0.0003-0.0142]^{acj}	0.9251
Side	5,870^{abdj}	7.4 ±5.4^{abd}	14.3 [11.4-20.9]^{abdj}	43.7	112,096	1,683 [859-2,899]^{abdj}	6,513	12,990,598	0.0003 [0.0001-0.0011]^{abdj}	0.0425
Top	343^{abci}	8.2 ±6.4^{cj}	16.4 [12.3-23.5]^{cj}	45.7	7,191	1,943 [1,009-4,311]^{cj}	10,479	1,084,961	0.0005 [0.0002-0.0041]^{cj}	0.6508
Second Half Season										
Front	3,026^{bcdi}	6.5 ±4.4^{bci}	12.4 [11.0-16.8]^{bci}	36.6	49,956^{b}	1,891 [891-3,817]^{bdi}	9,102	8,639,447	0.0003 [0.0001-0.0021]^{bi}	0.2513
Back	1,957^{acd}	7.1 ±4.8^{ai}	14.6 [11.9-20.8]^{acdi}	45.8	37,716^{ad}	3,348 [1,958-5,725]^{acdi}	10,435	8,208,020	0.0013 [0.0004-0.0135]^{acdi}	0.5211
Side	1,495^{abdi}	7.3 ±5.4^{a}	13.3 [11.2-18.6]^{abi}	49.9	27,972	1,954 [799-3,353]^{bi}	8,170	3,892,898	0.0004 [0.0001-0.0015]^{bi}	0.1999
Top	372^{abci}	6.5 ±4.7^{i}	13.0 [11.4-16.6]^{bi}	41.6	6,730^{b}	1,160 [778-3,090]^{aci}	8,663	911,904	0.0002 [0.0001-0.0013]^{bi}	0.2086

SD = Standard Deviation; ms = milliseconds; IQR = Interquartile [25th to 75th] Range; rad/s^2 = radians per second per second; * = The total impact frequency burden is the sum of all the impacts by linear and rotational accelerations; Significant ($p<0.05$) difference than (a) = Front; (b) = Back; (c) = Side (d) = Top; (e) = Home games; (f) = Away games; (g) = Games won; (h) = Games lost; (i) = First half season; (j) = Second half season

s^2) (2,252 rad/s^2 vs. 1,991 rad/s^2), when compared with games lost. This could potentially be reflective of an increased amount of tackles, rucks and mauls during those matches won. It has been reported [20], that successful teams are more patient, employ a more evasive style of play and have a greater control of the game. As well, a higher frequency of rucks and mauls with possession retained were also associated with successful teams [20]. Conversely, unsuccessful teams have a more direct pattern of play and have a lower frequency of rucks and mauls, lose possession of the ball and conceded more penalities [20]. In an analysis of the 1987 World Rugby Cup, it was reported [21], that the most successful team of the competition recorded the highest number of contact situations and the greatest ball retention. It has been identified [22], that impacts of a greater magnitude have a higher associated risk curve for concussion and higher magnitude accelerations were recorded in matches won when compared with matches lost. Unfortunately, the number of rucks, mauls, penalties conceded and free kicks awarded during matches were not recorded during the study and the concussions that occurred have been previously reported [23], but not by matches won or lost. Given these aspects, the finding that there were more impacts recorded per match for games won may be reflective of the higher incidence of rucks and mauls that occurred during matches. As there are new rules regarding the ruck for rugby union this may have changed and further research is warranted to see if the changes to the ruck have resulted in a change to the number of impacts that occur when comparing matches won and lost.

The finding that there were far more impacts experienced by players during the first half of the season compared to the second half of the season could be related to the players level of fitness. Although a limitation to this study is that player fitness was not recorded, it has been previously reported [24], that the varied physical stresses involved in the seasonal nature of rugby union may compromise physical development. Male rugby players have been reported to have the greatest improvement in strength, flexibility and aerobic fitness during the pre-season, before returning to baseline during the competitive season [25]. This reduction may also occur towards the end of a season due to low training loads, injury rates and high match loads [25]. This may have been the case with the current cohort where the median resultant linear (15.2 *g* vs. 13.2 *g*), acceleration recorded was lower in the second half of the season but the median resultant rotational (2,141 rad/s^2 vs. 2,231rad/s^2) accelerations were higher. When compared by player groups, this was not always the case as FRF had a reduction in resultant median PLA but similar resultant median PRA whereas OSB had a reduction in both resultant median PLA and PRA. These changes may reflect decreasing levels of fitness, limited injury rehabilitation time and increasing demands for team participation towards the end, when compared with the beginning, of the competition season. Further research is warranted to identify if any correlation exists between the level of fitness of players and the frequency of head impacts that occur.

There were player positional differences for the nature of matches. These differences may be a result of the way the game of rugby union is played. The finding that FRF recorded more impacts to the head in away games, matches won and in the first half of the competition may be related to the nature of the games played under study and to the differing positional roles that FRF play compared with other playing positions. Typically, FRF have a higher body mass, are in continual close contact with the opposition, have limited opportunities to run with the ball and are required to gain possession of the ball [26]. Although BRF also have a high body mass, they are leaner and have a wider roving role in the game in support of the FRF and support the ISB and OSB. The ISB and OSB are required to have a higher endurance, be faster in speed and avoid the opposition. These differences in the positional roles of the players are reflective of the differences in the number of impacts and acceleration magnitudes recorded by player positional groups.

The finding that the head impact location varied by the analysis conducted was unexpected. There were more impacts recorded to the side of the head in matches won and the first half of the season when compared with the back, front and back of the head. Interestingly both away and home matches recorded the most impacts to the side of the head. What was unexpected was the finding that more impacts were recorded to the front of the head in the second half of the season and in matches lost when compared to the side, back and top of the head. Again, this may be related to how the matches were played. As previously reported [20], unsuccessful teams have a more direct pattern of play and have a lower frequency of rucks and mauls, lose possession of the ball and conceded more penalties when compared with successful teams. As a result the players may be leading into the tackles with their body in a forward position and trying to break the tackle, or may be attempting to remove the opposition player over the ruck in order to turn over the possession of the ball. With the new rule changes to rugby union in relationship to the ruck this finding may have changed. Further research is warranted to identify the impacts in rucks and mauls for successful and unsuccessful teams to identify possible injury reduction measures.

The use of accelerometer devices to record impacts in different sporting environments has become more prolific in recent times. The number of studies is growing across a wide variety of sports (American football [5], Lacrosse [27], Soccer [4], Australian Rules Football [28], Rugby Union [1], and Rugby League) [29], recording the overall magnitude, frequency and duration of impacts during match and training situations. Although the number of published studies reporting on head impacts in sport is increasing, these are limited to headbands [4], helmet fitted accelerometers [2,17,22], and behind the ear patches (XPatch) [15,29]. As well the accuracy of the linear and rotational acceleration measurements has been reported to vary widely under different testing environments [30], Comparisons between the different technologies should be undertaken with some caution. We chose instrumented mouthguards to collect head impact data as players are used to wearing mouthguards, and the devices used have been shown to be reliable and valid in their data outputs [1,7].

CONCLUSION

Matches played at away venues, won, and in the first half of the competition season recorded notably more, and had a greater magnitude, impacts to the head. Male rugby players have been reported to have the greatest improvement in strength, flexibility and aerobic fitness during the pre-season, before returning to baseline during the competitive season. This reduction may also occur towards the end of a season due to low training loads, injury rates and high match loads. This may have been the case with the current cohort where the median resultant linear (15.2 *g* vs. 13.2 *g*) acceleration recorded was lower in the second half of the season but the median resultant rotational (2,141 rad/s^2 vs. 2,231rad/s^2) accelerations were higher. Further research is warranted to identify if any correlation exists between the level of fitness of players and the frequency of head impacts that occur.

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