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Research Article

Head impact exposure comparison between male and female amateur rugby league participants measured with an instrumented patch

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Abstract

Background: Epidemiological studies report that females experience greater rates of concussion when compared with males. Biomechanical factors may result in greater post-impact head velocities and accelerations for a given force for females when compared with males.

Purpose: To quantify the magnitude, frequency, duration and distribution of impacts to the head and body in rugby league match activities for females versus males.

Design: Prospective descriptive epidemiological study.

Methods: 21 female and 35 male amateur rugby league players wore wireless impact measuring devices (X2Biosystems; xPatch) behind their right ear over the mastoid process during match participation across a single season. All impact data were collected and downloaded for further analysis.

Results: Male amateur rugby league players experienced more head impacts than female amateur rugby league players (470 ±208 vs. 184 ±18; $t_{(12)}$=-3.7; p=0.0028; d=1.94) per-match over the duration of the study. Male amateur rugby league players recorded a higher median resultant Peak Linear Acceleration (PLA(g)) (15.4 vs. 14.6 g; $F_{(824,834)}$=51.6; p<0.0001; $t_{(1658)}$=-3.3; p=0.0012; d=0.10) but a lower median resultant Peak Rotational Acceleration (PRA(rad/s^2) (2,802.3 vs. 2,886.3 rad/s^2; $F_{(831,827)}$=3.1; p<0.0001; $t_{(1658)}$=5.7; p<0.0001; d=0.13) when compared with female amateur rugby league players

Conclusion: Females recorded lower median values for PLA(g) and Head Impact Telemetry severity profile (HIT$_{SP}$) for all positional groups but had a higher PRA(rad/s^2) for Hit-up Forwards (HUF) and Outside Backs (OSB's) when compared with male HUF and OSB's. Females also recorded more impacts to the side of the head (48% vs. 42%) and had a higher 95th percentile resultant PRA(rad/s^2) (12,015 vs. 9,523 rad/s^2) to the top of the head when compared with male rugby league players.

Introduction

The incidence of concussion in rugby league have been reported to vary from 0.0 to 40.0 per 1,000 playing hr., but this is dependent on the injury definition that is utilised (time-loss vs. no time loss) [1]. In a recent pooled analysis [2], it was reported that the incidence of concussion varied from 7.0 per 1,000 playing hr. for junior participants to

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19.1 per 1,000 playing hr. for amateur participants. Rugby league is a challenging contest of intense frequent bouts of high-intensity activity (e.g. sprinting) and collisions (e.g. offensive ball carrying and defensive tackling), interspersed with short bouts of low-intensity activities (e.g. walking, jogging) [3]. As a result of these activities, participants often experience between 29 and 74 physical collisions (tackles and ball-carries) per game [4,5]. These collisions carry an inherent risk of injury, including concussion [1], as impacts to the body and head occur frequently [6].

It has been reported [2] that males participating in rugby league activities record more concussions (7.7 vs. 6.1 per 1,000 playing hours) than females. Despite this finding, epidemiological studies report that females experience greater rates of concussion when compared with males [7]. The reason for the differences in the incidence of concussion between males and females remains unknown [8]. Biomechanical factors have been postulated as a possible reason for the differences in male and female incidence of concussion. Due to these biomechanical factors, there would be greater post-impact head velocities and accelerations for a given force for females when compared with males [9]. As greater magnitudes of head linear and rotational accelerations are associated with a greater probability of a concussion occurring [10], these biomechanical factors provide a potential mechanistic explanation for the relations between head kinematics, neck strength and concussion risk [11].

To better understand concussive injuries, head impact biomechanics have been extensively studied in a variety of sporting environments such as American football [11-14], soccer [15,16], ice hockey [17,18], lacrosse [19], Australian rules football [20], rugby union [21] and rugby league [22-24]. The studies reporting on head impact biomechanics in rugby league have been undertaken at junior [22], senior amateur male [23] and senior amateur female [24], levels of participation. It has been reported that junior rugby league players [22] recorded a mean of 13 impacts per-player per-match, resulting in a median PLA(g) and PRA(rad/s^2) of 16g and 2,773 rad/s^2. This was similar for senior female amateur rugby league players [24] with a mean of 14 impacts per-player per-match resulting in median PLA(g) and PRA(rad/s^2) of 15g and 2,886 rad/s^2. Senior amateur male rugby league players [23] recorded a higher number of impacts with a mean of 52 impacts per-player per-match resulting in a median PLA(g) and PRA(rad/s^2) of 14g and 3,181 rad/s^2.

Although these studies [22-24] identified the magnitude, frequency and location of impacts to the head, only a few studies [11,18,19,25], have compared male and female head impact biomechanics within the same sporting activity. All these studies [11,18,19,25] reported that males recorded more impacts to the head in both match and practice sessions when compared with females. When comparing male and female collegiate lacrosse players [19] it was reported that at the 10g threshold there were no differences in the number of impacts recorded, but for average in-game impacts, males had a 44% greater resultant PLA(g) and 55% greater PRA(rad/s^2) when compared with females. This was similar when comparing male and female collegiate ice hockey players [25,18], but in a more recent study [11], it was reported that females recorded greater mean magnitudes for PLA(g) (18.7 vs. 17.7g) and Head Impact Telemetry severity profile (HIT$_{SP}$) (19.0 vs. 17.7) when compared with male ice hockey players. It must be noted that there are variations in some rules between these male and female sporting activities. For example, in female ice hockey it is illegal for purposeful body contact with an opposing player, but this is allowed in male ice hockey matches [18]. There are gender specific rules in lacrosse where female participants are required to wear protective eyewear whereas male participants wear protective eyewear and helmets [19]. Despite these studies, no study to date has compared male and female sports where both sexes participate under the same rules and regulations.

Rugby league and rugby union are two sporting codes where the rules and regulations are identical for both male and female participants. Although studies

[21-24,26] have been published in both these sporting codes, only rugby league have reported on male [23] and female [24] impacts to the head at the same level of participation. Previous studies [11,18,19,25] have reported comparisons between male and female participants where gender specific rules applied. However these studies [23,24] were played under the international rugby league rules for the same duration (2 x 40 min halves). As a result, this study was undertaken to compare a year of head impact biomechanics between male and female participants in the same competition year. These head impact data will provide a better understanding of how female rugby league players compare to men. This is important as it form the basis for discussion of whether changes in the rugby league game are needed for either or both sexes for rules to reduce the amount of head impacts and concussion.

Methods

A prospective cohort design was used to study the impact frequency, magnitude and duration of head impacts during amateur domestic senior women's [24] and amateur domestic senior men's [23] rugby league matches. A total of 21 female (age: 29.2 ±7.8 yr.) and 35 male (age: 23.8 ±4.9 yr.) rugby league participants were enrolled into the individual studies. The researcher's university ethics committee (AUTEC 16/35) approved all procedures in the study and all participants gave informed signed consent prior to participating in the studies.

Instrumentation

The xPatch system (X2Biosystems, Seattle WA) was utilized to capture the head impact biomechanics. Measuring 1 cm x 2 cm, the xPatch is a lightweight device affixed over the mastoid process behind the player's right ear with an adhesive patch. The xPatch contains a triaxial accelerometer and triaxial angular gyroscope to capture six degrees of freedom for linear and rotational velocity and contains a 4.2 V battery and a small memory chip measuring at 1 kHz for linear acceleration and 800 Hz for angular velocity that is triggered when impacts greater than 10*g* occur. This threshold was chosen based on a review of previously published studies [21,27] and it has been reported that running and jumping were observed to elicit a maximum of 9.54*g* of linear head acceleration [28]. Once triggered, the xPatch saves 10-ms prior to the impact and 90-ms after the impact providing X, Y, and Z coordinates of acceleration at 1-ms intervals. Peak linear acceleration (PLA(*g*)) was measured and peak rotational acceleration (PRA(rad/s^2)) was then calculated. The time stamp of the match was synchronised with the X2 xPatch prior to every game. The frequency, location, PLA(*g*), PRA(rad/s^2) and duration of all head impacts ≥10*g* threshold of linear acceleration were recorded by the xPatch for each match and stored on the device until uploaded. The xPatch has a strong correlation with peak linear acceleration (PLA(*g*): $r^2 = 0.93$) with a normalised root square error of 18%, but may over predict PLA(*g*) and PRA(rad/s^2) by 15g ± 7g and 2,500 ±1,200 rad/s^2, respectively [29]. The xPatch has also been reported [30] to have good agreement between the headform III and the recorded PLA(*g*), but can underestimate PRA(rad/s^2) by at least 25%. More recently it has been reported that the xPatch has a significant statistical correlation with the Head Impact Telemetry System (HITS) for PLA(*g*) ($r = 0.144$; $p<0.001$), PRA(rad/s^2) ($r = 0.15$; $p<0.001$) and Head Impact Telemetry severity profile (HITsp) ($r = 0.34$; $p<0.001$) [31].

Procedures

The xPatch's were synchronised and time checked in the morning of the match. Prior to commencing warm-up, the lead researcher applied the xPatch behind each player's right ear (n=17) ensuring it was fitted over the mastoid process and loose hair was not in the adhesive. The patches were allocated to player positions and the participants' names were recorded. Data collection was delimited to matches only—not team training sessions. Immediately following the matches, the xPatch's were removed by the lead researcher and these were then prepared for data export and recharging. Throughout the week, between matches, the xPatch's were checked to ensure they were charged and all data from previous matches were downloaded and removed from the xPatch memory chip.

Data processing and statistical analyses

Several steps were undertaken to exclude data identified as not representing on-field head impacts. The data contained on the xPatch were uploaded and filtered through the Impact Management System (IMS) to remove any spurious linear acceleration that did not meet the proprietary algorithm for a head impact [32]. The data underwent a second filtering waveform parameter proprietary algorithm during data exporting to remove spurious linear acceleration data with additional layers of analysis [32]. This included the area under the curve, the number of points above threshold and filtered versus unfiltered peaks [32]. The remaining data were exported onto an Excel spreadsheet (version 2013; Microsoft Corporation, Redmond, WA) for visual examination. All data were reviewed and any impacts less than 10*g* were removed. The data were then adjusted to estimates of the Hybrid III head form criterion standard [15] and all impacts <10*g* were removed from the database following the completion of the adjusted calculations in line with previous results [15] that showed the xPatch over-estimates linear accelerations when compared with the centre of gravity of the headform criterion. Finally, a review was undertaken of all data to identify those impacts that occurred outside of the match times and these were removed.

The resulting filtered data were analyzed with SPSS V.25.0.0. (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. The impact variables were not normally distributed (Male: $D_{(4231)}=0.22$, $p<0.0001$; $t_{(4231)}=100.8$, $p<0.00001$; Female: $D_{(1658)}=0.22$, $p<0.0001$; $t_{(1658)}=67.00$, $p<0.0001$). Players were categorized into positional groups; hit-up forwards (HUF) (props n=2, second row forwards n=2), outside backs (OSB) (centers n=2, wings n=2) or adjustables (ADJ) (hooker n=1, loose forward n=1, halfback n=1, standoff n=1, fullback n=1) [33].

Two measures of impact frequency were computed for each player: (1) *Impacts per match*, the total and average number of impacts for all matches, and (2) *Player group impacts*, the total and average number of recorded head impacts for the playing group (HUF, OSB, ADJ) for all matches. Head impact location variables were computed as azimuth and elevation angles relative to the centre of gravity (CG) of the head centered on the mid-sagittal plane [21,26,34]. These were categorized as front, side, back and top. Impacts to the top of the head were defined as all impacts above and α of 65° from a horizontal plane through the CG of the head [35]. Additional analysis was undertaken to establish the Risk Weighted Exposure Combined Probability (RWE_{CP}) [36] and Head Impact telemetry Severity profile (HIT_{SP}) [35]. The RWE_{CP} is a logistic regression equation and regression coefficient of injury risk prediction of an injury occurring based on previously published analytical risk functions [36] and the HIT_{SP} is a weighted composite score including linear and rotational accelerations, impact duration, and impact location [35]. The RWE_{CP} combines the linear and rotational accelerations to elucidate individual player and team-based exposure to head impacts

Descriptive statistics were calculated for impact counts, locations and magnitudes in terms of resultant peak line acceleration (PLA(*g*)), peak rotational acceleration (PRA(rad/s^2)), HIT_{SP} and RWE_{CP} units. As the data were positively skewed and to control for this violation of normality, the impact magnitudes the data were natural log transformed before analysis. It must be noted that, for interpretability, all impact magnitude results are presented in the original non-transformed units therefore data were expressed as median [IQR] and 95th percentile [27]. Analysis of variance (ANOVA) were utilized to compare impact magnitudes by gender and positional group. Individual *t*-tests were conducted for any significant ANOVA result. We then analyzed the top 10%, 5% and 1% of impacts (i.e. excluded those impact of magnitude <90th,

<95th and <99th percentiles) focusing only on gender. Cohen's effect size (d) were utilized 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 [37]. A one sample chi-squared (χ^2) test, risk ratio (RR) and Odds Ratio (OR), with 95% confidence intervals (CI), were used to determine whether the observed impact frequency was significantly different from the expected impact frequency. Statistical significance was set at $p<0.05$.

Results

Over the course of the study, female amateur rugby league players participated in nine competition matches resulting in a match exposure of 155.6 match hr. To enable comparison, only those matches played by the male amateur rugby league players on the same weekends were compared with the female amateur rugby league matches. As a result, there were nine competition matches resulting in a match exposure of 155.6 match hr.

Impact frequency

During the competition a total of 4,232 and 1,659 head impacts were analyzed in the male and female amateur rugby league players respectively (Table 1). Male amateur rugby league players experienced more head impacts per-match than female amateur rugby league players (470 ±208 vs. 184 ±18; $t_{(12)}=-3.7$; $p=0.0028$; $d=1.94$) during the study. Although male amateur rugby league players recorded a longer mean impact duration (12.4 ±8.7 ms vs. 11.6 ±8.7 ms; $t_{(1658)}=1.4$; $p=0.1573$) when compared with female amateur rugby league players this was not significant. Male OSB recorded more impacts (RR: 2.2 [95% CI: 2.0 to 2.5]; $p<0.0001$) when compared with female OSB.

Impact magnitudes

Male amateur rugby league players recorded a higher median resultant PLA; g (15.4 vs. 14.6 g; $F_{(824,834)}=51.6$; $p<0.0001$; $t_{(1658)}=-3.3$; $p=0.0012$; $d=0.10$) but a lower median resultant PRA; rad/s^2 (2,802.3 vs. 2,886.3 rad/s^2; $F_{(831,827)}=3.1$; $p<0.0001$; $t_{(1658)}=5.7$; $p<0.0001$; $d=0.13$) when compared with female amateur rugby league players (Table 1). Male OSB's recorded a higher median resultant PLA; g (15.8 vs. 15.5 g; $F_{(77,134)}=1185.7$; $p<0.0001$; $t_{((211)}=-11.3$; $p<0.0001$; $d=0.33$) when compared with female amateur rugby league players. Female HUF's recorded a higher resultant median PRA; rad/s^2 (3,078 vs. 2,717.5 rad/s^2; $F_{(365,336)}=1.1$; $p=0.1230$; $t_{(701)}=-19.7$; $p<0.0001$; $d=0.28$) when compared with male amateur rugby league players.

Impact location

The distribution of impacts differed between the genders ($\chi^2_{(3)}=1921.4$; $p<0.0001$) (Table 3). Males recorded more impacts to the front (OR: 1.15 [95% CI: 1.04-1.28]; $p=0.0173$; $d=1.90$) and top (OR: 1.68 [95% CI: 1.18-2.40]; $p=0.0039$; $d=1.08$) of the head, while females recorded more impacts to the side (OR: 1.15 [95% CI: 1.08-1.22]; $p=0.0015$; $d=1.10$) of the head. Impact magnitudes varied by impact location and genders. Male amateur rugby league players recorded a higher resultant median PLA (g) to the back (16.7 vs. 16.3 g; $F_{(62,315)}=33.2$; $p<0.0001$; $t_{(377)}=2.1$; $p=0.0337$; $d=0.14$) and side (14.3 vs. 13.2 g; $F_{(65,725)}=15.1$; $p<0.0001$; $t_{(790)}=2.4$; $p=0.0188$; $d=0.21$) of the head when compared with female amateur rugby league players. Female amateur rugby league players recorded a higher resultant median PLA(rad/s^2) to the back (3,420.2 vs. 3,046.9 rad/s^2; $F_{(93,284)}=2.1$; $p<0.0001$; $t_{(377)}=-4.7$; $p<0.0001$; $d=0.21$), side (2,421.0 vs. 2,270.8 rad/s^2; $F_{(126,664)}=2.0$; $p<0.0001$; $t_{(790)}=-4.4$; $p<0.0001$; $d=0.06$) and top (3,897.3 vs. 2,880.7 rad/s^2; $F_{(19,17)}=3.9$; $p=0.0033$; $t_{(36)}=-2.9$; $p=0.0057$; $d=0.53$) of the head when compared with male rugby league players. As a result, female amateur rugby league players recorded a higher median RWE$_{CP}$ to the back (0.0015 vs. 0.0012; $F_{(134,243)}=2.4$; $p<0.0001$; $t_{(377)}=-2.6$; $p=0.0087$; $d=0.09$) and top (0.0029 vs. 0.0010; $F_{(20,16)}=5.9$; $p=0.0004$; $t_{(36)}=-3.4$; $p=0.0018$; $d=0.24$) of the head when compared with male amateur rugby league players.

Table 1: Impacts to the head greater than 10*g* in men's and women's domestic amateur rugby league for total impacts recorded and player positional groups over one season of club matches for total impacts, percentage of total impacts, impacts per-match, impacts per-player per-match, impact duration, resultant peak linear and rotational accelerations, head impact telemetry severity profile and risk weighted exposure (rotational and linear) combined probability. Data are presented as mean (±Standard Deviation), median [25th - 75th interquartile range] and 95th percentile.

Impact to the head					Peak Linear Acceleration (PLA(g))		Peak Rotational Acceleration (PRA(rad/ s^2))		Head Impact Telemetry severity profile (HIT_{SP})		Risk Weighted Exposure combined probability (RWE_{CP})	
n= (%)		Per Match Mean ±SD	Per-Player Per-Match Mean ±SD	Impact Duration (ms) Mean ±SD	Median [IQR]	95%	Median [IQR]	95%	Median [IQR]	95%	Median [IQR]	95%
Male Amateur Rugby League												
Total	4,232 (100)	470 ±208	36 ±55	12.5 ±8.7	15.4 [12.0-22.4]	45.6	2,802.3 [1,742.4-4,711.5]	14,675.5	15.5 [13.3-20.4]	43.6	0.0009 [0.003-0.0060]	0.5382
Positional Group												
HUF[1]	1,556 (36.8)	173 ±146	43 ±73	12.6 ±8.8	15.5 [12.1-22.7]	46.0	2,717.5 [1,672.0-4,812.4]	10,481.5	15.5 [13.3-20.8]	45.3	0.0008 [0.0003-0.0067]	0.5872
OSB[1]	1,196 (28.3)	133 ±82	33 ±49	12.4 ±8.7	15.8 [12.3-22.5]	46.3	2,960.3 [1,992.2-4,922.9]	10,043.4	15.7 [13.5-20.6]	42.7	0.0011 [0.0004-0.0077]	0.6155
ADJ[2]	1,480 (35.0)	164 ±93	33 ±43	12.4 ±8.7	15.1 [11.7-22.1]	44.9	2,743.5 [1,660.5-4,427.1]	9,085.7	15.3 [13.1-20.1]	39.9	0.0009 [0.0003-0.0046]	0.3473
Female Amateur Rugby League												
Total	1,659 (100)	184 ±18	14 ±12	11.6 ±8.1	14.6 [11.7-20.6]	41.3	2,886.3 [1,963.6-4,544.9]	9,348.1	15.2 [13.0-20.6]	45.8	0.0009 [0.0003-0.0041]	0.3535
Positional Group												
HUF[1]	702 (42.3)	78 ±25	20 ±15	10.8 ±7.7	14.8 [11.7-21.0]	42.5	3,078.3 [2151.3-4,647.3]	8,783.1	15.4 [13.1-20.2]	43.9	0.0010 [0.0004-0.0043]	0.3650
OSB[1]	212 (12.8)	24 ±4	6 ±2	10.5 ±7.1	15.5 [12.0-24.1]	45.9	3,029.7 [1,871.1-4,781.4]	11,214.9	15.6 [13.0-21.9]	51.6	0.0009 [0.0004-0.0043]	0.7144
ADJ[2]	745 (44.9)	83 ±20	17 ±11	12.6 ±8.7	14.2 [11.7-19.7]	39.4	2,659.2 [1,652.8-4,307.3]	9,350.6	15.2 [12.8-20.5]	48.0	0.0007 [0.0003-0.0035]	0.3437

SD = Standard Deviation; ms = milliseconds; IQR = interquartile [25th-75th] percentile; 95th = 95th percentile; HUF = Hit Up Forwards; OSB = Outside Backs; ADJ = Adjustables; (%) = percentage of impacts; (1) = 4 player positions; (2) = 5 player positions; Significant differences (p<0.05) than (a) = males; (b) = females; (c) = Hit-Up Forwards; (d) = Outside Backs; (e) = Adjustables.

Table 2: Impacts to the head greater than 10*g* in men's and women's domestic amateur rugby league by player position group over one season of club matches for total impacts, percentage of total impacts, impact duration, resultant peak linear and peak rotational accelerations and risk weighted exposure (rotational and linear) combined probability for the top 10%, 5% and 1% of impacts recorded.

	Male amateur rugby league players				Female amateur rugby league players			
	Threshold	n =	Impact duration (ms)	Median [IQR]	Threshold	n =	Impact duration (ms)	Median [IQR]
PLA, *g*								
Top 10%	35.0	423	23.0 ±9.5	45.6 [39.4-56.8][b]	33.8	166	20.2 ±8.1	41.3 [36.5-49.9][a]
Top 5%	45.6	212	25.5 ±9.3[b]	56.8 [50.5-66.7][b]	41.3	84	21.3 ±9.0[a]	49.9 [45.3-69.3][a]
Top 1%	70.1	42	27.8 ±10.3	84.8 [74.0-94.8][b]	72.6	18	21.6 ±9.3	74.0 [73.2-81.3][a]
PRA(rad/s^2)								
Top 10%	7,906.6	424	21.6 ±9.5	9,874.7 [8,732.3-12,174.7][b]	7,179.0	166	18.9 ±8.5	9,321.0 [7,974.0-11,670.0][a]
Top 5%	9,892.0	211	23.3 ±9.8	12,194.9 [10,815.9-13,939.1][b]	9,348.1	79	19.2 ±9.2	11,833.0 [10,460.5-14,974.3][a]
Top 1%	14,675.5	42	26.0 ±10.2[b]	17,308.0 [15,815.6-18,960.2][b]	15,280.8	16	17.3 ±5.7[a]	16,693.3 [15,837.6-18,982.5][a]
HIT_{SP}								
Top 10%	31.2	426	24.1 ±9.1	43.6 [35.6-57.0][b]	32.8	168	21.2 ±8.0	45.5 [37.2-58.3][a]
Top 5%	43.6	213	27.0 ±9.0	56.8 [49.2-72.2][b]	45.8	84	22.4 ±8.8	57.5 [50.5-80.8][a]
Top 1%	80.9	42	34.4 ±8.1	105.3 [92.1-125.8][b]	83.2	16	29.4 ±8.2	93.0 [88.8-121.9][a]
RWE_{CP}								
Top 10%	0.1089	423	21.9 ±9.5	0.4905 [0.2288-0.8867][b]	0.0498	166	19.5 ±8.3	0.3535 [0.1232-0.7903][a]
Top 5%	0.4907	211	24.2 ±9.7	0.8867 [0.6683-0.9776][b]	0.3535	84	20.5 ±8.8	0.7903 [0.5830-0.9889][a]
Top 1%	0.9877	42	26.3 ±9.9	0.9986 [0.9946-0.9999][b]	0.9930	16	20.9 ±10.3	0.9966 [0.9942-0.9995][a]

PLA; *g* = Peak Linear Acceleration; PRA; rad/s^2 = Peak Rotational Acceleration radians per second per second; HITSP = Head Impact Telemetry severity profile; RWECP = Risk Weighted Exposure combined (linear and rotational) probability; Significant difference (p<0.05) than (a) = males; (b) = females.

Table 3: Impacts to the head greater than 10*g* in men's and women's domestic amateur rugby league by impact location over one season of club matches for total impacts, percentage of total impacts, impact duration, resultant peak linear and peak rotational accelerations, head impact telemetry severity profile and risk weighted exposure (rotational and linear) combined probability. Data are presented as mean (±Standard Deviation), median [25th - 75th interquartile range] and 95th percentile.

	Impact to the head		Peak Linear Acceleration (PLA(*g*))		Peak Rotational Acceleration (PRA (rad/ s^2))		Head Impact Telemetry severity profile (HIT$_{SP}$)		Risk Weighted Exposure combined probability (RWE$_{CP}$)	
	Total	Impact Duration (ms)								
	n= (%)	Mean ±SD	Median [IQR]	95th	Median [IQR]	95th	Median [IQR]	95th	Median [IQR]	95th
Male Amateur Rugby League										
Front	1,111 (26.3)^{b}	12.4 ±8.3	15.9 [12.4-24.2]	49.2	3,337.3 [2,310.8-5,610.4]^{b}	10,876.4	14.9 [12.5-21.0]	49.5	0.0015 [0.0005-0.0148]^{b}	0.7330
Back	1,200 (28.4)	11.7 ±8.1	16.7 [12.5-24.5]^{b}	48.6	3,046.9 [1,887.5-5,014.3]^{b}	10,757.4	15.7 [13.4-20.7]	41.3	0.0012 [0.0004-0.0079]^{b}	0.4024
Side	1,762 (41.6)^{b}	13.1 ±9.3	14.3 [11.5-20.3]^{b}	41.6	2,270.8 [1,404.6-3,964.2]^{b}	8,845.6	15.5 [13.4-20.4]	46.9	0.0005 [0.0002-0.0029]	0.3017
Top	159 (3.8)^{b}	12.4 ±9.6	16.3 [13.2-23.2]	52.3	2,880.7 [1,633.3-4,802.2]^{b}	9,523.0	14.9 [12.5-20.3]	47.5	0.0010 [0.0003-0.0097]^{b}	0.4078
Female Amateur Rugby League										
Front	378 (22.8)^{a}	9.8 ±7.5^{def}	15.0 [11.6-21.9]	30.3	3,173.9 [2,255.1-5,200.1]^{a}	10,398.4	14.9 [12.5-20.0]	48.2	0.0011 [0.0004-0.0075]^{a}	0.6841
Back	453 (27.3)^{a}	12.7 ±8.2^{cef}	16.3 [12.7-23.6]^{a}	25.0	3,420.2 [2,421.9-5,656.5]^{a}	11,534.6	14.7 [12.1-21.0]	42.8	0.0015 [0.0005-0.0119]^{a}	0.7847
Side	791 (47.7)	11.7 ±8.3^{cdf}	13.2 [11.3-17.8]^{a}	32.0	2,421.0 [1,452.1-3,713.7]^{a}	6,945.2	15.0 [11.8-22.0]	51.6	0.0006 [0.0002-0.0021]	0.0492
Top	37 (2.2)^{a}	12.0 ±6.7^{cde}	15.9 [12.5-30.1]	23.1	3,897.3 [2,763.0-6,515.4]^{a}	12,015.9	13.9 [10.6-23.8]	68.0	0.0029 [0.0007-0.0293]^{a}	0.8520

SD = Standard Deviation; ms = milliseconds; rad/s^2 = radians per second^2; IQR = Interquartile [25th-75th] range; 95th = 95th percentile; Significant difference (p<0.05) than (a) = male; (b) = female

Discussion

This study compared head impact biomechanics between male and female rugby league players during one competition year. Unlike previous studies [11,1819,25] that have reported on comparisons between male and female participants where there were gender specific rules, the current cohort of male and female participants played rugby league under the international rules for the same duration (2 x 40 min halves). In our study, males recorded more impacts per-match, had a higher resultant median PLA (g), but a lower resultant median PRA rad/s^2 over the duration of the study when compared with female amateur rugby league players. When examined by positional groups, females recorded lower median values for PLA (g) and HIT$_{SP}$ for all positional groups but had a higher PRA rad/s^2 for HUF and OSB's when compared with male HUF and OSB's. Females also recorded more impacts to the side of the head (48% vs. 42%) and had a higher 95th percentile resultant PRA rad/s^2 (12,015 vs. 9,523 rad/s^2) to the top of the head when compared by categories with the males.

Females recording less impacts than males (1,659 vs. 4,232) over the same number of competition matches was not unexpected. Gabbett [38] reported that the physiological and anthropometric characteristics of women rugby league players are poorly developed in comparison to other women team sports participants. As well, when compared with male rugby league players, female players have a lower sprint speed, lower muscular strength and a higher body mass index [39]. Therefore, female rugby league matches may be played at a slower speed, cover less total distances and have fewer collisions resulting in less head impacts when compared with male rugby league players. Although there are an increasing number of published studies reporting on the match demands of male rugby league participants, we were unable to find any studies published to date reporting on the match demands of female rugby league players. As a result, the differences in the physiological demands between male and female rugby league players has yet to be identified. Future research is warranted to identify the physiological demands of female rugby league matches.

An interesting finding in this study was that the resultant median PLA (g) recorded was higher in male, when compared with female, amateur rugby league players in all impact locations. However, the resultant median PRA rad/s^2 was higher in the back, side and top of the head in female, when compared with male, amateur rugby league players. This was similar when comparing the total median PLA (g) (14.6 vs. 15.4 *g*) and PRA rad/s^2 (2,886 vs. 2,802 rad/s^2) and the positional groups of female and male amateur rugby league players over the duration of the study. Females experience greater rates of concussion [7], when compared with males, have a greater number and a higher severity of concussion symptoms and require a longer duration to recover [7,40-42]. Rotational accelerations contribute a major role in concussive injuries [43] and the finding that female amateur rugby league players recorded higher median rotational accelerations, when compared with male amateur rugby league players, highlights the biomechanical differences previously reported. This finding highlights the need for gender specific injury prevention programs to assist in reducing the risk of concussion in female sporting environments.

As previously identified, females experience greater rates of concussion [7] and this was similar for the current study where the female rugby league players recorded three concussions (19.3 per 1,000 math hr.) while males recorded one concussive injuries (6.4 per 1,000 match hr.) over the duration of the study period. It has been speculated that this occurs to be due to a variety of reasons [7,44-46] including biomechanical differences [1,7,47-50] between males and females. For example, females reportedly have a lower body mass index, smaller head and neck sizes [1,7,47] and a lower average neck strength [48-50] when compared with males. Other studies have speculated that the differences between the incidence of concussion for males and females may be related to variances in sex hormone levels [7,41,51], dissimilarity in neuroanatomical and neurophysiological functional brain organisation [51], cerebral glucose metabolism, cerebral blood flow [41], and in the reporting of symptoms by females when compared with males [7,44-46]. Some studies describe the potential role of cervical musculature in controlling the heads response to external force application, and in reducing the risk of a concussion occurring [42,52,53]. Given the differences in head and neck sizes and the lower neck strength in females, when compared with males, the ability for females to couple the head to the torso by cervical muscle activation while bracing for an impact is presumed to be lower than that of males [8].

As a result of these differences, it was theorized that, due to the biomechanical differences in females, when compared with males, there would be greater post-impact head velocities and accelerations for a given force [9]. Similar to previous studies [1,7,8,47-50], the findings of our study support the possibility that biomechanical differences contribute to greater head accelerations in females, when compared with males. In addition, it must also be noted that there are differences between our study when comparing with previous studies [1,7,8,47-50] in relationship to the type of sporting environments in which these studies were conducted. For example, the influence of gender specific rules in place for female ice hockey matches result in females participating in a non-contact rule structure and this may have resulted in female players being unprepared for any impacts that occurred resulting in higher impact biomechanics. In contrast, due to the contact rule structure in female amateur rugby league, players train and are prepared for contact and collision impacts during matches. Although the findings of our study support the possibility of biomechanical differences based on head impact biomechanics, other aspects should also be included in future studies such as anthropometric aspects of the head and neck, and the movement demands and physiological responses of male and female rugby league participants at the same level of participation.

In comparing the findings of this study with other head impact studies, it must be noted that there are differences in the proprietary impact-processing algorithms utilized by the xPatch when compared with the Head Impact Telemetry system (HITs) and this has the potential to differentially screen for, and remove, errant impacts from the respective data sets [8]. In addition, the HITs are a helmet-mounted system whereas the xPatch is a skin-mounted system [8]. Both teams wore the xPatch, played in the same district competition, utilized the same xPatch's, the matches were one day apart and the data was analyzed through the same IMS system. The results of this study were compared to other head impact biomechanical studies reporting on male and female comparisons and these were in ice hockey [8,18,25] and lacrosse [19]. Two studies [18,25] recorded the head impacts on a helmet-mounted system while the other studies [8,19] utilised the xPatch skin-mounted system.

Like other studies [8,18,19,25], it was identified that males recorded notably more head impacts during match participation than females. Although the number of impacts per-player per-match was more than that reported in the other studies, the game of rugby league is a collision-based full contact sport and the use of protective hard-shelled helmets is banned. Some players do wear rugby scrum caps made of foam padding encased material, but this is not a mandatory requirement and used primarily to protect the head and ears from cuts and abrasions. Additionally, and as noted previously, female ice-hockey is a non-contact sport, whereas male and female senior rugby league are both full contact sports with no variations in rules and regulations. The higher number of head impacts recorded by males also resulted in higher acceleration magnitudes when compared with females which is similar to a few [18,19,25], but not all [8] previous studies. It has been reported [7,54] that impacts of a greater magnitude have a higher associated risk curve for concussion and females have a higher incidence of concussion but, similar to a previous study [18], this seems counterintuitive given the current results. Although, it is important to note that the incidence of concussion was not recorded for this study. Further research is warranted to identify if the findings of this study are similar to other male and female rugby league participants.

The median PLA(*g*) varied by positional groups with the OSB recording a higher median for both male (15.8*g*) and females (15.5*g*) amateur rugby league players when compared with HUF and ADJ over the duration of the study. The reason for this is unclear but may be related to the role differences between ADJ, HUF and OSB. In studies [55,56] reporting on the movement demands of rugby league players with micro technology, it was identified that the ADJ and OSB covered greater distances than HUF and had greater prolonged high-speed-running during matches [55,56]. This may have been similar in the current study with the possible result being higher collision forces, when compared to lower speed, shorter distance running of the HUF. Further research is warranted to evaluate the correlation between head impact biomechanics and running speed at all levels of rugby league participation.

Impacts to the side of the head were commonly reported in male (n=1,762; 42%) and female (n= 791; 48%) amateur rugby league participants. This is similar to junior [26] and amateur senior [21] rugby union and junior [22] rugby league. The impact side differed in each of the comparison studies with males recording impacts to the front [8], side [18] and back [25] of the head while females recorded impacts to the side [8] and back [18,25] of the head. When viewed by the 95th percentile, female amateur rugby league players recorded the highest PLA(*g*) on the side of the head (32.0*g)* but the highest PRA(rad/s^2) (12,016 rad/s^2) to the back of the head. Male amateur rugby league players recorded the PLA(*g*) on the back of the head (52.3*g*) but the highest PRA(rad/s^2) (10,876 rad/s2) for the front of the head. Impacts to the back of the head were similar to the comparison studies [18,25] reporting on ice hockey with the back of the head recording the highest PLA(*g*) at the 95th percentile. As video analysis was not available to identify what occurred when the impacts were recorded, it is unknown whether the impacts recorded to the back of the head resulted from head-to-head or head-to-ground contact and whether it occurred during or after a tackle was completed. Future head impact research should include video capture to allow for the identification of the impact mechanism to be recorded.

Limitations

The accuracy of the linear and rotational acceleration measurements has been reported to vary widely under different testing environments [29,30,57]. The PRA was found to underestimate in a study utilizing a non-helmeted anthropometric test device but, when utilizing cadaveric model with a helmet, it was reported that the xPatch overestimated PLA(g) and PRA(rad/s^2) when compared with a reference device mounted at the foramen magnum [57]. In addition, the cadaveric model also reported a significant difference in impact location between the xPatch and the reference sensor for forehead impacts but when tested on side and rear impacts the agreement was better [57]. As the xPatch is adhered to the side of the head over the mastoid process there is the potential problem of dermal artefact that can occur with imperfect coupling between the skin patches and the skull causing inaccuracy [29]. As well there may have been some measurement error resulting from relative motion between the skin at the mastoid process and the skull which may have amplified the resultant head impact accelerations.

Another concern that has been reported for the xPatch is the proprietary algorithm utilized to remove errant events from the recorded data set. If these erroneous events are not appropriately identified and removed this can lead to an elevated false-positive rate for the xPatch dataset [58,59]. As the xPatch does not have the ability to detect when they are worn by the athlete there is the risk that the algorithm may include false-positive impacts in the data set recorded from any time the device is turned on until they are switched off [8]. Conversely, there is the potential for the algorithm to identify valid impacts as false negative and exclude these from the data set [8]. The classification of false-positive and false-negative impacts has the potential to influence impact counts and impact magnitude calculations, especially if the rate of false-positive and/or false-negative rates vary over the range of impact magnitudes [8]. As a result, the number of impacts, impact magnitudes and impact locations reported in this study may vary when compared with studies recorded by other impact-sensing devices [8]. Therefore the results of this study should be interpreted cautiously. In an endeavour to reduce the risk of false-positive impacts, all the xPatch's were calibrated to the correct time and following the downloading of the dataset, these were manually reviewed and any impacts outside of the match start and stop times were removed from the data set.

A further limitation to this study was not having multi-angled video footage of the matches to enable correlation between the head impacts recorded and physical contacts that occurred during match participation. As such, the authors are unable to establish whether the impacts were from body contact or from contact with the ground and hence, the results must be interpreted accordingly. Future head impact studies should use high quality multiple angled cameras in an elevated position to enable verification of the impacts recorded. As well, female rugby league matches were played on Sunday's a day after the male rugby league matches and often on the same grounds. As the game of rugby league is played out-door in winter sometimes the condition of the ground playing surface varied. Playing on a softer ground, sometimes muddy, may have also resulted in decreased running speed and this may have resulted in the lower impact frequency and magnitudes reported. Further research is warranted to compare male and female rugby league head impact biomechanics where participants are competing on similar ground conditions. Lastly, the number of concussions reported were not utilized in the analysis.

Conclusion

This study undertook a comparison between male and female amateur rugby league player head impact biomechanics. Although females did record some impact magnitudes higher than males in some categories, they recorded more impacts to the side of the head (48% vs. 41%) and had a higher median resultant PRA to the top of the head, whilst males recorded more impacts and had higher magnitudes for all the parameters reported. Female amateur rugby league players recorded the highest PLA(g) on the side of the head (32.0g) but the highest PRA(rad/s^2) (12,016 rad/s^2) to the back of the head. Male amateur rugby league players recorded the PLA(g) on the back of the head (52.3g) but the highest PRA(rad/s^2) (10,876 rad/s^2) for the front of the head. Although some studies support the possibility that biomechanical differences contribute to greater head accelerations in females, when compared with males, the result of this study does not support this. Other aspects should be included in future studies such as anthropometric aspects of the head and neck and the movement demands and physiological responses of male and female rugby league participants at the same level of participation.

What is known about this subject?

- Concussion incidence rates are higher among female than male athletes in sports played by both genders;
- Biomechanical differences may contribute to the higher incidence of concussion in female athletes;
- Males record more impacts to the head than females;
- Male high school athletes record disproportionately more impacts to the front of the head than female high school athletes

What this study adds to existing knowledge

- This is the first study to undertake head impact comparisons between male and female participants in an intentional collision sport;
- In collision contact sports females recorded a higher percentage of impacts to the side of the head when compared with male collision contact sports participants;

This study supports the possibility of biomechanical differences based on head impact biomechanics, other aspects should also be included in future studies such as anthropometric aspects of the head and neck, and the movement demands and physiological responses of male and female rugby league participants at the same level of participation.

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