HHS Public Access

Author manuscript

J Sci Med Sport. Author manuscript; available in PMC 2021 October 01.

Published in final edited form as:

J Sci Med Sport. 2020 October ; 23(10): 927–931. doi:10.1016/j.jsams.2020.03.008.

Patterns of head impact exposure in men’s and women’s collegiate club water polo

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Abstract

Objectives: Recent reports have demonstrated a risk of concussion and subconcussive head impacts in collegiate varsity and international elite water polo. We sought to characterize patterns of head impact exposure at the collegiate club level of water polo.

Design: Prospective cohort study.

Method: Head impact sensors (SIM-G, Triax Technologies) were worn by men’s (n=16) and women’s (n=15) collegiate club water polo players during 11 games. Peak linear acceleration (PLA) and peak rotational acceleration (PRA) of head impacts were recorded by the sensors. Two streams of competition video were used to verify and describe the nature 0f head impacts.

Results: Men’s players sustained 52 verified head impacts of magnitude 39.7±16.3g PLA and 5.2±3.2 krads/sec^2 PRA, and women’s players sustained 43 verified head impacts of magnitude 33.7±12.6g PLA and 4.0±2.8 krads/sec^2 PRA. Impacts sustained by men had greater PLA than those sustained by women ($p = .045$). Athletes were impacted most frequently at the offensive center position, to the back of the head, and by an opponent’s torso or limb.

Conclusions: Our cohort of male and female athletes sustained relatively infrequent head impacts during water polo competitions played at the collegiate club level. The amount of head impact exposure in our cohort was dependent on player position, with offensive centers prone to sustaining the most impacts. Head impact sensors are subject to large amounts of false positives and should be used in conjunction with video recordings to verify the validity of impact data.

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Keywords

concussion; head injury; head impact sensor; peak acceleration; sex differences

Introduction

Sport-related concussions are common across a wide variety of contact sports.[1] While concussions can lead to devastating neurological consequences,[2] sport-related head impact exposure, aside from any reported symptoms or diagnosis of concussion, is also frequent in contact and collision sports and has been associated with acute and chronic physiological and psychological dysfunction.[3]

Sport-specific rule changes that aim to reduce the risk of head injury[4–6] can be informed by patterns of head impact risk based on player position, sex, and level of competitive game play. Reports in soccer,[7] water polo,[8] and American football[9,10] have found that certain player positions are at a significantly greater risk of sustaining head impacts than other positions in that sport. Greater head impact magnitudes and frequencies have also been observed in male ice hockey athletes, relative to their female counterparts[11,12] and greater head impact frequencies and magnitudes have been observed in the transition from high school to varsity intercollegiate competition in soccer[13] and American football.[10] However, athletes at the collegiate club level, who compete regionally and nationally, but typically without institutional incentives such as scholarships or priority registration, are rarely studied.

Water polo is a rigorous contact sport played extensively in the United States at the collegiate club level.[14] It is a sport that carries a risk of head injury[15,16] and exposes athletes to repeated, subconcussive (i.e., asymptomatic) head impacts.[8,15] In an epidemiological survey of USA Water Polo members, respondents reported sustaining an average 2.27 “serious blows to the head” per game,[15] and an investigation of collegiate varsity men’s water polo found that a single team sustained an average 18.4 head impacts per game.[8] Both investigations reported that water polo players were most commonly impacted on offense, with players in the offensive center position sustaining the most head impacts.[8,15] However, Blumenfeld et al. were unable to draw a conclusion regarding patterns across levels of competition (i.e., Master’s club, College, Highschool). This could be because the survey was designed only to compare lifetime cumulative exposure, such that a Master’s club water polo player would be reporting lifetime exposure, not just their perceived exposure at the Master’s club level.[15] Sex was considered as a factor in both comparisons of head impacts (position, level of competition), but statistically significant differences were not found. Additional prospective investigations during game play are needed to further describe the location and mechanism of head impacts in water polo and to extend these findings to female water polo players and athletes playing at the collegiate club level.

We sought to quantify and compare head impact exposure in one season of men’s and women’s water polo played at the collegiate club level to test two hypotheses. First, we hypothesized that patterns of risk based on player position and game scenario would be consistent, for women and men, with those previously reported by survey[15] and observed at the collegiate varsity level.[8] Second, we hypothesized that men would sustain head impacts

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of greater magnitude and higher frequency than women at the club level. While our second hypothesis contrasts with the finding that women report more concussions than men in collegiate water polo competition,[15] this effect was small-to-moderate (Cohen's d = .37) and could be attributed to sex differences in the tendency to report symptoms.[17] On the other hand, differences in strength and speed between men and women have been suggested to contribute to the greater incidence of time-loss match injuries observed in men at the international level of water polo competition[16] and the greater dose of head impact exposure in men compared to women in other sports in which men and women play by a similar set of rules.[11,12]

Methods

Data Collection:

All members of a men's (n=16) and a women's (n=15) collegiate club water polo team were monitored during one season of intercollegiate competition. Each team played 11 games that were sanctioned by the Collegiate Water Polo Association. All research activities were approved by the Institutional Review Board of the University of California, Irvine, and written informed consent was obtained from all participants. Smart Impact Monitor (SIM-G) sensors (Triax Technologies; Norwalk, CT) were placed in custom Velcro pockets sewn into the back of each water polo cap, according to manufacturer's specifications, to tightly couple the sensor against the occipital protuberance. The SIM-G sensors are capable of recording peak linear acceleration (PLA), via low-g and high-g triaxial accelerometers, and peak rotational acceleration (PRA), via a 3-axis gyroscope, when tightly coupled to the occipital protuberance. Each participant was monitored by a single SIM-G sensor for the duration of the season.

SIM-G sensors relayed time-stamped head impact data to a sideline device. The SIM-G sensors had a recording threshold of 16g, and thus, only impacts registering a PLA of >16g were recorded. These sensors have embedded algorithms aiming (i) to distinguish the nature of accelerative events recorded by the sensor (i.e. 'true' head impacts or non-impact related movements such as voluntary head movement or headgear adjustments) and (ii) to determine where (on the head) the impact was sustained. However, these algorithms have performed poorly under ideal conditions in lab-based evaluations.[18] Therefore, all competitions were recorded from two camera angles, and the videos were later reviewed by research staff to eliminate false positives, confirm impact locations on the head, and identify impact mechanisms and player positions. A sensor was manually triggered by research staff in the view of both cameras at the end of each competition to provide a reference marker for use in synchronization of time stamps recorded by the sensors with the video footage. This allowed for individual accelerative events to be reviewed in the video recordings.

Data Processing:

Six research team members reviewed accelerative events independently. Each game was reviewed by two reviewers. All accelerative events in which a consensus ('head impact', 'false positive') was not reached by independent review were then subjected to group review and discussion, and a decision concerning impact validity was ultimately made by group

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consensus. Accelerative events were only deemed as true head impacts if the reviewers could clearly identify the location and mechanism of head impact. Accelerative events that occurred while an athlete's cap was not securely coupled to his or her head, or the athlete's head could not be seen (e.g., when underwater or out of the view of either camera) were marked as false positives. Independent review was generally indicative of the final group of true head impacts (>85.4% agreement). Accelerative events deemed by the group to be false positives (91.4%) were excluded from further analysis.

To classify head impact location, the head was separated into 5 sections: 4 quartered sections —right, left, front, and back—and a top (i.e., crown) section, defined as a circle around the head at roughly a 45° elevation. Mechanisms of head impact were classified as ball-related or player-related. Player-related impacts were further classified by impact surface: head, limb (arm, hand, leg, foot), or torso. Impacts were further classified by game scenario (offense, defense, transition) and 16 traditionally defined zones consistent with a previous report of head impacts in water polo.[8] Briefly, there is 1 goalie, the only position independent of game scenario, and 15 field positions: 5 perimeter positions and 1 center position on both offense and defense and 3 positions occurring when players are in transition.

Statistical Analysis:

Statistical analyses were performed using SPSS 25 (IBM; Armonk, NY). The null hypotheses that impact frequencies were equally distributed between player positions (n=16), impact locations (n=5), and impact mechanisms (n=4) were tested using a series of independent Chi-square 'goodness-of-fit' tests. Significant differences were decomposed by Chi-square tests of the null-hypothesis that head impacts were equally distributed across head impact locations, mechanisms, or player-by-position groupings and game scenarios based on patterns of risk revealed by Blumenfeld et al.[15] and Cecchi, Monroe, Fote, et al.[8] Bonferroni corrections for multiple comparisons were applied by factor (positions: p-value*6; locations: p-value*5; mechanism: p-value*4); corrected p-values are reported. Cramér's V (φ_c) was computed as an effect size, representing the strength of the association between each fact and frequency of impact exposure, using the following formula:

$$\varphi_c = \sqrt{\frac{X^2}{N(k-1)}}$$

where X^2 is the chi-square test statistic, N is the total number of impacts observed across all levels of the factor, and k is the number of levels of each factor. Separate Kruskal-Wallis analyses were used to test for differences in impact magnitudes (PLA, PRA) between player positions, impact locations, and impact mechanisms. Differences in average PLA and PRA between men and women were tested using separate independent t-tests, and Cohen's d effect sizes are reported.

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Results

A total of 95 verified head impacts (men = 52; women = 43) recorded during 11 men's and 11 women's games were included in the analysis. There was no difference in the number of impacts sustained over the season between men and women [$X^2(1)=1.27$, $p=.3032$, $\varphi_c=.116$]. Head impacts during men's game play averaged 39.7±16.3g PLA and 5.2±3.2 krads/sec^2 PRA and head impacts during women's game play averaged 33.7±12.6g PLA and 4.0±2.8 krads/sec^2 PRA (Fig. 1). On average, head impacts sustained by men resulted in greater PLA [$t(92.609)=2.028$, $p=.045$, Cohens $d=.413$]. Head impacts sustained by men and women did not differ in PRA [$t(93)=1.1902$, $p=.6224$, Cohens $d=.397$].

There was a difference in impact frequencies sustained during game play across all player positions for men [$X^2(12)=75.000$, $p<.001$, $\varphi_c=.347$] and for women [$X^2(14)=53.233$, $p<.001$, $\varphi_c=.297$]. Men sustained no impacts at the 2 and 3 positions on defense; neither men nor women sustained impacts during the sprint. Field players sustained more head impacts on offense than on defense or during transition for both men [$X^2(1)>26.56$, $p<.001$, $\varphi_c>.786$] and women [$X^2(1)>19.00$, $p<.0085$, $\varphi_c>.716$), but impact frequency was no different between defensive and transition positions [$X^2(1)<1.67$, $p>.303$, $\varphi_c<.333$]. Players in the offensive "center" positions sustained more impacts than athletes in the perimeter offensive positions for men [$X^2(1)=34.83$, $p<.001$, $\varphi_c=.970$] and women [$X^2(1)=24.24$, $p<.001$, $\varphi_c=.948$], but the same pattern was not observed on defense [$X^2(1)<1.3$, $p>.4751$, $\varphi_c=.360$]. Impact PRA and PLA did not differ across player positions for men [$p>.687$] or women [$p>.147$]. H ad impact data by player positions are summarized in Table 1.

Impact mechanisms [$X^2(3)>22.615$, $p<.001$, $\varphi_c>.381$] and locations [$X^2(4)>23.860$, $p<.001$, $\varphi_c>.339$] differed in both men and women. Men were impacted more frequently at the back of the head, relative to the front, right, or top [$X^2(1)>14.230$, $p<.003$, $\varphi_c>.620$], and by the opposing player's limb or to so, relative to their head or the ball [$X^2(1)>9.000$, $p<.03$, $\varphi_c>.600$]. Women were impacted more frequently at the back of the head, relative to the front or top [$X^2(1)>9.85$, $p<.03$, $\varphi_c>.615$], and by the opposing player's torso, relative to their head or the ball [$X^2(1)>8.33$, $p<.04$, $\varphi_c>.555$] or the opposing player's limb, relative to the ball [$X^2(1)=12.25$, $p=.006$, $\varphi_c=.875$]. Frequency of head impact locations and mechanisms are summarized in Figure 2a and 2b, respectively. Among men and women, neither impact PRA, nor PLA differed across impact locations [$X^2(4)<6.850$ $p>.144$] or between impact mechanisms [$X^2(3)<4.659$, $p>.199$].

Discussion

In the present study, we sought to characterize the nature of head impacts in one season of men's and women's collegiate club water polo and test two hypotheses. In support of our first hypothesis, we report that men's and women's collegiate club water polo carry a similar risk of head impact that is dependent on player position. Consistent with patterns observed in an epidemiological (retrospective) survey of water polo players[15] and a prospective investigation of collegiate varsity men's water polo players,[8] athletes monitored in this study sustained more impacts on offense than in defense or transition and athletes playing the offensive center position were most susceptible to head impacts. As previously elaborated,

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we believe that this pattern of exposure can be attributed to common water polo strategies that aim to optimize scoring opportunities by directing the ball to the offensive center.[8] Unlike perimeter players, offensive centers face away from their respective defenders, receive the ball while facing away from the goal, and often use their head to create separation from the defender behind them. The risk inherent to this strategy is compounded by a defender's frequent positioning over the offensive center's head and shoulders when attempting to steal the ball or prevent scoring opportunities. This positioning of opposing players could also explain the frequent impacts we observed to the back of the offensive center's head from a defender's limb or torso. Due to the widespread use of these strategies by many teams and leagues, we expect that these patterns are generalizable to other water polo teams competing at the collegiate and elite levels of play. Therefore, it is possible that rule changes that limit or more strictly penalize contact at the center position may aid in reducing the number of head impacts sustained by offensive centers.

Despite the similarities between patterns of head impact exposure in men's and women's collegiate club water polo players and collegiate varsity men's water polo players, the frequency of head impacts in collegiate club athletes was noticeably lower. On average, we observed 4.32 head impacts per collegiate club water polo game and 18.4 head impacts per collegiate varsity game.[8] On one hand, this finding is consistent with studies of soccer[13] and American football[10] in which players have generally been found to sustain more frequent head impacts as a function of increasing skill level, but most of these comparisons are between high school and collegiate athletes and therefore between athletes of different ages. Potential differences in the neurobiological effects of these head impacts between athletes at the same age and stage of development, but playing at different levels of competition (i.e., collegiate club vs collegiate varsity), warrants investigation. However, we cannot rule out the possibility that this stark contrast could be due to an evolution in our approach to head impact verification: in our current report, multiple observers stringently reviewed video of competitions to eliminate false positives, whereas our previously published observations of collegiate varsity players were verified by only one observer, either in real-time or by video review.[8] Notwithstanding these methodological differences, the collegiate club water polo athletes we observed sustained fewer head impacts than both collegiate and high school athletes competing in other contact s orts such as soccer, American football, and ice hockey.[19] In order to accurately relate head impact exposure across other reports of water polo and other sports, studies must employ the same sensor and same methods of head impact verification, so that these methodological differences cannot confound these comparisons.

Differences in the frequency and magnitude of head impacts between men and women have been observed in ice hockey competition, with men sustaining impacts more frequently and of greater magnitude than females.[11,12] We observed only small and statistically non-significant differences in the frequency of head impacts between men and women in our cohort, but in partial support of our second hypothesis we report that impacts sustained by men were associated with moderately greater PLA than those sustained by women (Cohen's d =.413). A similar-sized difference in average PRA was observed between men and women (Cohen's d = .397), but this effect was not statistically significant. We speculate that the similar frequencies of head impacts observed between men and women can be attributed to

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the nearly identical rules governing men’s and women’s water polo and thus similar competitive strategies employed in the men’s and women’s games.

The results of research studies employing head impact sensors have informed the development of testing methodologies for headgears used in contact sports.[20,21] Although none of the athletes we monitored wore protective headgears, the characterization of head impacts in the present study can inform the design of protective water polo headgears and the methods used to test their efficacy. A previous study of protective water polo headgears reported attenuated head impact magnitudes from a ball launched at the front of the head,[22] an impact scenario commonly self-reported in an epidemiological survey of water polo players.[15] However, ball impacts and front impacts were relatively uncommon in this cohort. Therefore, further research is necessary to validate the effectiveness of protective water polo headgears in significantly attenuating the kinds of head impact more frequently observed in this study (i.e., player-to-player interactions resulting in impacts to the rear of the head) before they can be appropriately recommended for use in game play.

Head impact sensors, including the SIM-G, suffer from high false-positive rates and significant amounts of device error.[19] Video verification of sensor accelerative events has become an accepted tool by researchers to address high false-positive rates.[23,24] We used video recordings and multiple raters to eliminate false positives and classify player position, game scenario, and head impact mechanism and location. Agreement between individual raters and the group consensus of impact legitimacy was high, conveying confidence that the frequency and patterns of exposure accurately represent the true nature of head impact exposure sustained in this sample. Head impact exposure quantified using head impact sensors has been associated with physiological and psychological changes in athletes participating in a variety of sports,[3] but whether or not repeated head impacts in water polo players may lead to any physiological dysfunction or neurological sequelae warrants investigation. Although we report head impact magnitudes, sensor inaccuracies preclude the interpretation of these values as indicating head injury risk. These values may only be useful as relative values across cohorts employing the same research methods (i.e., the same sensor and video confirmation techniques).

Conclusion

In summary, collegiate club water polo competition carries a relatively low risk of head impact exposure that is dependent on player position, with offensive centers sustaining the most frequent impacts. Head impacts sustained by male athletes were associated with greater PLA than those sustained by female athletes monitored in this cohort, but patterns of head impact frequency, location, and mechanism were similar between men’s and women’s games at the collegiate club level. Upon replication, the results of this study have the potential to inform possible rule changes to reduce the incidence of head impacts in collegiate club water polo. Comparing the effects of head impact exposure between collegiate athletes competing in contact sports at the club and varsity level may be useful in elucidating individual risk of sport participation on athlete brain health.

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Acknowledgments

This work was supported by the Center for Exercise Medicine and Sport Sciences at the University of California, Irvine and the National Institutes of Health [5T32AR047752-15]. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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Practical Implications

- Offensive centers in collegiate water polo are at a greater risk of sustaining impacts than athletes playing other positions. Changes to water polo rules that limit or more strictly penalize contact between players at the center position may aid in reducing this risk of head impact.
- Head impacts were sustained most frequently to the back of the head and as a result of player-to-player interactions, rather than the ball. Protective water polo headgears should be designed and tested to attenuate the magnitudes of these more commonly observed head impacts.
- Head impact sensors are subject to a high false positive rate. Researchers seeking to relate head impact exposure to clinical outcomes should use these sensors in conjunction with video recordings. These sensors may not be practical for monitoring and managing athletes beyond the research setting.

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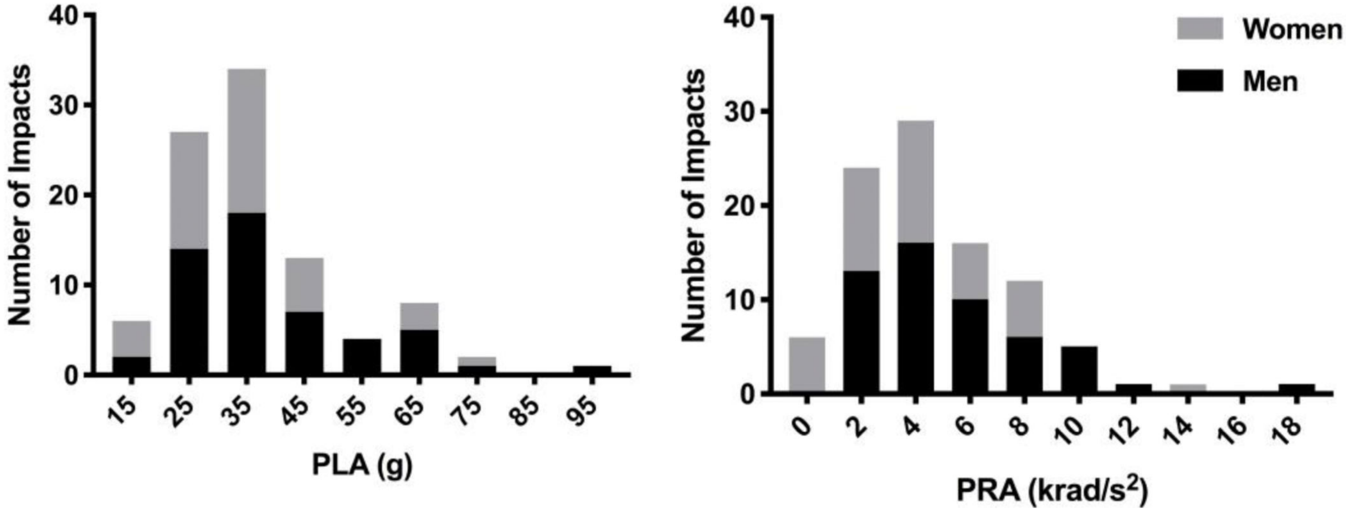

Figure 1.

Frequency distribution of head impacts by magnitude of A) peak linear acceleration (PLA) and B) peak rotational acceleration (PRA) in men (black) and women (gray).

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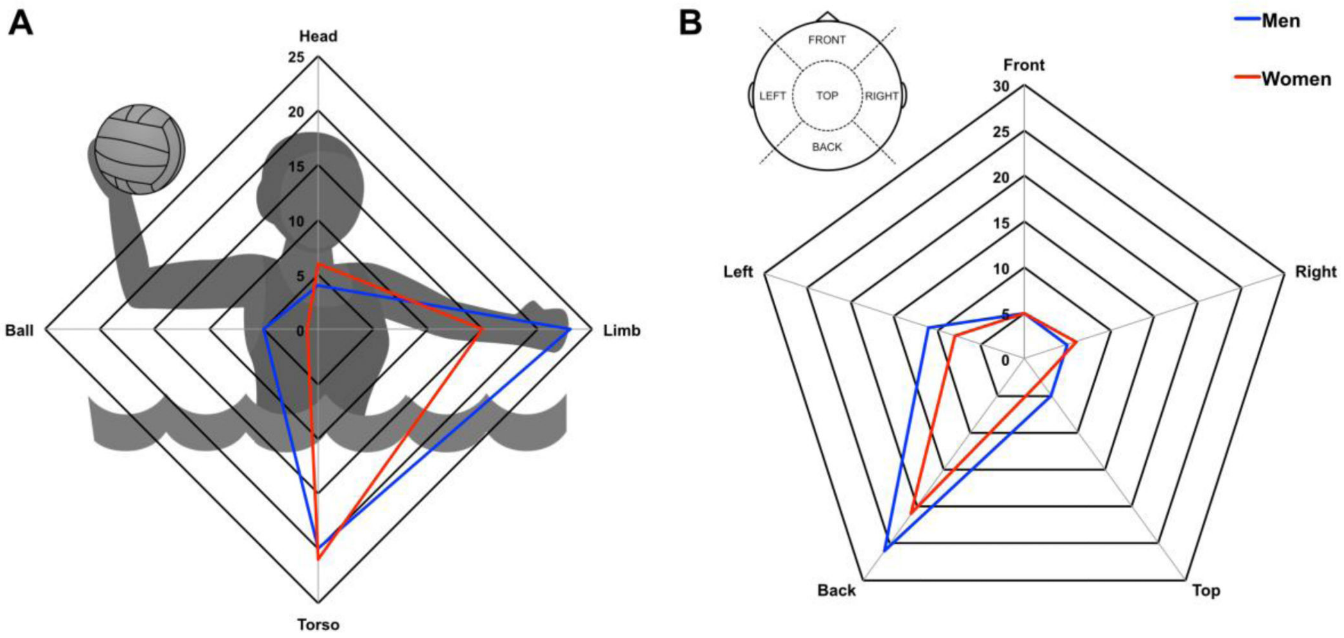

Figure 2.

Total number of head impacts sustained by men’s and women’s water polo players distributed by A) head impact mechanisms and B) head impact locations. Number of impacts is reported on the axes inside each radar chart.

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Table 1:

Summary of Recorded Head Impacts by Player Positions

	Total No. of Head Impacts		**Mean (SD) PLA Per Impact**		**Mean (SD) PRA Per Impact**	
Player Position	***Men***	***Women***	***Men***	***Women***	***Men***	***Women***
Offense	**37**	**27**	**39.7 (17.1)**	**34.7 (13.4)**	**5.3 (3.5)**	**3.8 (2.3)**
1	2	2	37.0 (15.4)	40.1 (29.1)	5.0 (3.0)	5.1 (4.5)
2	4	5	36.3 (6.8)	30.7 (9.3)	6.1 (2.7)	4.5 (2.7)
3	4	1	43.5 (18.1)	35.9	5.2 (3.6)	3.2
4	4	2	39.6 (17.3)	35.9 (11.6)	6.3 (3.7)	3.1 (0.3)
5	3	3	34.5 (28.0)	39.5 (22.0)	4.7 (2.6)	4.1 (3.0)
6	20	14	40.7 (18.6)	34.1 (12.9)	5.0 (4.0)	3.5 (2.3)
Defense	**4**	**10**	**51.0 (23.0)**	**35.0 (12.4)**	**6.2 (1.6)**	**4.5 (3.8)**
1	1	2	26.8	49.6 (14.8)	4.3	5.3 (0.0)
2	0	1	--	42.4	--	3.5
3	0	2	--	23.6 (4.8)	--	2.6 (3.0)
4	1	1	38.6	31.5	5.5	4.8
5	1	1	78.7	28.7	7.9	14
6	1	3	59.9	33.8 (13.1)	6.9	2.2 (1.5)
Transition	**6**	**5**	**33.8 (5.9)**	**25.0 (6.1)**	**4.7 (2.9)**	**4.0 (3.3)**
DO	3	3	33.0 (5.6)	20.8 (2.0)	4.2 (2.7)	2.7 (3.8)
OD	3	2	34.6 (7.4)	31.4 (2.3)	5.3 (3.5)	5.9 (1.9)
Sprint	0	0	--	--	--	--
Goalie	**5**	**1**	**37.6 (10.5)**	**36.5**	**4.4 (2.5)**	**5.6**

DO = Defense-to-Offense

OD = Offense-to-Defense