Differences in the Mechanism of Head Impacts Measured Between Men's and Women's Intercollegiate Lacrosse Athletes

Rachel K. Le,* MS, ATC, Tabitha D. Saunders,* ATC, Katherine M. Breedlove,† PhD, ATC, Debbie A. Bradney,* DPE, ATC, Jill M. Lucas,* PhD, and Thomas G. Bowman,*‡ PhD, ATC

Investigation performed at the University of Lynchburg, Lynchburg, Virginia, USA

Background: Lacrosse is a rapidly growing sport in the United States. Comparing the magnitude and frequency of head impact mechanisms between sexes will provide data for injury prevention techniques and risk reduction of head injuries.

Purpose: To compare sex-specific differences in the magnitude and frequency of head impact mechanisms in National Collegiate Athletic Association (NCAA) Division III intercollegiate lacrosse athletes.

Study Design: Cohort study; Level of evidence, 2.

Methods: A total of 31 NCAA Division III intercollegiate lacrosse athletes (16 men [mean age, 21 ± 1 years; mean height, 179.70 ± 5.82 cm; mean weight, 80.71 ± 6.33 kg] and 15 women [mean age, 20 ± 1 years; mean height, 165.43 ± 5.25 cm; mean weight, 64.08 ± 7.59 kg]) voluntarily participated in this study. Participants wore xPatch sensors at every event during the 2015 spring season. Sensors recorded the magnitude, frequency, and location of head impacts over 10*g*. Linear (*g*) and rotational (deg/s^2) acceleration determined impact magnitudes. We calculated incidence rates (IRs; per 1000 athlete-exposures [AEs]) and incidence rate ratios (IRRs) with 95% CIs to determine frequency differences. Film footage from each event was synchronized with the time of each head impact for verification and mechanism coding. Sex and impact mechanism served as the independent variables.

Results: A significant interaction was found between impact mechanism and sex ($P < .001$) and main effects for impact mechanism ($P < .001$) and sex ($P < .001$). The most common mechanism in men's lacrosse was head to body (IR, 970.55/1000 AEs [95% CI, 266.14-331.98]), and in women's lacrosse, stick to head (IR, 289.87/1000 AEs [95% CI, 124.32-184.55]) was most common. Only 9 of 419 impermissible head impacts in men's lacrosse games were classed as penalties (2%); 7 of 25 impermissible head impacts in women's lacrosse games were called as penalties (28%).

Conclusion: The impact mechanisms of head to body in men's lacrosse and stick to head in women's lacrosse are penalties but occur frequently, suggesting that a focus on stressing rule enforcement is warranted. Because mechanism and sex affect the magnitude of head impacts, proper offensive and defensive techniques against opponents should be encouraged to reduce head impacts.

Keywords: head impact biomechanics; xPatch; head trauma

Sports-related head injuries are a growing concern across varying skill levels in both contact and noncontact sports. An average of 1.6 to 3.8 million head injuries and concussions occur annually in the United States.[15] Impacts to the head can cause cognitive impairment from 24 to 48 hours.[15,22] Short-term impairment can possibly lead to long-term consequences if athletes return to play before cognitive function returns to baseline levels.[7,8,15] Repetitive blows to the head and varying mild traumatic brain injuries may result in long-term neurodegenerative consequences.[7,8,20] To reduce the number of head injuries and traumas documented annually, coaching techniques and rule enforcement in contact and noncontact sports should be rigidly followed.[4-6]

Head impacts have been studied in football and men's ice hockey, which are both sports in which head impacts are permissible within the rules.[7,22] In contact sports, players are more likely to sustain head impacts from intentional mechanisms within legal participation.[7,22] Players in noncontact sports are more likely to sustain head impacts from incidental contact.[7] Previous research[2,11,17,25] has found that different mechanisms altered the magnitude and

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frequency of head impacts in contact sports, such as football and ice hockey, but research determining the mechanisms for head impacts is lacking in men's lacrosse, which falls under the category of a collision sport.

Sports rules and policies are intended to promote the safer mechanics of player-to-player contact during high-collision sports such as football, ice hockey, wrestling, and men's lacrosse.[10] In men's lacrosse, body contact and stick checking are permissible and legal in accordance with the rules and policies.[22] Mechanisms such as body checking below the waist, above the shoulders, and from behind and an avoidable check after clearance plays are illegal, as is head contact with a stick.[22] Men's lacrosse players often sustain head injuries or concussions from intentional player-to-player collision contact during games and practices.[17,22] On the contrary, women's lacrosse players sustain concussive head injuries from incidental contact in practices and games.[17,22] In women's lacrosse, mechanisms such as deliberate body contact, stick slashing, dangerous propelling, or exaggerated follow-throughs are not permitted and are cause for penalties.[22] Although women's lacrosse athletes are protected via a 7-inch imaginary sphere around the head with an aim to preventing blows to the head, impermissible head impacts still occur.[22]

Lacrosse is one of the fastest growing sports in the United States[22]; however, there is limited research regarding the biomechanics of head impacts among this increasing population of lacrosse participants. Lincoln and Lager[17] found that 85% of male and 41% of female collegiate lacrosse athletes sustained brain injuries over 4 seasons of competition. Reynolds et al[23] found that men's and women's lacrosse players sustained more head impacts in games compared with practices, but mechanisms for the impacts were not determined. Further, the mechanisms of intentional and incidental contact against opponents have been shown to alter the magnitude and frequency of head impacts in lacrosse participants.[22] Therefore, the purpose of our study was to compare the magnitude and frequency of head impact mechanisms between men's and women's National Collegiate Athletic Association (NCAA) Division III intercollegiate lacrosse players.

METHODS

Participants

This project was approved by the University of Lynchburg's institutional review board before recruitment. NCAA Division III men's and women's lacrosse players were contacted via email to enroll in the study. A total of 31 lacrosse players (16 men [mean age, 21 ± 1 years; mean height, 179.70 ± 5.82 cm; mean weight, 80.71 ± 6.33 kg] and 15 women [mean age, 20 ± 1 years; mean height, 165.43 ± 5.25 cm; mean weight, 64.08 ± 7.59 kg]) from the 2015 spring season were enrolled in the study and completed informed consent forms.

TABLE 1
Coding Structure for Determining Head Impact Mechanisms

Code	Description
1	Head to head
2	Head to body (other than head to head)
3	Head to ground
4	Stick to head
5	Long stick to head
6	Ball to head
7	Goal to head
8	Combination

Instrumentation

Each participant was numerically assigned an xPatch sensor (X2 Biosystems), which was worn for every game and practice during the 2015 spring season. The xPatch sensor measures the magnitude with linear (g) and rotational (deg/s^2) acceleration, as well as the frequency and location of head impacts.[5] Linear acceleration is defined as the rate of change of velocity in a linear or straight line in a single plane: x, y, z. Rotational acceleration is the rate of change of velocity in multiple planes; it is a vector with movement in at least 2 planes and velocity.[22] According to King et al,[13] activities such as walking, jumping, running, and sitting are considered to be noncontact and are typically under 10g. Most head impacts that occur in sports are greater than 10g.[5] We therefore focused on head impacts over 10g in this study.

Researchers have found that xPatch sensors are useful for making frequency and magnitude comparisons between groups when all participants are wearing the xPatch sensor.[5,27] Further, head-mounted sensors, such as the xPatch, provide an accurate detection of the peak angular acceleration of head impacts compared with other helmet-mounted systems.[6]

Every practice and game was filmed using a Vixia HF R600 camera (Canon). The footage was then downloaded onto a password-protected computer (HP TouchSmart; Hewlett-Packard) that was only accessible to research team members. Every filmed practice and game was later viewed

‡Address correspondence to Thomas G. Bowman, PhD, ATC, Department of Athletic Training, University of Lynchburg, 1501 Lakeside Drive, Lynchburg, VA 24501, USA (email: bowman.t@lynchburg.edu) (Twitter: @TGBowmanATC).

*Department of Athletic Training, University of Lynchburg, Lynchburg, Virginia, USA.

†Department of Kinesiology, University of Michigan, Ann Arbor, Michigan, USA.

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Ethical approval for this study was obtained from the University of Lynchburg.

Figure 1. The xPatch sensor adhered over the right mastoid process.

by 3 research team members to verify the mechanism of each head impact using a standardized coding structure (Table 1).[16] The film included time stamps to facilitate the verification of head impacts from the xPatch sensors. At the end of the season, research team members verified and coded every head impact occurrence. We identified 3012 head impacts during men's lacrosse activities and were able to verify 671 using video analysis. For women's lacrosse, the xPatch recorded 1854 head impacts during the season, and we verified 204.

Procedures

Each lacrosse player who participated was assigned an xPatch sensor to wear over the right mastoid process (Figure 1). Player exposures (participation in 1 event [practice or game]) were also counted daily using a data collection sheet. The sensors were applied using double-sided adhesive patches provided by X2 Biosystems and a barrier spray to prevent skin irritation (Cavilon No Sting Barrier Film; 3M). Sensors were applied approximately 30 minutes before practices and 1 hour before games. Upon completion of the practices or games, sensors were removed from the application site and returned to a research team member. The head impact data obtained from the sensors were downloaded onto the password-protected computer containing Impact Monitoring System software (X2 Biosystems), which collected and stored cumulative data. Once impacts were uploaded onto the software system, we then cleared the impacts from each xPatch sensor and returned all sensors to the dock to be charged.

Statistical Analysis

We analyzed the frequency of head impacts across impact mechanisms and sexes by calculating incidence rates (IRs; per 1000 athlete-exposures [AEs]) and incidence rate ratios (IRRs; game IR/practice IR) with corresponding 95% CIs.[14,19] We defined an athlete-exposure as participation in a practice or game for any amount of time. In addition, we separated exposures between practices and games. The independent variables consisted of sex and mechanism, and the dependent variables consisted of the frequency and magnitude (linear and rotational acceleration) of head impacts. We analyzed linear and rotational acceleration using multivariate analysis of variance (MANOVA), and assumptions were met using the Wilks lambda. We also followed up significant findings with analyses of variance (ANOVAs). We further used Bonferroni post hoc tests to identify any pairwise magnitude differences due to mechanism. Calculations were performed using SPSS (version 23; IBM) and Excel 2013 (version 15; Microsoft). We set the α value to $P = .05$ a priori.

RESULTS

Head Impact Frequencies

A total of 671 head impacts were verified during 1060 combined game and practice exposures in men's lacrosse (IR, 633.02/1000 AEs [95% CI, 585.12-680.92]). Of these, 433 head impacts were verified from 270 game exposures (IR, 1603.70/1000 AEs [95% CI, 1452.65-1754.76]), and 238 head impacts were verified from 790 practice exposures (IR, 301.27/1000 AEs [95% CI, 262.99-339.54]; IRR, 5.32 [95% CI, 4.54-6.24]). In women's lacrosse, 204 head impacts were verified across 654 combined game and practice exposures (IR, 311.93/1000 AEs [95% CI, 269.12-354.73]). Women's lacrosse players had 28 verified head impacts from 99 game exposures (IR, 282.82/1000 AEs [95% CI, 178.07-387.59]) and 176 verified head impacts from 555 practice exposures (IR, 317.12/1000 AEs [95% CI, 270.27-369.97]; IRR, 0.89 [95% CI, 0.75-1.67]). Across all events, men's lacrosse players were more likely to sustain head impacts than women's lacrosse players (IRR, 2.03 [95% CI, 1.74-2.37]) (Table 2).

Across men's lacrosse events, head to body was the most common mechanism (Figure 2), while stick to head was the most common mechanism during women's lacrosse play (Figure 3). In men's lacrosse games, of the 419 head impacts that should have been called penalties, only 9 (2%) were actually called. In women's lacrosse games, of the 25 head impacts verified as mechanisms that should have been called penalties, only 7 (28%) were acually called.

Head Impact Magnitudes

MANOVA results showed a significant interaction between mechanism and sex across the combined dependent variables (multivariate $F_{8,1194} = 3.659, P < .001, \eta^2 = .024$) and main effects for mechanism (multivariate $F_{16,1194} = 3.853$, $P < .001$, $\eta^2 = .049$) and sex (multivariate $F_{2,597} = 8.212$, $P < .001$, $\eta^2 = .027$). ANOVA results revealed significant interactions for both linear ($F_{4,598} = 4.474$, $P = .001$, $\omega^2 =$

TABLE 2
IRs and IRRs Based on Common Mechanisms Across Sexes and Events[a]

Mechanism	Men					Women				
	Practice Impact, n	Practice IR	Game Impact, n	Game IR	IRR	Practice Impact, n	Practice IR	Game Impact, n	Game IR	IRR
Head to head	12	15.19	33	122.22	8.05	1	1.80	0	—	—
Head to body	85	107.59	233	862.96	7.98	80	144.14	12	121.21	0.84
Head to ground	9	11.39	13	48.15	4.23	2	3.60	3	30.30	8.41
Stick to head	114	144.30	153	566.67	3.93	88	158.56	13	131.31	0.83
Ball to head	10	12.66	0	—	—	5	9.01	0	—	—
Goal to head	3	3.80	0	—	—	0	—	0	—	—
Combination	5	6.33	1	3.70	4.58	0	—	0	—	—
Total	238	301.27	433	1603.70	5.32	176	317.12	28	282.82	0.89

[a]Incidence rate (IR) calculated per 1000 athlete-exposures. Incidence rate ratio (IRR) = game IR/practice IR.

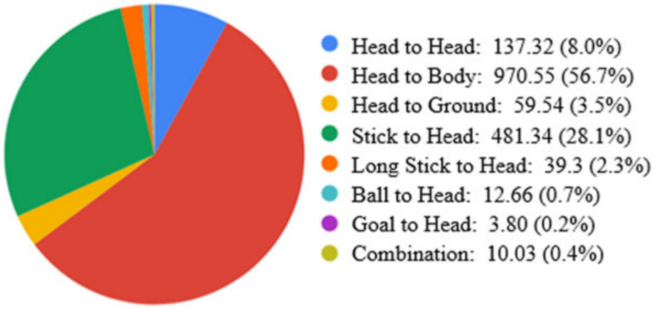

Figure 2. Incidence rates per 1000 athlete-exposures across head impact mechanisms in men's lacrosse events.

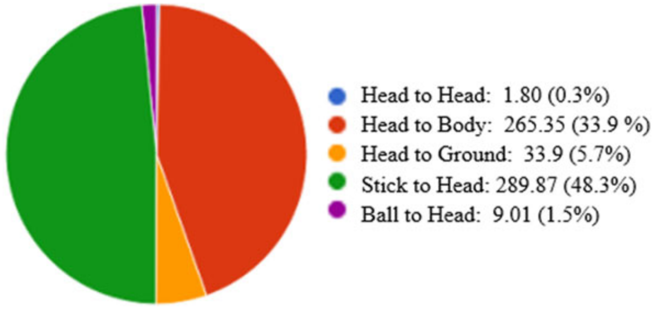

Figure 3. Incidence rates per 1000 athlete-exposures across head impact mechanisms in women's lacrosse events.

.004) and rotational acceleration ($F_{4,598} = 4.178$, $P = .002$, $\omega^2 = .007$). Further ANOVAs resulted in a significant main effect for sex for linear ($F_{1,598} = 16.392$, $P < .001$, $\omega^2 = .025$) and rotational acceleration ($F_{1,598} = 8.319$, $P = .004$, $\omega^2 = .013$) (Figure 4). Among common mechanisms, women had higher mean linear and rotational acceleration for head to head, head to ground, and ball to head. There were also significant main effects for mechanism for linear ($F_{8,598} = 3.608$, $P < .001$, $\omega^2 = .006$) and rotational acceleration ($F_{8,598} = 3.805$, $P < .001$, $\omega^2 = .006$). Bonferroni post hoc tests revealed no significant pairwise differences between mechanisms.

In men's lacrosse across combined games and practices, head to head produced the highest mean linear acceleration (25.150*g* [95% CI, 21.093*g*-29.188*g*]). In men's lacrosse games, long stick to head produced the highest peak linear acceleration of 161.74*g*. The mechanism coded as combination produced the highest mean rotational acceleration (274,913.317 deg/s^2 [95% CI, 156,353.306-393,473.327 deg/s^2]). In men's lacrosse games, head to ground produced the highest peak rotational acceleration of 893,767.000 deg/s^2. In women's lacrosse for both games and practices, head to head produced the highest mean linear acceleration (77.203*g* [95% CI, 50.053*g*-104.353*g*]). In women's lacrosse practices, head to body produced the highest peak linear acceleration of 92.484*g*. Head to head also accounted for the highest mean rotational acceleration of 487,200.000 deg/s^2 (95% CI, 196,788.470-777,611.530 deg/s^2). In women's lacrosse practices, ball to head created the highest peak rotational acceleration of 845,893.000 deg/s^2 (Figure 4).

DISCUSSION

Our purpose in this study was to compare the magnitude and frequency of head impact mechanisms between men's and women's lacrosse athletes. In women's lacrosse, we found that the most common mechanism of head impacts was stick to head across both events. This finding is similar to previous studies. Both Lincoln and Lager[17] and Putukian et al[22] found that the most common mechanism of head injuries is incidental stick to head contact in girl's youth and women's intercollegiate lacrosse players. In a study by Matz and Nibbelink,[18] stick to head was also found to be the most common mechanism of head injuries in collegiate women's lacrosse athletes. In women's lacrosse, the ball is cradled in front of the face near the head during possession.[1,18] Defenders will stick check near this area to knock the ball loose to gain possession of the ball. A restricted 7-inch sphere around the head is mandated by rule to protect against stick-to-head contact.[1] Our findings indicate that officials should enforce the rule of "checking

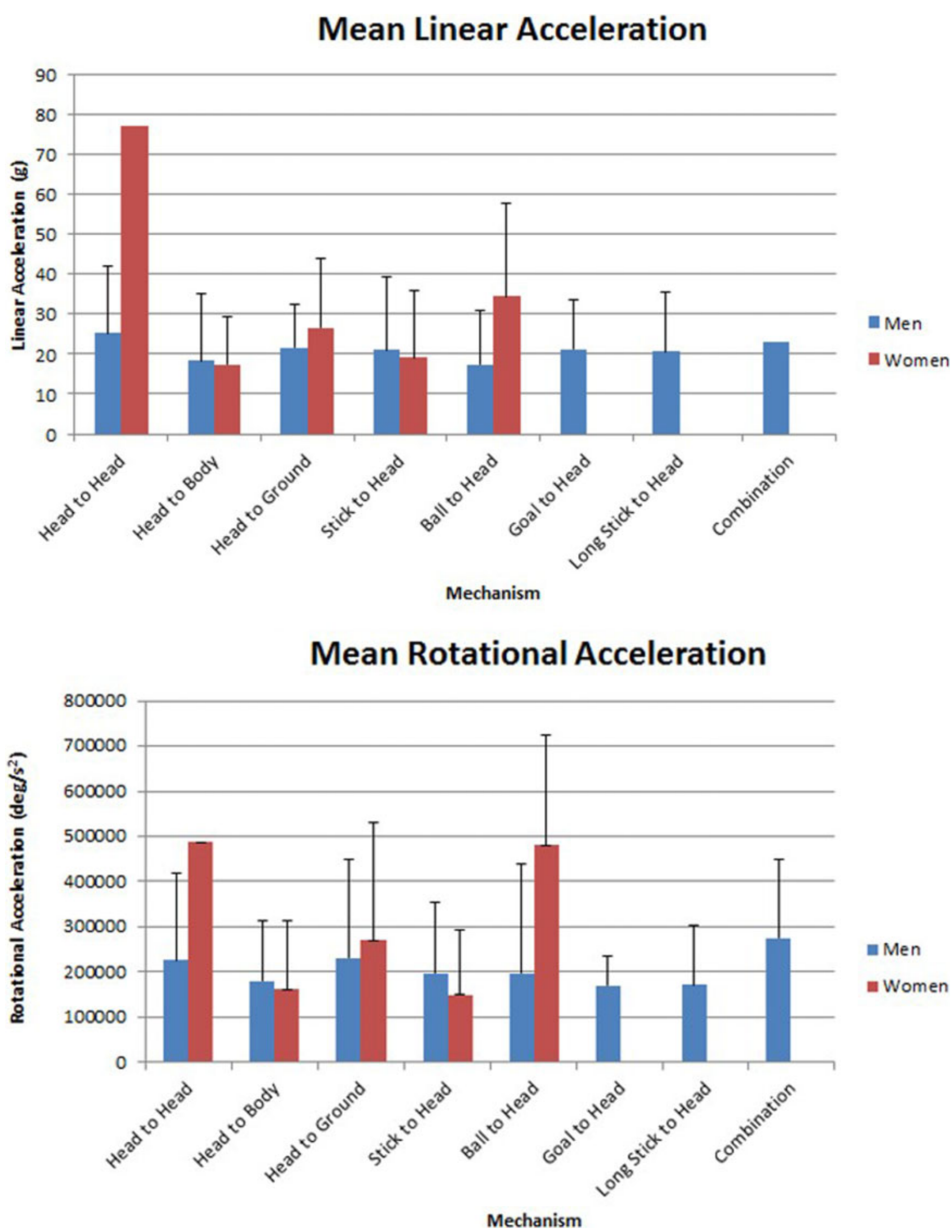

Figure 4. Magnitude across mechanisms in men's and women's lacrosse games and practices.

into the sphere" during games, as stick to head contact commonly occurs from defenders to attackers when advancing to the goal to shoot.

In a study by Wilcox et al,[26] men's collegiate ice hockey players sustained more head impacts during contact with another player in comparison with other mechanisms. In our study, head to body was the most common mechanism in men's lacrosse, which closely relates to the mechanism found in men's collegiate ice hockey players. In men's lacrosse, similar to women's lacrosse, possession of the ball is maintained by cradling near the head and face.[5] Stick checking above the shoulder to gain possession of the ball is impermissible and discouraged via penalties.[22] Leading with the head to initiate deliberate contact to gain or maintain possession of the ball is also an illegal mechanism.[17] Perhaps stiffer penalties or more consistent enforcement of penalties would further discourage contact with the head during women's and men's lacrosse activities. However, stricter enforcement of the rules may not decrease illegal contact during practices.

Covassin et al[4] also found that intercollegiate lacrosse players had higher IRs of sustaining head injuries in games than practices. However, in previous studies,[9,10,14,21,24] there has been limited research studying the magnitude and frequency of head impacts based on the impact mechanism, which is a potentially important factor to consider when studying head impacts and contemplating steps to reduce the risk of head injuries.

Head-to-head impacts in intercollegiate male ice hockey players have registered a mean linear acceleration of 26.4*g* with a peak linear acceleration recorded at 28.0*g*.[26] In our study, we found that head-to-head contact produced the highest mean linear acceleration for men's lacrosse players (25.150*g* [95% CI, 21.093*g*-29.188*g*]), which was similar to the linear acceleration in ice hockey players with the same mechanism. However, previous studies[16,22,24] did not reach the same conclusions as our results. We found that head-to-head contact produced the highest mean linear acceleration of 77.203*g* (95% CI, 50.053*g*-104.353*g*) and also accounted for the highest mean rotational acceleration of 487,200.000 deg/s^2 (95% CI, 196,788.470-777,611.530 deg/s^2) during women's lacrosse.

Because this research provides evidence that frequency and magnitude are dependent on the impact mechanism, athletes should be taught to modify their behavior when being hit or checking opposing players to ensure the proper technique within the rules. Coaches should attempt to eliminate illegal hits or checks during practices to reduce the frequency of head impacts. In a study by Kerr et al,[12] youth football athletes participated in the Heads Up Football (HUF) program, which included proper tackling techniques, concussion awareness, and strategies for reducing player-to-player contact. The researchers concluded that youth football players had fewer head impacts in practices where the HUF program was implemented compared with practices that did not have the program implemented.[12] Wasserman et al[25] also found that implementing playing behavior interventions in high school football athletes decreased the magnitude of head impacts. In addition, the football athletes and coaches recognized an improvement in playing behavior and safety.[25] These findings suggest that similar interventions may be able to modify player and coach behavior in other sports, such as lacrosse. Implementing prevention plans and encouraging proper techniques may reduce head impacts in practices and ultimately games. Officials should also stress limiting impacts to the head by enforcing rules and calling penalties in an effort to prevent occurrences of trauma to the head.[7,8] If increased emphasis on penalizing impacts to the head does not reduce their frequency, perhaps the penalties need to be stiffer.

Interventions to limit head impacts and techniques to improve player-to-player contact should be enforced, although the protective equipment worn by lacrosse athletes may also play an important role in minimizing the injury risk. The purpose of protective equipment such as helmets and padding is to dissipate and distribute energy from direct blows.[9,16] In men's lacrosse, all players wear gloves, combined chest and shoulder pads, elbow protection, helmets, and mouthguards.[13,16] Women's lacrosse field players only wear protective eye goggles and mouthguards, while goalies wear helmets, mouthguards, and full chest and thigh pads.[16] There is a growing concern with the lack of head protection in women's lacrosse in relation to impact mechanisms and occurrences of head impacts.[9]

Putting helmets on women's lacrosse athletes may encourage contact based on the Peltzman effect.[21] For example, there is some evidence to suggest that hockey players who wear extra face protection play more aggressively and earn more penalty minutes than those who wear less face protection.[5] However, head protection may be considered if stricter rule enforcement is not implemented because head impacts are occurring currently, despite being illegal. During men's lacrosse games in this study, penalties were issued for only 9 (2%) head impacts, suggesting that 98% of head impacts should have been deemed a penalty. Of those penalty-issued impacts, 4 were verified as head to body, 2 as stick to head, 2 as head to head, and 1 as long stick to head, all of which are considered impermissible mechanisms in men's lacrosse. During women's lacrosse games, only 7 (28%) head impacts verified as being due to impermissible mechanisms were issued a penalty, suggesting that 72% of head impacts should have been deemed a penalty. Five of the penalty-issued impacts were stick to head, 1 was head to ground, and 1 was head to body.

In a study by Reynolds et al,[23] both men's and women's lacrosse athletes sustained more head impacts in games than practices. Similarly, in our study, women's lacrosse athletes sustained more head impacts during games compared with practices. However, it is interesting to note that the disparity was much lower for the women compared with the men. We suspect that this difference is caused by the fact that most women's lacrosse head impacts occur because of incidental contact that likely is not affected by the event type (game vs practice). We speculate that during men's practices, more time is spent on skill development, in which head impacts are unlikely to occur compared with games. In addition, men's lacrosse has a significantly higher number of AEs, which may contribute to a higher cumulative effect of repetitive head impacts. It is important to note that our IRs for head impacts (633.02/1000 AEs for men; 311.93/1000 AEs for women) are much lower than those reported by Reynolds et al[23] (games: 11.5 for men, 9.2 for women; practices: 3.1 for both men and women). We believe that this is because we verified head impacts based on video analysis and time synchronization, which is a step that reduces false-positive impact readings.[3]

Limitations and Further Research

This study has several limitations to consider that may have influenced the results. For this study, only NCAA Division III lacrosse players at a single institution participated, providing a relatively small sample size compared with some other studies, especially those studying football teams, which typically have much larger roster sizes. Higher levels of lacrosse, such as NCAA Division I institutions, may have participants who are faster or bigger in size, which may alter head impact susceptibility and/or biomechanics. In addition, officiating may be different between NCAA levels, which also may contribute to head impact frequency and/or magnitude. Generalizing our results to other levels of play, including youth teams, other collegiate levels, and professional leagues, is inappropriate. Future studies should investigate head impacts among these groups to determine the head impact risk. We believe that it is important to further understand how head impact magnitude and frequency may affect brain function, especially for subconcussive blows. Further research should compare baseline test results of cognitive function before versus after participation while tracking head impacts over a season or career. Finally, we used the xPatch to collect our data, and differences in measurement accuracy need to be taken into consideration when comparing our results with those of others who used different head impact measuring tools.

CONCLUSION

This study introduced a method of measuring the frequency and magnitude of head impacts during athletic events using sensors on lacrosse players. We were able to find significant differences between sexes and across mechanisms with our combined dependent variables (linear and angular acceleration). We also found frequency differences between the sexes and across mechanisms. In both men's and women's lacrosse, the most common impact mechanisms that we found were illegal but rarely penalized. Stressing fouls and awarding penalties for illegal checking or hits in games may encourage participants to avoid impacts to the head. We encourage officials to closely monitor game play and penalize illegal checking or hitting. During practices, coaches should encourage players to avoid illegal hitting and checking mechanisms against teammates.

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