Original Research

The Effects of Headgear in High School Girls' Lacrosse

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Background: Girls' lacrosse headgear that met the ASTM International performance standard (ASTM F3137) became available in 2017. However, the effects of headgear use on impact forces during game play are unknown.

Purpose: To evaluate potential differences in rates, magnitudes, and game-play characteristics associated with verified impacts among players with and without headgear during competition.

Study Design: Cohort study; Level of evidence, 3.

Methods: A total of 49 female high school participants (mean age, 16.2 ± 1.2 years; mean height, 1.66 ± 0.05 m; mean weight, 61.2 ± 6.4 kg) volunteered for this study, which took place during the 2016 (no headgear; 18 games) and 2017 (headgear; 15 games) seasons. Wearable sensors synchronized with video verification were used. Descriptive statistics, impact rates, and chi-square analyses described impacts and game-play characteristics among players with and without headgear. Differences in mean peak linear acceleration (PLA) and peak rotational velocity (PRV) between the no headgear and headgear conditions were evaluated using a linear generalized estimating equation regression model to control for repeated within-player measurements.

Results: Overall, 649 sensor-instrumented player-games were recorded. A total of 204 impacts $\geq 20g$ recorded by the wearable sensors were verified with video analysis (102 no headgear; 102 headgear). Most impacts were imparted to the player's body (n = 152; 74.5%) rather than to the player's head (n = 52; 25.5%). Impact rates per player-game did not vary between the no headgear and headgear conditions (0.30 vs 0.34, respectively; impact rate ratio, 0.88 [95% CI, 0.37-2.08]). There was no association between impact frequency by mechanism or penalties administered between the no headgear and headgear conditions for overall or direct head impacts. The generalized estimating equation model estimated a significant reduction in mean impact magnitudes overall (PLA: –7.9*g* [95% CI, –13.3 to –2.5]; PRV: –212 deg/s [95% CI, –359 to –64]) with headgear relative to no headgear. No game-related concussions were reported during this study.

Conclusion: Lacrosse headgear use was associated with a reduction in the magnitude of overall impacts but not a significant change in the rate of impacts, how they occur, or how penalties were administered for impacts sustained during competition. Further research is needed with a larger sample and different levels of play to evaluate the consequences of headgear use in girls' lacrosse.

Keywords: helmets; women's lacrosse; effectiveness

Girls' lacrosse is the fastest growing team sport among National Federation of State High School Associations (NFHS) member schools in the United States.[20,30] Concurrent with its increasing popularity is a greater reporting of head injuries.[3,12,17] Although girls' lacrosse is an incidental contact sport, recent studies incorporating sensor technology and video surveillance have characterized head impacts[6] and head injuries.[5] These concerns have contributed to the recent development of interventions to reduce this risk of injury in girls' lacrosse.

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Most concussions in girls' lacrosse occur during games from stick or ball impacts.[5,6] To help mitigate this threat, a performance standard (ASTM F3137) for girls' lacrosse headgear was developed to reduce game-related impacts in non-goaltending field players.[1] The headgear became commercially available in 2017 as optional equipment according to US Lacrosse and NFHS rule books.[33] The specification indicates that the use of lacrosse headgear meeting the ASTM International performance standard may decrease the severity of impacts from a stick, the ball, another player, the ground, or other objects.[1] Protective equipment (eg, helmets) in sports other than lacrosse has been shown to reduce head impact magnitudes and the number of head and facial injuries.[10,16]

Considerable debate exists among the lacrosse community regarding the intended benefits and potential adverse consequences of women's lacrosse headgear.[24,28,31] Advocates propose that headgear use will decrease the severity of impacts and reduce the risk of injury.[32] Opponents allude to the Peltzman effect,[23] first coined in automobile safety research, which argues that when increased safety measures are implemented, at least some of their benefits will be offset by increased risky behavior. Similarly, headgear opponents predict that any benefits of headgear will be counteracted by more aggressive game-play and risk-compensation behaviors by players.[25] Yet, the novelty of women's lacrosse headgear, coupled with a lack of rigorous research, has hampered the ability to inform policy makers and health care providers regarding appropriate recommendations about headgear for general sport use. Therefore, the primary aim of the study was to determine whether differences in the rates and magnitudes of impacts to the head and other areas of the body occurred in players with and without headgear during competition. The secondary aims were to determine if the distribution of impact mechanisms and penalties called for impacts were different with the introduction of headgear.

METHODS

Study Sample

Data were prospectively gathered from field players participating on 1 girls' high school varsity lacrosse team (N = 49; mean age, 16.2 ± 1.2 years; mean height, 1.66 ± 0.05 m; mean weight, 61.2 ± 6.4 kg) over the 2016 and 2017 spring seasons. In 2016 (18 games), no field players wore headgear; this constituted the no headgear condition. In 2017 (15 games), players wore the Women's LX Headgear (Cascade Lacrosse), meeting the ASTM International performance standard[1]; this constituted the headgear condition (Figure 1). The goalie position was not included in this study, as players in this position wore a boys' lacrosse helmet during both study years. Written informed parental consent and participant assent were obtained for all participants. This study was approved by an institutional review board.

Figure 1. (A) Front and (B) lateral views of lacrosse headgear and wearable sensors affixed behind the ear.

Measures

In each year of the study, all participants were instrumented with wearable sensors (X2 Biosystems) affixed to the right mastoid process before each game. A trained member of the research team using a high-definition camcorder (XA10 HD; Canon) digitally recorded all competitions. All game-related impacts recorded by the sensors were verified on video. Similar to prior research,[4,6,9,19] we limited our analyses to impacts $\geq$20*g* to remove low-acceleration events (10-19*g*) commonly associated with normal and expected physical activities of game play (eg, jumping, hard stops, cuts, etc) and unlikely to result in deleterious neurophysiological changes. Consistent with prior research,[4,6,9,15] an impact was verified if the following criteria were met: (1) linear acceleration $\geq$20*g*, (2) player was identified on the field, (3) player was in the camera's view, and (4) the impact mechanism could be clearly identified.

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Statistical Analysis

Descriptive statistics (frequency, median, and interquartile range) for impact characteristics of peak linear acceleration (PLA) and peak rotational velocity (PRV) were calculated to accommodate for skewed impact data[21] for all verified game impacts by headgear condition (no headgear vs headgear). Verified impacts were further characterized as "body impacts" or "head impacts." Body impacts were defined as verified impacts in which the initial location of contact was to the instrumented player's body and resulted in a measured head impact $\geq 20g$. Head impacts were defined as verified impacts in which the initial location of contact was to the instrumented player's head. Game-related mechanisms of impact were described, consistent with prior research by headgear condition.[4,6,9]

Impact Rates, Mechanisms, and Penalties. Impact rates (IRs) were calculated as the number of verified impacts divided by the number of player-games, as consistent with prior literature.[4,6,9] The formula was as follows:

$$IR = \frac{\Sigma \text{ verified impacts} \geq 20g}{\Sigma \text{ player} - \text{games}}.$$

Corresponding 95% CIs were calculated using a sandwich covariance estimator.[8,22] Impact rate ratios (IRRs) compared IRs between the no headgear and headgear conditions. The IRRs with 95% CIs excluding 1.00 were considered statistically significant.

To evaluate potential changes in game play associated with headgear use, chi-square tests were used to examine the proportion of impact mechanisms and penalties administered between headgear conditions. Consistent with prior research,[4,6,9] the distribution of impact mechanisms (eg, stick, ball, body, or ground) was compared by headgear condition. We included all penalties referenced in the US Lacrosse and NFHS girls' lacrosse rule books[2] that were the result of the impact and also shown on video.

Impact Magnitudes. Differences in mean magnitudes for body and head impacts between headgear conditions were evaluated using a linear generalized estimating equation regression model to control for repeated within-player measurements.[34] This model provided estimated 95% CIs for the mean differences in PLA and PRV by headgear condition. All analyses were conducted using R (Version 3.6.2; R Core Team).[26]

RESULTS

Across the 2 seasons, there were 649 (n = 345 in 2016; n = 304 in 2017) sensor-instrumented player-games. A total of 229 impacts $\geq 20g$ were recorded by the wearable sensors. Of these, 209 (91.3%) impacts were able to be observed on video; 5 (2.4%) of these impacts (no headgear: 2 impacts; headgear: 3 impacts) were determined to not occur during game play (ie, postgoal celebrations) and were excluded from our analyses. In total, 204 (89.1%) impacts $\geq 20g$ recorded by the wearable sensors were verified as game-related impacts using video analysis (no headgear: 102 impacts; headgear: 102 impacts) and were included in our analyses.

Comparison of Headgear Conditions

IRs, Mechanisms, and Penalties. Overall, the IR was 0.31 per player-game (95% CI, 0.18-0.53). Most impacts were imparted to the player's body (n = 152; 74.5%) rather than to the player's head (n = 52; 25.5%). The most common impact mechanisms were contact with a player (n = 109; 53.4%) and then a stick (n = 82; 40.2%), followed by the ground (n = 9; 4.4%) and the ball (n = 4; 2.0%). The majority of impacts did not result in a penalty (n = 155; 76.0%). Of note, no game-related concussions were reported during this 2-year study.

IRs did not vary significantly between the no headgear and headgear conditions for overall impacts (0.30 vs 0.34, respectively; IRR, 0.88 [95% CI, 0.37-2.08]) or body impacts (0.21 vs 0.26, respectively; IRR, 0.84 [95% CI, 0.35-2.00]). Additionally, the rates for impacts directly striking the head were the same between headgear conditions (IR, 0.08 for both; IRR, 1.03 [95% CI, 0.39-2.71]).

There was no association between the proportions of impacts by mechanism between the no headgear and headgear conditions for overall ($\chi^2[3] = 0.98$; $P = .81$), body ($\chi^2[3] = 0.57$; $P = .90$), or direct head ($\chi^2[3] = 0.27$; $P = .97$) impacts. Often, impacts sustained by players did not result in a penalty by game officials (no penalty: n = 155 [76.0%] vs penalty: n = 49 [24.0%]). There was no association between headgear condition and the frequency of penalties administered for overall ($\chi^2[1] = 0.25$; $P = .62$), body ($\chi^2[1] = 0.45$; $P = .50$), or direct head ($\chi^2[1] = 0.36$; $P = .55$) impacts. Table 1 presents the frequencies and rates of overall, body, and head impacts by headgear condition, location, mechanism, and penalties administered.

Impact Magnitudes. The median PLA and PRV for all verified impacts were 26.4*g* and 1452 deg/s, respectively (Figure 2). A summary of unadjusted median impact magnitudes by headgear condition, location, mechanism, and penalties administered is presented in Table 2. Results of the generalized estimating equation model estimated a significant reduction in mean impact magnitudes for overall (PLA: –7.9*g* [95% CI, –13.3 to –2.5]; PRV: –212 deg/s [95% CI, –359 to –64]) and body (PLA: –8.5*g* [95% CI, –13.3 to –3.6]; PRV: –287 deg/s [95% CI, –454 to –120]) impacts with headgear relative to no headgear. The model indicated no significant differences in PLA (–1.9*g* [95% CI, –17.9 to 14.2]) or PRV (93 deg/s [95% CI, –259 to 444]) for those impacts directly striking the head. See Figure 3 for the adjusted model. Overall, 83.2% of the highest-magnitude impacts ($\geq 49.6g$; >90th percentile of PLA) were incurred with no headgear (n = 16), while 4 such impacts (16.8%) were observed with headgear.

DISCUSSION

Girls' lacrosse headgear meeting the ASTM International performance standard became commercially available in 2017. The headgear is designed to mitigate the severity of impacts from a stick, the ball, other players, the ground, or other objects.[1] The present study is the first to characterize impacts in girls' lacrosse game play before and after

TABLE 1
Frequencies and Rates for Verified Impacts[a]

	No Headgear		Headgear		Overall	
	n (%)	IR (95% CI)	n (%)	IR (95% CI)	n (%)	IR (95% CI)
Location						
Body	74 (72.5)	0.21 (0.13-0.36)	78 (76.5)	0.26 (0.13-0.52)	152 (74.5)	0.23 (0.14-0.40)
Head	28 (27.5)	0.08 (0.04-0.15)	24 (23.5)	0.08 (0.04-0.16)	52 (25.5)	0.08 (0.05-0.14)
Mechanism						
Ball	2 (2.0)	0.01 (0.00-0.02)	2 (2.0)	0.01 (0.00-0.04)	4 (2.0)	0.01 (0.00-0.02)
Stick	41 (40.2)	0.12 (0.06-0.24)	41 (40.2)	0.13 (0.07-0.27)	82 (40.2)	0.13 (0.07-0.22)
Player	55 (53.9)	0.16 (0.09-0.27)	54 (52.9)	0.18 (0.09-0.36)	109 (53.4)	0.17 (0.10-0.29)
Ground	4 (3.9)	0.01 (0.00-0.03)	5 (4.9)	0.02 (0.00-0.06)	9 (4.4)	0.01 (0.01-0.03)
Penalty						
No	74 (72.5)	0.21 (0.13-0.35)	81 (79.4)	0.27 (0.14-0.51)	155 (76.0)	0.24 (0.15-0.39)
Yes	28 (27.5)	0.08 (0.04-0.16)	21 (20.6)	0.07 (0.03-0.17)	49 (24.0)	0.08 (0.04-0.15)
Total	102 (100.0)	0.30 (0.18-0.49)	102 (100.0)	0.34 (0.17-0.67)	204 (100.0)	0.31 (0.18-0.53)

[a]IR, impact rate.

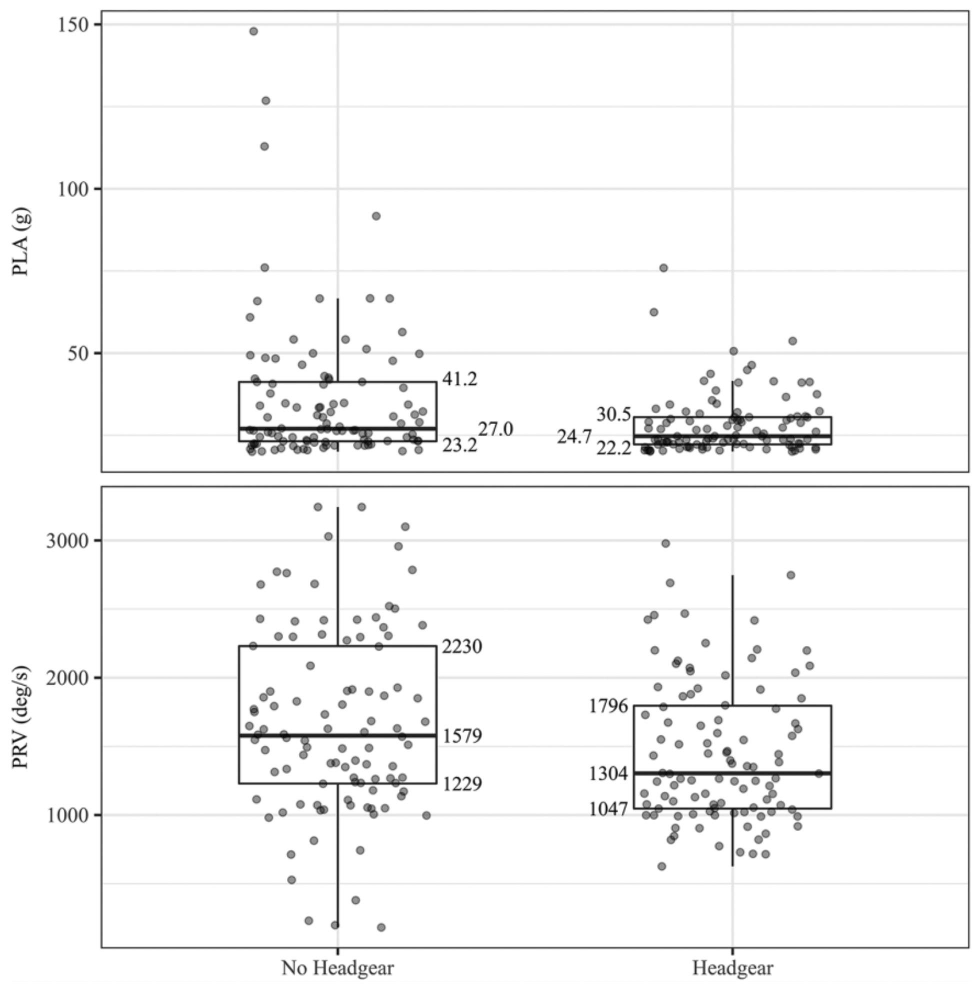

Figure 2. Box plots showing median peak linear acceleration (PLA) and peak rotational velocity (PRV) impact magnitudes by headgear condition (N = 204).

TABLE 2
Unadjusted Impact Magnitudes[a]

	No Headgear		Headgear		Overall	
	PLA, *g*	PRV, deg/s	PLA, *g*	PRV, deg/s	PLA, *g*	PRV, deg/s
Location						
Body	28.1 (23.7-40.2)	1587 (1246-2230)	24.3 (22.1-29.6)	1265 (1051-1673)	26.4 (22.5-32.2)	1446 (1097-1885)
Head	24.5 (22.2-46.9)	1545 (1101-1993)	30.8 (22.9-41.3)	1490 (1033-2101)	26.6 (22.3-42.7)	1545 (1076-2101)
Mechanism						
Ball	49.0 (35.5-62.5)	1583 (1163-2003)	27.3 (23.8-30.8)	1298 (1102-1495)	28.1 (21.5-44.8)	1298 (865-1874)
Stick	26.4 (22.3-47.7)	1548 (1114-2272)	24.7 (22.4-30.0)	1300 (1039-1674)	25.9 (22.3-34.3)	1376 (1073-1774)
Player	27.1 (24.0-37.7)	1571 (1251-2001)	24.8 (22.2-30.5)	1265 (1055-1837)	26.6 (22.9-33.5)	1466 (1130-1899)
Ground	35.6 (30.9-38.2)	2079 (1910-2249)	21.6 (21.4-32.2)	2123 (2048-2206)	32.2 (21.6-36.7)	2123 (1928-2231)
Penalty						
No	26.5 (23.2-39.0)	1560 (1128-2279)	24.9 (22.3-30.5)	1306 (1026-1730)	26.3 (22.5-33.7)	1438 (1075-1884)
Yes	32.8 (24.1-47.9)	1626 (1327-1967)	24.0 (21.6-29.7)	1265 (1050-1914)	28.8 (22.8-40.7)	1543 (1137-1928)
Total	27.0 (23.2-41.2)	1579 (1229-2230)	24.7 (22.2-30.5)	1304 (1047-1796)	26.4 (22.5-34.4)	1452 (1085-1914)

[a]Data are shown as median (interquartile range). PLA, peak linear acceleration; PRV, peak rotational velocity.

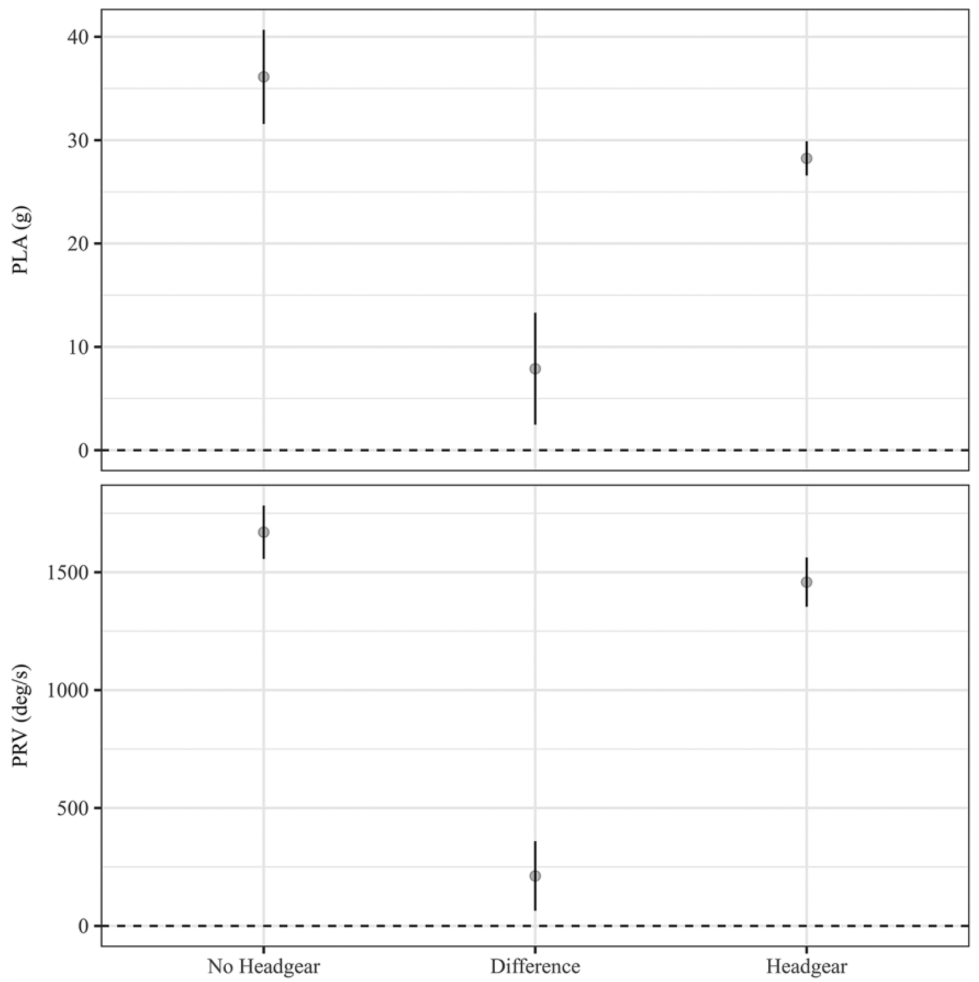

Figure 3. Generalized estimating equation model results of estimated means and 95% CIs for impact magnitudes in the headgear and no headgear conditions as well as absolute differences in magnitudes between conditions. PLA, peak linear acceleration; PRV, peak rotational velocity.

headgear use. Our findings demonstrate that wearing headgear did not have an effect on the rate of overall, body, or head impacts. Further, our findings suggest potentially meaningful reductions in mean and median impact magnitudes with protective headgear for both overall and body impacts. However, when isolating impacts directly to the head, no significant differences were observed in IRs or impact magnitudes between the no headgear and headgear conditions. Our findings also revealed that neither impact mechanism nor the number of penalties administered changed with the use of lacrosse headgear.

Opinions vary regarding the effectiveness of women's lacrosse headgear and possible associated changes in game play that may increase the risk of injury. Advocates believe that headgear use will decrease the severity of impacts and reduce the risk of head injuries including concussions,[1,11] while opponents maintain that headgear use will change the tenor of the game, resulting in risk compensation[14] and increased aggressive game-play behaviors (ie, gladiator effect).[11] Overall, the rate of verified impacts observed in this study was more than twice as high as previously reported among high school girls' lacrosse per player-game (IR: 0.31 vs 0.12, respectively).[6] Despite the overall higher rate of impacts compared with prior studies, our present findings revealed no IR change after the adoption of headgear. We were especially interested if headgear resulted in an increased rate of those impacts directly striking the head. Caswell et al[4] reported that 48% of all impacts in girls' high school lacrosse directly struck the head. Our findings are encouraging, as we found that fewer than one-third (25.5%) of impacts directly struck the head. Counter to the argument that wearing headgear may result in more head impacts, we observed no significant change in the rate of head impacts after the adoption of headgear. These findings suggest that headgear use does not increase the frequency of head impacts in girls' high school lacrosse.

The impact magnitudes were lower than previously reported in high school girls' lacrosse.[6] For overall impacts (including both body and head impacts), we found that the players wearing headgear experienced a significant reduction in impact magnitudes. This finding supports the proponents of headgear, who contend that headgear use decreases the severity of impacts and the risk of injury. We suggest caution, however, as this reduction was primarily driven by impacts sustained to the body and not those directly to the head. When restricting our analysis to direct head impacts, which accounted for one-fourth of all impacts in this study, we found that the players wearing headgear did not experience a statistically significant reduction in PLA or PRV impact magnitudes.

No concussions were diagnosed in either season of this study. It is well-accepted that concussions can be caused by either a direct impact to the head or from elsewhere on the body with an impulsive force transmitted to the head.[18] To date, a universally accepted biomechanical threshold of a concussion continues to be elusive.[7,13] As such, it remains unknown whether the size of the reduction in impact severity that we observed for overall and body impacts among players wearing headgear is clinically meaningful. Perhaps a potentially important finding was that we observed considerably fewer extreme-magnitude impacts (>90th percentile) among those players wearing headgear. This suggests that headgear use may help achieve the broader safety goal of reducing exposure to high-magnitude impacts. Alternatively, it could also be possible that fewer high-magnitude impacts occurred among players wearing headgear.

It is interesting to note that the most common impact mechanism in the current study was contact with another player, as opposed to previous research of ours that identified stick contact as the most common mechanism.[6] A comparison of the distribution of impact mechanisms before and after the adoption of headgear from 2016 to 2017 revealed no differences by headgear condition. Moreover, we found no differences in the proportion of impacts that resulted in a penalty. Although not direct measures of player aggression or risk compensation, these are measures of game play, and one could reasonably expect differences to be revealed between the no headgear and headgear conditions. Our findings suggest that headgear use may not affect how impacts occur or how aggressively the game is played. However, more research is needed with larger study populations and various levels of play to confirm this finding.

As a whole, we observed that headgear use among high school girls' varsity lacrosse players did not result in increased impacts or changes in game-play behaviors. Furthermore, the addition of headgear resulted in no changes in the frequency of penalties administered for illegal game play by officials. Nearly a quarter (24.0%) of all impacts in this study resulted from foul play. Girls' high school lacrosse rules dictate that all stick and bodily contact should be considered illegal and warrant a penalty. This suggests that officials missed 76.0% of illegal game play. This presents an opportunity to significantly reduce impacts through improved rule enforcement and coaching techniques that are targeted to reduce stick and bodily contact. It is worth noting that only 1 team wore headgear during game play; this factor may have influenced game play. Future studies are necessary to evaluate if our findings persist when both teams are wearing headgear.

Limitations and Strengths

Our study was not without limitations. First, we utilized a small convenience sample of a single team, which may not be representative of all high school girls' lacrosse players. Several of the same players as a team wore no headgear in 2016, were introduced to headgear in 2017, and were measured by the same investigative team, all of which may have introduced systematic errors such as performance and measurement bias. Further, the participants in the present study during the 2017 (headgear) season competed in games in which their opponents did not wear headgear. This could have affected the manner in which the team and opponents played as well as the nature of the head impacts measured. As such, a larger study with teams or leagues randomized by headgear/no headgear condition would better account for repeated measurements within players. Despite these limitations, the strength of the design was a realistic capture of impacts in the competitive setting, with a novel system for data capture. Finally, as previously reported,[6,9,19,27,29] the use of impact-monitoring sensors should be interpreted with caution, as random measurement errors are possible. While the present study did pair all sensor data with time-synchronized video verification, the accuracy of the impact magnitudes over the course of a season may be limited.

CONCLUSION

The findings of this study suggest that the use of headgear meeting the ASTM F3137 performance standard by high school girls' varsity lacrosse players was not associated with a significant change in the rate of impacts, how they occur, or how penalties were administered for impacts sustained during competition. Additionally, the use of lacrosse headgear was associated with a significant reduction in the magnitude of overall impacts sustained during game play. However, the clinical significance of this reduction remains unknown, as it was largely driven by body impacts, and we observed no such reduction in magnitude when examining only verified impacts directly striking the head. Collectively, these findings provide preliminary evidence that wearing lacrosse headgear meeting the ASTM F3137 performance standard does not appreciably change game-play behaviors, while it does reduce the magnitude of head accelerations associated with body impacts sustained during high school girls' lacrosse. Future research should continue to examine headgear use at all levels of girls' and women's lacrosse to validate and improve upon these study findings.

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