Head Impact Magnitude in American High School Football

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abstract

OBJECTIVES: To describe determinants of head impact magnitudes between various play aspects in high school football.

METHODS: Thirty-two high school American football players wore Head Impact Telemetry System instrumented helmets to capture head impact magnitude (linear acceleration, rotational acceleration, and Head Impact Technology severity profile [HITsp]). We captured and analyzed video from 13 games ($n = 3888$ viewable head impacts) to determine the following play aspects: quarter, impact cause, play type, closing distance, double head impact, player's stance, player's action, direction of gaze, athletic readiness, level of anticipation, player stationary, ball possession, receiving ball, and snapping ball. We conducted random intercepts general linear mixed models to assess the differences in head impact magnitude between play aspects ($\alpha = 0.05$).

RESULTS: The following aspects resulted in greater head impact magnitude: impacts during the second quarter (HITsp: $P = .03$); contact with another player (linear, rotational, HITsp: $P < .001$); initial head impact when the head is struck twice (linear, rotational, HITsp: $P < .001$); longer closing distances, especially when combined with a 3-point stance or when being struck in the head (linear: $P = .03$); the 2-point stance (linear, rotational, HITsp: $P < .001$); and offensive linemen not snapping the ball compared with those snapping the ball (rotational: $P = .02$, HITsp: $P = .02$).

CONCLUSIONS: Preventing head impacts caused by contact with another player may reduce head impact magnitude in high school football. Rule or coaching changes that reduce collisions after long closing distances, especially when combined with the 3-point stance or when a player is being struck in the head, should be considered.

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WHAT'S KNOWN ON THIS SUBJECT: Greater understanding about which aspects of football result in higher-magnitude head impacts may usefully inform rule changes, coaching technique changes, and athlete preparation.

WHAT THIS STUDY ADDS: Preventing head impacts caused by contact with another player (not necessarily all player-to-player contact) may reduce head impact magnitude in high school football. Rule or coaching changes that reduce collisions after long closing distances should be considered.

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American football is a collision sport with a concerning incidence of brain injury.[1–3] Growing concern focuses on the sport's ability to improve player safety, specifically by reducing the risk of sport-related concussion. There is particular concern about youth and adolescent athletes, who sustain concussions at higher rates[4,5] but have less access to medical care. Greater understanding of which aspects of the game result in higher-magnitude head impacts may usefully inform rule changes, coaching technique changes, and athlete preparation.

Extrinsic Aspects: Previous research suggests that injury risk increases later in the game, as players experience fatigue.[6,7] Special teams plays have long been theorized to be the most dangerous play in football because of the large closing distances and speeds[8]; however, regardless of play type, collegiate players involved in collisions that occurred after traveling over a long distance (>10 yards) sustain higher-magnitude head impacts.[8] Combining certain play aspects with a long closing distance may result in head impacts of higher magnitude.

Intrinsic Aspects: An athlete who is able to foresee an impending collision may mitigate head acceleration by reacting with protective anticipatory muscle and postural responses. Rugby ball carriers have a higher injury rate when tackled from behind their visual field.[6] Youth ice hockey collisions that are unanticipated tend to result in higher-magnitude head impacts compared with anticipated collisions.[9] Players who start in a 3- or 4-point stance, rather than a 2-point stance, generate greater trunk and head velocity before collision with the opposing players[10] and may limit an athlete's field of view,[10,11] making it difficult to anticipate and prepare for a collision. Studies that have reconstructed helmet-to-helmet impacts that resulted in concussion among National Football League players show that the struck players, on average, experience 98 g of linear head acceleration while the striking players only experience 59 g.[12,13] Struck players often must maintain gaze fixation on a target, such as the goal, the ball, or a teammate, which may limit their ability to anticipate and prepare for impending collision.[14]

No previous study has analyzed determinants of head impact magnitude among high school football players. The purpose of this study was to compare head impact magnitude across the following high school football game-based play aspects: quarter, impact cause, play type, closing distance, double head impact, player stance, player action, direction of gaze, athletic readiness, level of anticipation, player stationary, ball possession, receiving ball, and snapping ball. We hypothesized that the following game aspects would result in head impacts of higher magnitude: third and fourth quarters, player-to-player contact, high-contact special teams, initial impact, 2-point stance, struck player, not looking, not athletic ready, unanticipated, not stationary, possessing ball, receiving ball, and snapping ball.

METHODS

Study Participants

Thirty-two high school conference 3A varsity football players enrolled (age = 16.7 ± 0.9 years, range 14.9–18.3 years; height = 180.7 ± 6.6 cm, range 170.5–196.0 cm; mass = 88.5 ± 17.3 kg, range 63.1–124.5; years of football experience = 5.9 ± 2.4 years, range 0–11; position group: 7 offensive nonlinemen, 9 offensive linemen, 11 defensive nonlinemen, 5 defensive linemen). Data were captured at 11 regular season and 2 playoff high school football games. Participants and legal guardians signed Institutional Review Board–approved informed assent or consent forms.

Head Impact Biomechanics

The Head Impact Telemetry (HIT) System (Simbex, Lebanon, NH), used to capture head impact biomechanics, consists of MxEncoder units located in the football helmets, a signal transducer, and a laptop computer that houses the Sideline Response System (Riddell Corp, Rosemont, IL). MxEncoder units, installed in fitted Riddell Revolution and Speed helmet designs by the research team, consist of 6 spring-loaded single-axis accelerometers that detect, record, and then transmit time-stamped data in real time to the sideline computer. These data are processed with proprietary algorithms and exported for analysis. The HIT System has been described in detail elsewhere.[15,16]

Video Capture

A research assistant captured game video by using a professional grade video camera (Panasonic HMC-40, Secaucus, NJ) placed above the press box ~3 stories high at the 50-yard line. Video was recorded in full high-definition with a resolution of 1080 × 720 at 24 frames per second. The camera and HIT System were date and time synchronized before each game.

Data Reduction

Head Impact Biomechanics

We focused on 3 measures of head impact magnitude: linear acceleration, rotational acceleration, and Head Impact Technology Severity Profile (HITsp). The HITsp is a unitless weighted combination of several biomechanical inputs, including linear acceleration, rotational acceleration, impact duration, Gadd severity index, head injury criterion, and impact location.[17]

TABLE 1 Extrinsic Play Aspect Descriptive and Statistical Results

Variable: Question Answered by Rater	Response	*n*	Linear (*g*)	Rotational (rad/s^2)	HITsp
			Mean (95% CI)	Mean (95% CI)	Mean (95% CI)
Quarter			*P* = .19	*P* = .14	*P* = .03
Which quarter?	1st	1086	25.7 (24.7–26.8)	1589.2 (1470.9–1717.1)	16.4 (15.7–17.2)
	2nd	1191	26.6 (25.5–27.8)	1636.8 (1544.0–1735.4)	17.0 (16.3–17.7)[a]
	3rd	780	25.9 (24.5–27.3)	1561.3 (1444.8–1687.3)	16.4 (15.6–17.2)
	4th	670	25.3 (24.3–26.4)	1557.4 (1451.6–1670.9)	16.2 (15.4–17.1)
Impact cause			*P* < .001	*P* < .001	*P* < .001
Was the hit caused by a collision with another player?	Contact with player	3563	26.1 (25.1–27.1)[b]	1618.4 (1519.9–1723.3)[b]	16.7 (16.0–17.4)[b]
	Contact with other object or surface	262	22.7 (21.6–23.7)	1242.4 (1127.3–1369.2)	14.2 (13.4–15.0)
Play type			*P* = .34	*P* = .45	*P* = .37
What is the play type of this play?	Offensive	1491	25.6 (24.1–27.1)	1637.8 (1519.9–1764.8)	16.8 (15.9–17.7)
	Defensive	1775	26.0 (25.1–27.0)	1535.9 (1416.6–1665.5)	16.2 (15.3–17.2)
	Special teams–high contact	490	25.9 (24.7–27.2)	1611.5 (1464.8–1772.6)	16.6 (15.9–17.5)
	Special teams–low contact	87	23.9 (21.1–27.0)	1364.3 (1064.8–1748.0)	14.7(12.7–17.1)
Closing distance			*P* = .03	*P* = .24	*P* = .69
How far of a distance did the player cover before the collision?	Long distance (>10 yards)	599	26.7 (25.5–28.0)[c]	1635.2 (1520.4–1758.8)	16.6 (15.8–17.5)
	Short distance (<10 yards)	3088	25.5 (24.5–26.6)	1581.3 (1487.9–1680.6)	16.5 (15.8–17.2)
Double head impact			*P* < .001	*P* < .001	*P* < .001
Was this the second head impact from 1 collision?	Initial impact	3297	26.7 (25.6–27.9)[d]	1655.9 (1557.0–1760.9)[d]	17.0 (16.2–17.7)[d]
	Subsequent impact (immediately after initial impact)	454	20.2 (18.9–21.6)	1212.6 (1114.8–1319.1)	13.7 (13.1–14.2)

CI, confidence interval.

[a] Second quarter > first quarter (HITsp: $t_{74} = -2.46$, $P = .01$) and second quarter > third quarter (HITsp: $t_{74} = 2.44$, $P = .01$).

[b] Contact with player > contact with other object or surface (linear: $t_{21} = -8.70$, $P < .001$; rotational: $t_{21} = -6.71$, $P < .001$; HITsp: $t_{21} = -6.09$, $P < .001$).

[c] Long > short ($t_{26} = 2.25$, $P = .03$).

[d] Initial head impact > subsequent head impact (linear: $t_{25} = 7.49$, $P < .001$; rotational: $t_{25} = 8.90$, $P < .001$; HITsp: $t_{25} = 9.91$, $P < .001$).

Video Assessment of Play Aspects

Seven raters analyzed game video of on-field collisions by using a modified Player-to-Player form[8,9] transferred to spreadsheet format containing the date, time, and unique ID for each head impact but included no head impact biomechanical measures to avoid rater bias. Raters used the date and time of head impact to cue video footage. Raters responded to questions by choosing from responses contained in Table 1 (extrinsic) and Table 2 (intrinsic) if the collision was viewable. Raters were trained by the primary investigator (J.S.), completed 10 supervised reviews, and were instructed to select “Unknown” if the play aspect was not apparent. All raters completed a reliability segment of 91 head impacts. κ Values were used to compare the agreement between Rater 1 responses and the responses of Raters 2 through 7 for each play aspect and are presented in Table 3. Rater 1 was used for reliability comparison because this rater completed the most video analysis (29.7%), and no single rater had clearly superior expertise. Play aspects rated by raters with chance to fair reliability (κ < 0.40) were excluded from corresponding analyses for that play aspect only.[18]

Play aspect data were later merged with head impact biomechanical measures. Play type was recategorized as follows: offense (offensive rushing, offensive passing), defense (defensive rushing, defensive passing), special teams–high contact (punt, punt return, kickoff, kickoff return), or special teams–low contact (field goal, field goal block, extra point, extra point block).

Statistical Analyses

All statistical analyses were performed in SAS Version 9.4 (SAS Institute, Inc, Cary, NC). Head impact biomechanical data were $\log_e$ transformed to stabilize variances and provide a near-normal

TABLE 2 Intrinsic Play Aspect Descriptive and Statistical Results

Variable: Question Answered by Rater	Response	*n*	Linear (*g*)	Rotational (rad/s^2)	HITsp
			Mean (95% CI)	Mean (95% CI)	Mean (95% CI)
Player stance:			$P < .001$	$P = .001$	$P < .001$
What stance did the player start in?	2-Point	1489	26.1 (25.1–27.2)[a]	1644.7 (1563.8–1729.9)[a]	16.8 (16.3–17.4)[b,a]
	3-Point	2061	25.3 (24.0–26.7)[c]	1555.4 (1442.5–1677.4)[c]	16.2 (15.4–17.0)[c]
	4-Point	31	20.6 (19.7–21.5)	1389.4 (1266.7–1523.9)	14.8 (14.0–15.6)
Player action			$P = .94$	$P = .23$	$P = .25$
Player involvement in collision?	Striking	1059	26.4 (24.8–28.1)	1661.5 (1524.0–1811.5)	16.4 (15.5–17.5)
	Struck	856	26.4 (24.6–28.4)	1641.7 (1477.0–1824.8)	17.1 (15.9–18.3)
	Both	1799	26.7 (25.2–28.3)	1553.1 (1432.7–1683.8)	16.8 (16.0–17.7)
Direction of gaze			$P = .12$	$P = .52$	$P = .47$
Player appears to be looking in the direction of collision?	Looking	1291	26.6 (25.2–28.1)	1602.6 (1459.4–1760.1)	16.7 (15.8–17.7)
	Not looking	271	24.7 (22.7–26.8)	1532.3 (1357.2–1729.9)	16.2 (15.0–17.5)
Athletic readiness			$P = .39$	$P = .29$	$P = .95$
Player appears to be in an athletic readiness position?	Athletic ready	1425	26.6 (25.2–28.2)	1619.1 (1484.2–1766.2)	16.7 (15.8–17.7)
	Not athletic ready	489	25.9 (24.6–27.4)	1559.5 (1453.7–1672.7)	16.7 (15.8–17.7)
Level of anticipation			$P = .51$	$P = .83$	$P = .85$
Overall impression of body collision	Anticipated	3310	25.9 (24.8–27.1)	1605.5 (1503.9–1714.2)	16.6 (15.9–17.3)
	Unanticipated	339	26.5 (24.8–28.2)	1621.3 (1475.6–1781.5)	16.7 (15.6–17.9)
Player stationary			$P = .07$	$P = .13$	$P = .12$
Was the player stationary (taking <3 steps before collision)?	Stationary	703	25.0 (23.6–26.5)	1519.3 (1393.3–1656.9)	16.0 (15.1–17.0)
	Not stationary	2079	26.1 (25.1–27.2)	1609.1 (1508.8–1715.9)	16.7 (16.0–17.4)
Ball possession			$P = .59$	$P = .90$	$P = .41$
Did the player have possession of the ball?	Possessing ball	352	25.4 (23.6–27.3)	1587.2 (1450.1–1737.1)	16.1 (14.9–17.4)
	Not possessing ball	3468	25.9 (24.8–27.0)	1595.1 (1495.9–1700.9)	16.6 (15.9–17.3)
Receiving ball			$P = .62$	$P = .40$	$P = .74$
Was the player receiving or passing the ball at time of collision?	Receiving ball	47	26.8 (22.5–31.8)	1455.6 (1141.8–1855.7)	16.2 (14.0–18.7)
	Not receiving ball	3774	25.8 (24.7–26.9)	1597.8 (1497.7–1704.6)	16.5 (15.8–17.2)
Snapping ball	Offensive line only		$P = .17$	$P = .02$	$P = .01$
Was the player snapping the ball at the time of collision?	Snapping ball	175	26.0 (21.0–32.3)	1274.5 (1034.9–1569.6)	15.0 (13.3–16.9)
	Not snapping ball	794	23.8 (19.4–29.2)	1541.8 (1222.9–1944.0)[d]	16.1 (13.8–18.9)[d]

CI, confidence interval.

[a] 2-point > 4-point (linear: $t_{23} = 15.36$, $P < .001$; rotational: $t_{23} = 4.50$, $P < .001$; HITsp: $t_{23} = 6.96$, $P < .001$).

[b] 2-point > 3-point (HITsp: $t_{23} = 2.46$, $P = .02$).

[c] 3-point > 4-point (linear: $t_{23} = 9.40$, $P < .001$; rotational: $t_{23} = 2.77$, $P = .01$; HITsp: $t_{23} = 4.61$, $P < .001$).

[d] Not snapping ball > snapping ball (rotational: $t_2 = 6.30$, $P = .02$; HITsp: $t_2 = 7.76$, $P = .01$).

TABLE 3 κ Statistics for Interrater Reliability for Each Play Aspect

	Rater 1 Versus: 29.7% Completed					
	Rater 2	Rater 3	Rater 4	Rater 5	Rater 6	Rater 7
% Completed	20.7	26.4	12.2	4.2	4.5	2.4
Extrinsic						
Impact cause	NE	NE	NE	NE	NE	NE
Quarter	Not assessed					
Play type	0.85	0.92	0.95	0.75	0.91	0.95
Closing distance	0.78	0.67	0.81	0.75	0.83	0.53
Double head impact	0.78	0.73	0.73	0.81	0.89	0.81
Intrinsic						
Player's stance	0.75	0.84	0.87	0.82	0.65	0.92
Player's role	0.27[a]	0.36[a]	0.44	0.29[a]	0.42	0.52
Direction of gaze	0.39[a]	0.20[a]	0.46	0.28[a]	−0.04[a]	0.26[a]
Athletic readiness	0.11[a]	0.25[a]	0.45	0.46	0.63	0.35[a]
Level of anticipation	NE	NE	NE	NE	NE	NE
Player stationary	0.20[a]	0.73	0.50	0.45	−0.08[a]	0.30[a]
Ball possession	1.00	1.00	1.00	1.00	1.00	1.00
Receiving ball	NE	NE	NE	NE	NE	NE
Snapping ball	1.00	1.00	1.00	0.66	0.66	1.00

NE, Not enough data to calculate a κ statistics (typically because 1 response occurred too rarely within the reliability segment).

[a] Play aspects rated by raters with chance to fair reliability $\kappa < 0.40$ were excluded from corresponding analyses for that play aspect.

distribution. We excluded head impacts that were not viewable or were rated as unknown for all analyses. We conducted separate random intercepts general linear mixed model analyses to compare each head impact biomechanical measure of magnitude between rater responses for each extrinsic or intrinsic play aspect with an a priori significance level of $\alpha = 0.05$. In the event of a significant difference, the Tukey Honestly Significant Difference test was performed. We also ran 3 separate random intercepts general linear mixed model analyses for each measure of head impact magnitude to analyze the possible interaction effects of closing distance with play type, player stance, and player action.

RESULTS

We observed 6957 game head impacts, of which 3888 (55.9%) were viewable on video. Frequencies, descriptive statistics, and statistical results for extrinsic and intrinsic aspects are presented in Tables 1 and 2, respectively.

Extrinsic Aspects

Second quarter head impacts were slightly higher in magnitude than first and third quarters (0.6 HITsp units), but not the fourth, when measured by HITsp ($P = .03$) (Table 1). Linear and rotational acceleration did not differ between quarters ($P > .05$). Head impacts that resulted from contact with another player were significantly higher in magnitude than head impacts caused by other objects or surfaces for linear acceleration ($P < .001$), rotational acceleration ($P < .001$), and HITsp ($P < .001$). Play types did not significantly differ for linear acceleration, rotational acceleration, or HITsp. Head impacts after a long closing distance were an average of 1.2 g higher in magnitude than after a short closing distance for linear acceleration ($P = .03$) but not for rotational acceleration and HITsp. Initial head impacts were substantially higher in magnitude than the head impacts sustained after another head impact for linear acceleration ($P < .001$), rotational acceleration ($P < .001$), and HITsp ($P < .001$).

Intrinsic Aspects

Head impacts sustained from a 2- or 3-point stance were higher in magnitude than head impacts from a 4-point stance for linear acceleration ($P < .001$), rotational acceleration ($P = .001$), and HITsp ($P < .001$). For HITsp only, head impacts sustained from a 2-point stance were higher in magnitude than head impacts from a 3-point stance (Table 2). Offensive linemen not snapping the ball sustained higher-magnitude head impacts than linemen snapping the ball for rotational acceleration ($P = .02$) and HITsp ($P = .01$) but not for linear acceleration.

Closing Distance Interactions

There were no significant interactions between play type and closing distance for linear acceleration ($P = .20$), rotational acceleration ($P = .08$), and HITsp ($P = .08$). A significant interaction effect was observed between player stance and closing distance for HITsp ($P = .04$) but not for linear ($P = .44$) or rotational acceleration ($P = .15$). Generally, head impact magnitude was greatest when the 3-point stance was used over a long closing distance (see Fig 1 for post hoc results). There was a significant interaction effect between player action and closing distance for linear acceleration ($P = .04$) but not for rotational acceleration ($P = .23$) or HITsp ($P = .38$). Head impact magnitude

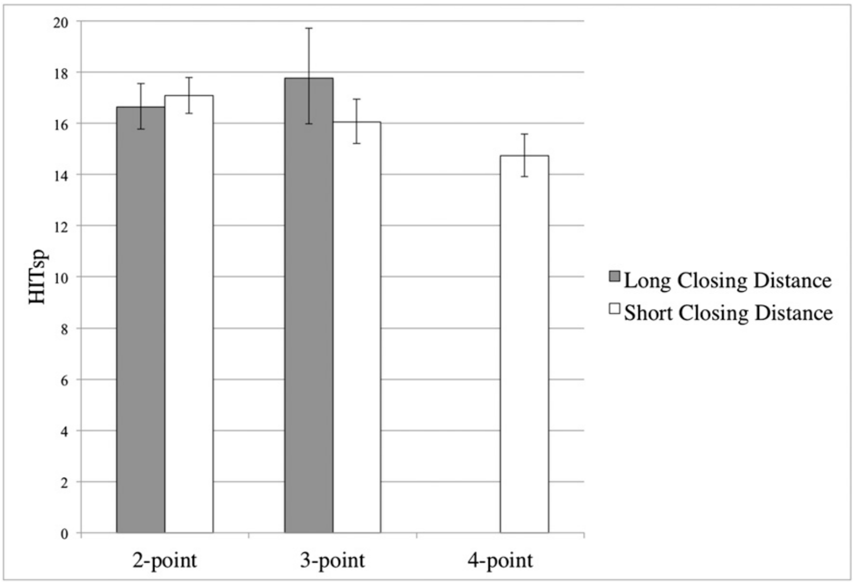

FIGURE 1

Interaction effect between closing distance and player stance for HITsp (no head impacts observed for 4-point stance over long closing distance). Omnibus: $F_{1,12} = 5.03$, $P = .04$. Post hoc: long closing distance and 2-point stance > short closing distance and 4-point stance ($P = .01$). Long closing distance and 3-point stance > short closing distance and 4-point stance ($P = .01$). Short closing distance and 2-point stance > short closing distance and 3-point stance ($P = .03$). Short closing distance and 2-point stance > short closing distance and 4-point stance ($P < .001$). Short closing distance and 3-point stance > short closing distance and 4-point stance ($P = .02$).

was greatest when players were struck after a long closing distance compared with those struck after a short closing distance (see Fig 2 for post hoc results).

DISCUSSION

These results expand our current knowledge of the influence of extrinsic and intrinsic play aspects on head impact magnitude among high school football players. Within the team studied, head impacts occurring in the second quarter were slightly, but significantly, higher in magnitude than head impacts occurring during the first and third quarters for 1 of the 3 magnitude measures (HITsp). Previous studies suggest that an individual's risk of injury may increase as he or she continues to participate in a single game.[6,7] Our results suggest that if this is true among high school football players, an increased injury risk does not result from increases in head impact magnitude as the game progresses. Returning to the game after the half may have had a restorative effect for participants of this study, minimizing fatigue-related increases in head impact magnitude.

Head impacts that resulted from contact with another player, the leading cause for concussion,[4,5,19,20] resulted in substantially greater head impact magnitude than head contact with other objects or surfaces among the team studied. Discussions of football safety occasionally suggest that player-to-player contact should be eliminated or that contact should be prohibited until players reach maturity.[3] Our results indicate that minimizing or eliminating head impacts caused by contact with another player (not necessarily all player-to-player contact) may reduce head impact magnitude in high school football. However, we did not quantify the effect of this reduction on concussion risk in this study. Rule changes in professional ice hockey regulating head contact have not been shown to reduce the risk of concussion.[21] However, head contact with the ice results in greater head impact magnitude than player-to-player contact in ice hockey.[22]

Our results and those of Ocwieja et al[8] support the notion that head impacts that occur after 2 players have traveled over a long closing distance are on average 1.2 *g* higher in magnitude than those with shorter closing distances. Head impact magnitude may depend less on the type of play than the closing distance, which is presumably closely related to closing speed, over which the individual players travel before head impact. Previous research suggests that the pass-first offensive strategy results in lower head impact frequencies but greater head impact magnitudes than a run-first offense.[23] A pass-first offensive style may be more likely to result in long closing distance collisions. Organizing sports bodies should consider these results when making rule change decisions. Promoting run-first offensive strategies may reduce head impact magnitude in high school football, but this change may have the unintended consequence of increasing overall head impact frequency.[23]

Subsequent head impacts may have been lower in magnitude within the team studied, compared with initial head impacts, because subsequent head impacts typically occur after the player's body velocity was slowed from the initial collision. The majority of energy involved in collision is probably transferred during initial contact between 2 players. However, it remains unknown whether 2 sequential head impacts sustained during the same play have separate or cumulative effects on the brain. Previous research assessing whether concussive head impacts are influenced by preceding head impacts sustained in the days, weeks, and months before injury diagnosis have shown conflicting results.[24,25] Future research should consider composite

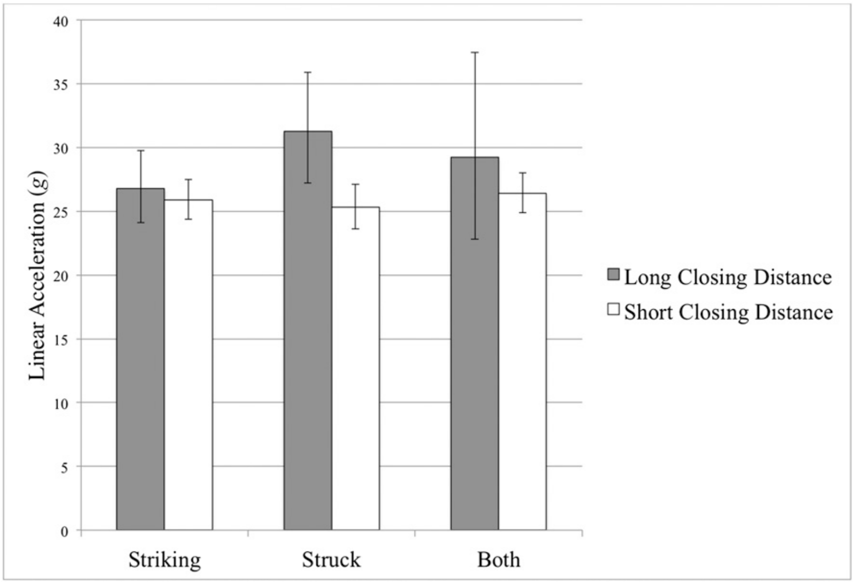

FIGURE 2
Interaction effect between closing distance and player action for linear acceleration. Omnibus: $F_{2,16} = 3.73$, $P = .04$. Post hoc: long closing distance and struck player > short closing distance and struck player ($P = .01$).

measures of head impact magnitude, frequency, location, and timing.

Of the intrinsic aspects we examined, only player stance and snapping the football affected head impact magnitude within the team studied. Players in this study who started in a 2-point stance experienced higher-magnitude head impacts across all 3 measures of head impact magnitude, probably because nonlinemen typically adopt the 2-point stance and sustain lower-frequency but higher-magnitude head impacts.[15,26] We found that the combination of the 3-point stance and a long closing distance resulted in the highest head impact magnitude (Fig 1). The 3-point stance may result in higher-magnitude head impacts because the player starts in a lowered position from which he or she can rapidly generate head and body speeds compared with the 2-point stance,[10] much like a sprinter coming out of the blocks. Tight ends and defensive ends may be most likely to combine the 3-point stance with a long closing distance off the line of scrimmage. In addition to the influence of play aspects on head impact magnitude, consideration should be given to the potential cumulative burden of frequent low-magnitude head impacts sustained in high school football.[24,27,28] The 4-point stance was rarely used (1%) by the team studied and was never combined with a long closing distance but has previously been reported to reduce player field of view and increase kinetic energy by 8%.[10] More research is needed to determine whether 3- or 4-point stances increase a football player's risk of concussion.

Overall, struck and striking players sustained head impacts of similar magnitude; however, when isolated by closing distance, players who were struck in the head after a long closing distance sustained head impacts of the greatest magnitude (Fig 2). The results of this study support previous reconstructions of concussive impacts among professional players[12] and studies that suggest that struck players are at higher risk for concussion,[20,29] but they indicate that head impact magnitude is influenced by both player action and closing distance. Efforts to reduce head impact magnitude in football should be aimed at reducing the incidence of players[30] being struck in the head after a long closing distance.

Head impact magnitude was not influenced by the player's direction of gaze, athletic readiness, level of anticipation, or whether the player was stationary. These results contrast with previous trends observed in youth ice hockey, wherein unanticipated collisions resulted in slightly greater head acceleration,[9] and boys' high school lacrosse, wherein 56% of concussions occurred when the player did not anticipate the collision.[20] Our finding support previous findings observed in collegiate football[29] and may be related to the fact that few impacts in football are truly unanticipated. Rules regarding striking a defenseless player may be effective in limiting the frequency and magnitude of unanticipated collisions. In contrast to other contact sports, football plays have a well-defined start, and offensive players typically execute well-planned actions. Linemen expect to make contact with an opponent during nearly every play. We examined level of anticipation as a binary variable, but it is likely that anticipation is not fully represented as a dichotomy or fully evident via video footage. Future studies should examine the influence of athlete anticipation on head protection in sports such as soccer, basketball, and rugby.

Although a high percentage of concussions occur when a player is fielding or handling a lacrosse ball,[20] we did not find that players possessing or receiving the football sustained higher-magnitude head impacts. These results contrast with previous results. A football player who is not in athletic readiness position and is not looking in the direction of impending collision may still anticipate an impending collision, particularly if this same player possesses the ball. During long snaps (snaps >7 yards), defensive players must wait a≥1 second before making contact with the snapper. The snapper also knows the snap count and can most accurately predict when the play will start. However, these results should be interpreted with caution because we isolated these analyses to offensive linemen only (n = 9) and had 1 starting center who completed the majority of snaps.

Our sample size and study duration precluded analysis of concussion risk, but future studies should assess concussion risk across play aspects. We observed low interrater reliability for some raters for some play aspects and addressed this limitation by excluding raters from corresponding analyses. For some play aspects, low reliability may have resulted from the infrequencies of responses within the reliability segment, such as ball receiving and anticipation. Intrinsic aspects, such as direction of gaze and athletic readiness, may be difficult to determine from video playback. We captured head impact biomechanics and video for 1 high school team over the course of 1 season. These results may not apply to all high school football programs, across other levels of play, or across other sports. Recent research suggests that the HIT System may overestimate head impact magnitude.[31,32] Head impact magnitude may be overestimated in this study, which should be considered when interpreting the results of this study. Future studies should examine head impact frequency and location, because magnitude alone does not capture all elements of head trauma.

CONCLUSIONS

In combination with previous and future studies, this study may guide safety improvements in football. This is the first study to provide detailed information about the influence of high school football play aspects on head impact magnitude. The results of our study support efforts to prevent head impacts that result from contact with other players in high school football. Rule changes that involve reducing the number of player-to-player interactions after long closing distances, particularly when combined with the 3-point stance or when a player is being struck in the head, should be considered.

ABBREVIATIONS

HIT: Head Impact Telemetry
HITsp: Head Impact Technology Severity Profile

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REFERENCES

1. DeLamielleure J. Concussion in the National Football League: viewpoint of an elite player. *J Law Med Ethics*. 2014;42(2):133–134
2. Harrison EA. The first concussion crisis: head injury and evidence in early American football. *Am J Public Health*. 2014;104(5):822–833
3. Robbins L, Conidi F. Stop football . . . save brains: a point counterpoint discussion. *Headache*. 2013;53(5):817–823
4. Gessel LM, Fields SK, Collins CL, Dick RW, Comstock RD. Concussions among United States high school and collegiate athletes. *J Athl Train*. 2007;42(4):495–503
5. Marar M, McIlvain NM, Fields SK, Comstock RD. Epidemiology of concussions among United States high school athletes in 20 sports. *Am J Sports Med*. 2012;40(4):747–755
6. King D, Hume PA, Clark T. Nature of tackles that result in injury in professional rugby league. *Res Sports Med*. 2012;20(2):86–104
7. Stevens ST, Lassonde M, de Beaumont L, Keenan JP. In-game fatigue influences concussions in National Hockey League players. *Res Sports Med*. 2008;16(1):68–74
8. Ocwieja KE, Mihalik JP, Marshall SW, Schmidt JD, Trulock SC, Guskiewicz KM. The effect of play type and collision closing distance on head impact biomechanics. *Ann Biomed Eng*. 2012;40(1):90–96
9. Mihalik JP, Blackburn JT, Greenwald RM, Cantu RC, Marshall SW, Guskiewicz KM. Collision type and player anticipation affect head impact severity among youth ice hockey players. *Pediatrics*. 2010;125(6). Available at: www.pediatrics.org/cgi/content/full/125/6/e1394
10. Bonnechere B, Beyer B, Rooze M, Sint JS. What is the safest sprint starting position for american football players? *J Sports Sci Med*. 2014;13(2):423–429
11. Harpham JA, Mihalik JP, Littleton AC, Frank BS, Guskiewicz KM. The effect of visual and sensory performance on head impact biomechanics in college football players. *Ann Biomed Eng*. 2014;42(1):1–10
12. Viano DC, Casson IR, Pellman EJ. Concussion in professional football: biomechanics of the struck player—part 14. *Neurosurgery*. 2007;61(2):313–327, discussion 327–328

13. Viano DC, Pellman EJ. Concussion in professional football: biomechanics of the striking player—part 8. *Neurosurgery*. 2005;56(2):266–280, discussion 266–280

14. van der Kamp J. Exploring the merits of perceptual anticipation in the soccer penalty kick. *Mot Contr*. 2011;15(3):342–358

15. Broglio SP, Sosnoff JJ, Shin S, He X, Alcaraz C, Zimmerman J. Head impacts during high school football: a biomechanical assessment. *J Athl Train*. 2009;44(4):342–349

16. Guskiewicz KM, Mihalik JP. Biomechanics of sport concussion: quest for the elusive injury threshold. *Exerc Sport Sci Rev*. 2011;39(1):4–11

17. Greenwald RM, Gwin JT, Chu JJ, Crisco JJ. Head impact severity measures for evaluating mild traumatic brain injury risk exposure. *Neurosurgery*. 2008;62(4):789–798, discussion 798

18. Viera AJ, Garrett JM. Understanding interobserver agreement: the kappa statistic. *Fam Med*. 2005;37(5): 360–363

19. Castile L, Collins CL, McIlvain NM, Comstock RD. The epidemiology of new versus recurrent sports concussions among high school athletes, 2005–2010. *Br J Sports Med*. 2012;46(8):603–610

20. Lincoln AE, Caswell SV, Almquist JL, Dunn RE, Hinton RY. Video incident analysis of concussions in boys' high school lacrosse. *Am J Sports Med*. 2013;41(4):756–761

21. Donaldson L, Asbridge M, Cusimano MD. Bodychecking rules and concussion in elite hockey. *PLoS One*. 2013;8(7):e69122

22. Wilcox BJ, Machan JT, Beckwith JG, Greenwald RM, Burmeister E, Crisco JJ. Head-impact mechanisms in men's and women's collegiate ice hockey. *J Athl Train*. 2014;49(4):514–520

23. Martini D, Eckner J, Kutcher J, Broglio SP. Subconcussive head impact biomechanics: comparing differing offensive schemes. *Med Sci Sports Exerc*. 2013;45(4):755–761

24. Beckwith JG, Greenwald RM, Chu JJ, et al. Timing of concussion diagnosis is related to head impact exposure prior to injury. *Med Sci Sports Exerc*. 2013;45(4):747–754

25. Eckner JT, Sabin M, Kutcher JS, Broglio SP. No evidence for a cumulative impact effect on concussion injury threshold. *J Neurotrauma*. 2011;28(10):2079–2090

26. Mihalik JP, Bell DR, Marshall SW, Guskiewicz KM. Measurement of head impacts in collegiate football players: an investigation of positional and event-type differences. *Neurosurgery*. 2007;61(6):1229–1235, discussion 1235

27. Baugh CM, Kiernan PT, Kroshus E, et al. Frequency of head-impact-related outcomes by position in NCAA division I collegiate football players. *J Neurotrauma*. 2015;32(5):314–326

28. Munce TA, Dorman JC, Thompson PA, Valentine VD, Bergeron MF. Head impact exposure and neurologic function of youth football players. *Med Sci Sports Exerc*. 2015;47(8): 1567–1576

29. Mihalik JP, Moise KF, Ocwieja KE, Guskiewicz KM, Register-Mihalik JK. The effects of player anticipation and involvement on head impact biomechanics in college football body collisions. In: *2012 ASTM Special Technical Publication*. Atlanta, GA: ASTM International; 2012: 41–55

30. Siegmund GP, Guskiewicz KM, Marshall SW, DeMarco AL, Bonin SJ. Laboratory Validation of Two Wearable Sensor Systems for Measuring Head Impact Severity in Football Players. *Ann Biomed Eng*. 2016;44(4): 1257–1274

31. Allison MA, Kang YS, Bolte JH IV, Maltese MR, Arbogast KB. Validation of a helmet-based system to measure head impact biomechanics in ice hockey. *Med Sci Sports Exerc*. 2014;46(1):115–123

32. Jadischke R, Viano DC, Dau N, King AI, McCarthy J. On the accuracy of the Head Impact Telemetry (HIT) System used in football helmets. *J Biomech*. 2013;46(13):2310–2315

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