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Frequency of Head-Impact–Related Outcomes by Position in NCAA Division I Collegiate Football Players

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Abstract

Concussions and subconcussive impacts sustained in American football have been associated with short- and long-term neurological impairment, but differences in head impact outcomes across playing positions are not well understood. The American Medical Society for Sports Medicine has identified playing position as a key risk factor for concussion in football and one for which additional research is needed. This study examined variation in head impact outcomes across primary football playing positions in a group of 730 National Collegiate Athletic Association Division I Football Championship Series athletes, using a self-report questionnaire. Although there were no significant differences between position groups in the number of diagnosed concussions during the 2012 football season, there were significant differences between groups in undiagnosed concussions ($p = 0.008$) and ''dings'' ($p < 0.001$); offensive linemen reported significantly higher numbers than most other positions. Significant differences were found between position groups in the frequencies of several postimpact symptoms, including dizziness ($p < 0.001$), headache ($p < 0.001$), and seeing stars ($p < 0.001$) during the 2012 football season, with offensive linemen reporting significantly more symptoms compared to most other groups. There were also positional differences in frequency of returning to play while symptomatic ($p < 0.001$) and frequency of participating in full-contact practice ($p < 0.001$). Offensive linemen reported having returned to play while experiencing symptoms more frequently and participating in more full-contact practices than other groups. These findings suggest that offensive linemen, a position group that experiences frequent, but low-magnitude, head impacts, develop more postimpact symptoms than other playing positions, but do not report these symptoms as a concussion.

Key words: American football; college; concussion; linemen; mild traumatic brain injury

Introduction

Each year, between 1.6 and 3.8 million concussions occur in the United States as a result of sports or recreational activities.[1,2] Concussion is a type of mild traumatic brain injury. Although pejorative terms, such as getting a ''ding'' or getting your ''bell rung,'' are sometimes used to describe concussion, this type of language inappropriately minimizes the seriousness of the injury.[3] Concussion can acutely produce somatic, cognitive, and emotional symptoms as well as physical manifestations,[4–9] and in some cases, repetitive concussive injury has been linked to the development of a neurodegenerative disease, chronic traumatic encephalopathy (CTE).[10–12] Owing to their prevalence and possible acute and long-term health implications, concussions are increasingly considered a public health priority.[13]

One of the activities with the highest risk of concussion is American football.[14–20] Among American males, football has the highest participation rate of all sports, with 3 million youth, 1.1

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million high school, and nearly 80,000 college football players participating in organized competitive leagues during the 2012 season.[21] The relative risk of concussion among the different levels of football is unclear; some studies report a greater rate of concussions in collegiate athletes, compared to high school athletes,[22] whereas others report the opposite.[16] Nonetheless, it is clear that football is a sport in which participants are at high risk of concussion,[16,19] and that understanding the incidence, prevalence, and health outcomes of concussion in youth and adolescent athletes requires an evaluation of the head impacts that occur in football.

Among football players, the likelihood of sustaining head impacts and the type of head impacts sustained varies substantially by playing position, owing to different on-field responsibilities. Offensive linemen and defensive linemen begin plays on the line of scrimmage and are involved in short-distance, lower-magnitude impacts on most plays as a result of their activities in blocking and rushing the quarterback.[23,24] In comparison, athletes in offensive and defensive skill positions, including running backs, linebackers, defensive backs, wide receivers, and quarterbacks, experience fewer, but often higher-magnitude, impacts resulting from activities such as full-speed open-field tackling.[24] The responsibilities of tight ends are a hybrid of linemen (e.g., blocking) and skill activities (e.g., pass catching and being tackled in the open field). Some special team positions, such as punters, kickers, and long snappers, are only involved in a very small percentage of plays and thus sustain less-frequent impacts during games. However, other special team players, such as those on kickoff or kickoff return, may sustain very-high-magnitude impacts.

As a result of variation in primary playing position, frequency and magnitude of head impacts and concussions vary considerably among football players. Examining the relationship between playing position and injury, including concussion, is not a new concept; in fact, there is research that was conducted decades ago.[25] Playing position has been identified by the American Medical Society for Sports Medicine (AMSSM) as an important risk factor for concussion among American football athletes.[26] Studies using in-helmet accelerometers to measure the variation in frequency and magnitude of head impacts across football playing positions have found significant differences.[23,24,27–29] Several studies have shown that, consistent with positional activities, offensive and defensive linemen sustain the greatest number of head impacts, but are less likely than skill positions to receive high-magnitude impacts.[23,24,27–29] Whereas linemen sustain an impact on almost every play, the magnitude of these impacts are typically lower, likely owing to the short distance between the offensive and defensive line players.[24] Schnebel and colleagues showed that skill positions receive a higher percentage of high-magnitude impacts, which can be explained by the greater distance and higher velocities involved in the impacts that they sustain.[23] Studies using clinical data (e.g., self-report or athletic trainer examination) have consistently found differences in concussion incidence across football player positions.[30–37] For example, using athlete self-report of concussion symptoms, Guskiewicz and colleagues found that linebackers and offensive linemen had the highest concussion rates per 1000 athletic exposures (AEs; exposure to a game or practice).[30] Based on self-report of concussion or postimpact symptoms, Delaney and colleagues found that tight ends and defensive linemen had the highest rates of diagnosed concussions in college football.[31] In an earlier study, Delaney and colleagues found that, in professional football, the highest incidence of concussion was among quarterbacks and running backs.[32] Pellman and colleagues utilized athletic trainer and team physician reports of concussion and indicated that, although defensive backs had the highest incidence of concussions in the National Football League (NFL), quarterbacks had the greatest risk of injury per 100 game AEs.[34] Other studies have combined clinically observed concussions with helmet sensor-based head impact data to generate concussion risk curves, including positional variation.[38–40]

Concussion symptoms vary across individuals, and this wide spectrum of symptomology increases the complexity of concussion diagnosis.[41] In football and other sports, concussions are often not diagnosed.[42–45] An undiagnosed concussion is problematic because athletes who sustain additional brain trauma while recovering from a previous injury are at risk of more-severe neurological consequences.[46–49] Given that many symptoms of a concussion are not readily visible to an observer,[50,51] timely removal from play and diagnosis usually depends on symptom disclosure by athletes to a coach, parent, athletic trainer, or team physician. Recent research suggests that symptom reporting is, at least in part, a motivational behavior, with athletes weighing the costs and benefits of reporting a possible concussion in their athletic environment.[45,52] Factors that athletes consider in this decision-making process include whether or not other athletes would report a concussion,[53] whether or not reporting a concussion means letting down the team,[43,45,54] or whether or not they think the injury is serious.[55] Concussion reporting intention can be considered an index of the motivational influences on concussion reporting.[56] It is not known whether the motivational aspects of reporting symptoms of a possible concussion vary systematically by football position. Therefore, understanding an athlete's intention to report a concussion, and whether it differs by playing position, is essential. Further, athletes sustain impacts during practice as well as competition; understanding how impacts sustained during practice differ by player position is critical.

In order to develop strategies to reduce concussions in football players, it is necessary to identify the football positions at highest risk and that are most likely to continue to play while symptomatic. This study examines the differences in self-reported concussion incidence, frequency of postimpact symptoms, intention to report concussion symptoms, frequency of returning to play while symptomatic following an impact, and the amount of contact during practice in a population of National Collegiate Athletic Association (NCAA) Division I Football Championship Series (FCS) athletes. Three hypotheses are tested: 1) Player positions that sustain more frequent head impacts based on helmet sensor studies (e.g., offensive linemen) will report more frequent postimpact symptoms, more undiagnosed concussions, and more ''dings'' than positions that sustain lower frequencies of head impacts; 2) high-frequency head impact positions (e.g., offensive linemen) will have lower intention to report concussions and will return to play while symptomatic more frequently than low-frequency head impact positions; and 3) linemen will report more frequent contact practices than skill players.

Methods

Sample and procedure

Using publicly available contact information, coaches and/or athletic trainers at 110 NCAA Division I FCS schools were contacted before the start of the 2013 football season and invited to have their team members participate in a survey-based research study about concussions in U.S. collegiate football. A convenience sample of 734 athletes from 10 teams whose coach and/or athletic trainer expressed interest participated in the study. Teams represented seven separate states, including those in the Northeast (four teams), the Midwest (five teams), and the South (one team). A

total of 230 athletes identified themselves as freshmen, 164 sophomores, 189 juniors, 134 seniors, and 17 ''other'' (primarily fifth-year students). Overall, 730 athletes indicated their primary playing position and were included in the present analyses. Detailed sample characteristics can be found in Table 1. All surveys were completed in person using paper and pen in a group setting. The same member of the research team (C.M.B.) described the study, distributed the surveys, answered any questions as they arose during survey completion, and collected surveys. All surveys were administered during the 2013 fall football season. Additional articles, including data from the larger study, can be found elsewhere.[57,58] All research activities were approved by the institutional review board at Boston University Medical Campus (Boston, MA), and all athletes provided informed consent prior to participation.

Measures

Concussion frequency. Athletes were asked to write in their numeric responses to a series of questions related to concussions and suspected concussions sustained while playing football. These included the following three questions, with regard to two separate time points (last football season [2012] and their entire football career): ''How many times have you been diagnosed with a concussion by a medical professional (doctor, athletic trainer, nurse)?''; ''How many times have you sustained an impact that you suspect was a concussion but that was never diagnosed?''; and ''How many times did you get a ding or get your bell rung?''

Returning to play while experiencing symptoms. Athletes were asked to write in their numeric responses to the question, ''How many times have you returned to a game or practice while experiencing symptoms after a hit?'' with respect to the 2 weeks preceding the survey, the 2012 football season, and their entire football career. Additionally, using items adapted from Kaut and colleagues' Head Injury Questionnaire (HIQ),[59] athletes were also asked how frequently the following things happened to them in the 2012 football season: experienced symptoms after a hit but continued to play in a game or practice; experienced symptoms after a hit but did not tell coaches or athletic trainers; and experienced symptoms the day after a hit but did not report them. Responses options were: never; once per season; once per month; once per week; once per day; or more than once per day.

Frequency of concussion-related symptoms. Using items adapted from Kaut and colleagues' HIQ,[59] athletes were asked how frequently each of the following things happened to them during the 2012 football season: dizziness after a hit; had their bell rung; lost consciousness after a hit; saw stars after a hit; vomited or felt nauseous after a hit; forgot what to do on the field after a hit; headache at least once during the week after a hit; and problems studying, concentrating, or doing classwork after a hit. Responses options were: never; once per season; once per month; once per week; once per day; or more than once per day.

Concussion reporting intention. Athletes were asked to indicate how strongly they agreed with the following statement: ''I intend to report my concussion symptoms,'' using a 7-point Likert scale with response options ranging from 1 (strongly disagree) to 7 (strongly agree).

Contact practice. Athletes were asked to write in their numeric responses to questions regarding the frequency of participation in various types of football practices. The item stem was, ''In a typical game week, how many times per week do you have…'' with the following specific options appended: full-contact practice (includes tackling to the ground and hitting drills); full pads, limited contact practice; half pads/shells/uppers practice; and helmets only/walk through practice.

Demographic characteristics. Athletes were asked to select their year in school, age in years, age at which they began playing contact football, duration of their football career to date, and their primary football playing position.

Statistical analysis

All analyses were conducted using SPSS statistical software (v.20; SPSS, Inc., Chicago, IL). An alpha level of 0.05 was used for all analyses. Based on precedent in previous literature,[29–33] responses to primary playing position were combined into the following nine position groups: offensive linemen (includes: offensive center, guard, and tackle); defensive linemen (includes: defensive end and defensive tackle); running backs (includes: fullback and running back); linebackers (includes: middle linebacker and outside linebacker); defensive backs (includes: cornerback and safety); special teams (includes: punter and kicker); tight ends; wide receivers; and quarterbacks. When coding the numbers of diagnosed concussions, undiagnosed concussions, and ''dings,'' only numeric entries were included with the exception of the following: ''none'' was entered as 0; ''couple'' was entered as 2; and ''few'' was entered as 3. When ranges were written, the average was used (e.g., 5–10 was coded as 7.5). When responses such as ''10+,'' ''10's,'' or ''≥ 10'' were written, the lowest value endorsed was coded (for all examples provided, 10 would have been coded). Ten percent of the data were randomly selected and entered by a second coder to assess data entry error, which was found to be $<0.01\%$. One-way analysis of variance (ANOVA) was used to examine differences between position groups in the following outcome variables: symptom frequency; intention to report concussion symptoms; returning to play with symptoms; and practice style frequency. Differences in respondent demographic characteristics by playing position were similarly assessed. Following a significant F test, Tukey's post-hoc tests were used to examine differences between position-group categories. Kruskal-Wallis' nonparametric ANOVAs were used to examine differences in concussion-diagnosis outcomes and write in return to play outcomes between position groups, given that these outcomes were not normally distributed based on measures of skewness and kurtosis. All outcome variables were then examined using generalized linear model (GLM) regressions to examine whether differences by primary playing position may be attributable to team membership or differences in duration of football career. Offensive linemen were selected as the referent position group for all GLM regressions.

Results

Demographic information

There were significant differences by position group in the age at which athletes started playing football ($F(8,719)=6.44$; $p<0.001$) and the total duration of athletes' football careers ($F(8,719)=6.72$; $p<0.001$). Notably, offensive linemen began playing football at a significantly older age than linebackers, defensive backs, running backs, and wide receivers; special team players reported significantly shorter careers than all other positions. Full details are in Table 1. Because number of years of collegiate football has been associated with an increase in clinically observed neurological symptoms,[60] and because duration of contact sports exposure has been linked to increased risk and severity of neurological impairment,[12,61] duration of football career was included in subsequent GLM regression analyses as a linear covariate. There were no significant differences in age ($F(8,718)=1.17$; $p=0.32$) or year in school ($F(8,721)=1.20$; $p=0.30$) by position group. Teams did not have significantly different positional composition ($F(9,720)=0.68$; $p=0.73$).

Table 1. Survey Respondents and Position Group Demographic Characteristics

	No. (%)											
	Overall	*OL*	*DL*	*RB*	*LB*	*DB*	*ST*	*TE*	*WR*	*QB*	p *value*[a]	*F*[a]
Total respondents	730	128 (17.5)	102 (14.0)	71 (9.7)	110 (15.1)	122 (16.7)	30 (4.1)	42 (5.8)	85 (11.6)	40 (5.5)		
Freshmen	229	34 (14.8)	33 (14.4)	28 (12.2)	32 (14.0)	35 (15.3)	16 (7.0)	10 (4.4)	27 (11.8)	14 (6.1)	0.30	1.20
Sophomores	162	31 (19.1)	23 (14.2)	13 (8.0)	30 (18.5)	26 (16.0)	5 (3.1)	11 (6.8)	13 (8.0)	10 (6.2)		
Juniors	189	33 (17.5)	22 (11.6)	16 (8.5)	29 (15.3)	36 (19.0)	6 (3.2)	15 (7.9)	26 (13.8)	6 (3.2)		
Seniors	133	23 (17.3)	22 (16.5)	14 (10.5)	14 (10.5)	24 (18.0)	3 (2.3)	6 (4.5)	17 (12.8)	10 (7.5)		
Fifth-year seniors	17	7 (41.2)	2 (11.8)	0 (0.0)	5 (19.4)	1 (5.9)	0 (0.0)	0 (0.0)	2 (11.8)	0 (0.0)		
	Mean (SD)										p *value*[a]	*F*[a]
Age at time of survey (years)	19.86 (1.49)	20.06 (1.51)	19.94 (1.55)	19.73 (1.60)	19.77 (1.39)	19.80 (1.39)	19.27 (1.31)	19.76 (1.34)	19.99 (1.59)	19.93 (1.61)	0.32	1.17
Age started contact football (years)	9.71 (2.97)	10.63 (2.77)	10.20 (3.18)	9.19 (2.77)	9.19 (2.82)	8.88 (2.92)	11.93 (2.85)	9.62 (2.92)	9.33 (2.88)	9.55 (2.66)	<0.001[b]	6.44
Duration of contact football career (years)	10.19 (3.03)	9.61 (3.00)	9.57 (2.93)	10.34 (2.99)	10.68 (2.95)	11.05 (2.83)	7.40 (2.81)	10.05 (3.26)	10.77 (2.99)	10.38 (2.61)	<0.001[c]	6.72

[a]*p* values reflect differences in outcomes between position groups based on one-way analysis of variance.
[b]Age started full-contact football significant positional differences from Tukey's post-hoc tests: ST > (TE, QB, WR, RB, LB, DB).
[c]Duration of contact football career significant positional differences from Tukey's post-hoc tests: DB > (OL, DL, ST); ST < (OL, DL, RB, LB, DB, TE, WR, QB).
OL, offensive linemen; DL, defensive linemen; RB, running backs; DB, defensive backs; ST, special teams; TE, tight end; WR, wide receiver; QB, quarterback; SD, standard deviation.

Diagnosed concussion, undiagnosed concussion, and "dings"

Kruskal-Wallis' H tests showed significant differences by primary playing position in career undiagnosed concussion ($\chi^2(8) = 22.88$; $p = 0.004$), as well as career ''dings'' ($\chi^2(8) = 38.92$; $p < 0.001$), 2012 undiagnosed concussion ($\chi^2(8) = 23.09$; $p = 0.003$), and 2012 ''dings'' ($\chi^2(8) = 46.22$; $p < 0.001$). There were no significant differences in diagnosed concussions in either time frame queried. Less than half of athletes reported having one or more diagnosed concussions in their football career (37.9%), and only 11.9% indicated that they had one or more diagnosed concussions in the previous football season. Means and Kruskal-Wallis' test results are reported in Table 2. Utilizing GLM regression to control for career duration and team membership, all previously significant outcomes remained for the overall models; however, position was not a significant predictor of career ''dings.'' Notably, offensive linemen reported significantly more undiagnosed concussions during the 2012 football season than all other position groups besides defensive linemen. They also reported more ''dings'' in 2012 than all other position groups, with differences reaching statistical significance in the majority of cases. Regression analyses of concussion-related outcomes by position and differences between position groups are reported in Table 3.

Self-reported frequency of postimpact symptoms

Results of one-way ANOVA analysis indicated that there were significant differences by position group in frequency several of postimpact symptoms: dizziness ($F(8,713) = 6.42$; $p < 0.001$); getting your ''bell rung'' ($F(8,716) = 8.63$; $p < 0.001$); seeing stars ($F(8,715) = 4.21$; $p < 0.001$); headache ($F(8,715) = 6.55$; $p < 0.001$); and concentration difficulties ($F(8,715) = 2.8$; $p = 0.004$). Athletes reported that these symptoms occurred relatively infrequently, with the group means indicating that these types of symptoms were experienced between once per month and once per season. The more clinically observable symptoms (loss of consciousness [LOC] and vomiting) did not have significantly different frequencies between position groups. These symptoms were reported as being experienced very infrequently or never. Means and ANOVA results, including specific between-position differences in symptom frequency, are reported in Table 4. In GLM regressions controlling for team membership and career duration, there were significant differences in postimpact symptom frequencies by position group. For example, offensive linemen reported significantly more-frequent dizziness than all other playing positions besides tight ends and linebackers as well as significantly more-frequent headache than all other position groups besides tight ends, linebackers, and running backs. Regression analyses examining differences in symptom frequencies by position, and specific between position group differences, are reported in Table 5.

Concussion reporting intention and returning to play while symptomatic

Results of a one-way ANOVA indicate that intention to report concussion was significantly different by position group ($F(8,716) = 1.98$; $p = 0.046$). However, a GLM regression examining differences in concussion reporting intention by position group, controlling for career duration and team membership, was not significant overall. Self-reported frequencies of returning to play while symptomatic ($F(8,716) = 6.10$; $p < 0.001$), experiencing postimpact symptoms and not telling a coach or athletic trainer

TABLE 2. DIAGNOSED CONCUSSION, UNDIAGNOSED CONCUSSION, AND DING BY PRIMARY FOOTBALL POSITION

	No. (SD)											*Kruskal-Wallis H*[a]
	Overall	*OL*	*DL*	*RB*	*LB*	*DB*	*ST*	*TE*	*WR*	*QB*	p *value*[a]	
During your football career												
Diagnosed concussion	0.64 (1.07)	0.68 (1.25)	0.64 (1.11)	0.71 (1.11)	0.54 (0.84)	0.66 (1.05)	0.37 (1.13)	0.79 (1.24)	0.65 (0.88)	0.74 (0.99)	0.50	7.33
Undiagnosed concussion	2.64 (4.51)	3.55 (5.52)	3.18 (6.24)	2.96 (4.84)	2.61 (3.80)	1.80 (2.73)	0.95 (1.86)	3.31 (4.63)	2.36 (4.12)	1.70 (1.89)	0.004	22.88
Ding	12.32 (44.09)	15.66 (33.72)	10.67 (16.68)	28.75 (129.04)	11.69 (18.89)	7.45 (14.47)	4.37 (9.93)	10.21 (16.28)	8.38 (14.91)	11.76 (14.19)	< 0.001	38.92
During the 2012 football season												
Diagnosed concussion	0.14 (0.50)	0.18 (0.42)	0.13 (0.37)	0.29 (1.13)	0.08 (0.31)	0.14 (0.37)	0.00 (0.00)	0.14 (0.42)	0.15 (0.45)	0.08 (0.27)	0.23	10.49
Undiagnosed concussion	0.85 (1.80)	1.38 (2.55)	0.93 (1.90)	0.78 (1.55)	0.89 (1.52)	0.66 (1.54)	0.16 (0.58)	0.70 (1.12)	0.81 (1.94)	0.39 (0.81)	0.003	23.09
Ding	3.00 (4.85)	4.55 (5.49)	2.62 (3.44)	3.32 (7.93)	3.46 (4.54)	2.24 (4.67)	0.59 (1.82)	3.18 (3.72)	2.36 (3.13)	2.58 (4.29)	< 0.001	46.22

[a]Reflects differences in concussion-related outcome between position groups, as measured by a Kruskal-Wallis' tests.
OL, offensive linemen; DL, defensive linemen; RB, running backs; DB, defensive backs; ST, special teams; TE, tight end; WR, wide receiver; QB, quarterback; SD, standard deviation.

Table 3. Regression: Positional Differences in Concussion Outcomes

	χ^2 (p *value*)	*B* (p *value*)								χ^2 (p *value*)		
	Overall	*OL*	*DL*	*RB*	*LB*	*DB*	*ST*	*TE*	*WR*	*QB*	*Position*	*Team*	*Duration*
During your football career													
Diagnosed concussion	18.69 (0.411)	Ref	−0.03 (0.851)	0.02 (0.899)	−0.17 (0.215)	−0.05 (0.734)	−0.27 (0.213)	0.08 (0.675)	−0.06 (0.707)	0.05 (0.808)	4.31 (0.828)	11.82 (0.224)	2.00 (0.158)
Undiagnosed concussion	33.74 (0.014)	Ref	−0.41 (0.492)	−0.66 (0.333)	−1.10 (0.064)	−1.79 (0.002)	−2.35 (0.010)	−0.39 (0.620)	−1.28 (0.042)	−1.93 (0.019)	17.60 (0.024)	14.42 (0.108)	0.77 (0.380)
Ding	36.49 (0.006)	Ref	−5.22 (0.383)	12.78 (0.063)	−5.70 (0.342)	−10.14 (0.081)	−9.87 (0.269)	−7.09 (0.380)	−8.60 (0.187)	−5.84 (0.469)	14.12 (0.079)	22.32 (0.008)	1.02 (0.312)
During the 2012 football season													
Diagnosed concussion	16.94 (0.527)	Ref	−0.05 (0.443)	0.10 (0.190)	−0.10 (0.117)	−0.04 (0.496)	−0.17 (0.100)	−0.05 (0.571)	−0.03 (0.669)	−0.11 (0.234)	10.57 (0.227)	5.95 (0.745)	0.33 (0.566)
Undiagnosed concussion	35.59 (0.008)	Ref	−0.46 (0.050)	−0.59 (0.027)	−0.53 (0.024)	−0.73 (0.001)	−1.16 (0.002)	−0.75 (0.017)	−0.58 (0.021)	−1.01 (0.002)	20.44 (0.009)	15.48 (0.079)	0.27 (0.601)
Ding	77.29 (<0.001)	Ref	−1.95 (0.002)	−1.20 (0.087)	−1.19 (0.053)	−2.48 (<0.001)	−3.68 (<0.001)	−1.59 (0.055)	−2.26 (0.001)	−2.18 (0.010)	29.46 (<0.001)	49.39 (<0.001)	1.73 (0.189)

Reflects differences in concussion diagnosis outcomes, based on GLM regression including position, team membership, and duration of football career.
OL, offensive linemen; DL, defensive linemen; RB, running backs; DB, defensive backs; ST, special teams; TE, tight end; WR, wide receiver; QB, quarterback.

Table 4. Positional Differences in Frequency of Postimpact Symptoms

	Mean[a] *(SD)*											
	Overall	*OL*	*DL*	*RB*	*LB*	*DB*	*ST*	*TE*	*WR*	*QB*	p *value*[b]	*F*[b]
Dizziness	2.19 (1.09)	2.54 (1.16)	2.26 (1.07)	2.11 (1.17)	2.35 (1.08)	1.97 (0.97)	1.41 (0.87)	2.61 (1.05)	1.92 (0.93)	2.00 (1.06)	<0.001[c]	6.42
Bell rung	2.53 (1.14)	2.86 (1.10)	2.50 (0.99)	2.46 (1.15)	2.82 (1.22)	2.23 (1.06)	1.35 (0.81)	2.90 (1.07)	2.47 (1.13)	2.43 (1.13)	<0.001[d]	8.63
Loss of consciousness	1.10 (0.41)	1.11 (0.44)	1.07 (0.29)	1.04 (.204)	1.13 (0.49)	1.12 (0.42)	1.00 (0.00)	1.07 (0.26)	1.21 (0.64)	1.05 (0.22)	0.149	1.51
Saw stars	1.84 (1.00)	1.98 (1.07)	1.86 (0.99)	1.73 (1.05)	2.17 (1.08)	1.72 (0.97)	1.21 (0.56)	1.83 (0.92)	1.66 (0.80)	1.83 (1.01)	<0.001[e]	4.21
Vomited or felt nauseous	1.14 (0.46)	1.21 (0.53)	1.15 (0.46)	1.13 (0.34)	1.16 (0.56)	1.13 (0.44)	1.00 (0.00)	1.07 (0.26)	1.12 (0.52)	1.05 (0.22)	0.267	1.25
Forgot what to do on the field	1.29 (0.64)	1.30 (0.61)	1.33 (0.76)	1.24 (0.55)	1.45 (0.75)	1.21 (0.55)	1.10 (0.56)	1.20 (0.56)	1.27 (0.63)	1.35 (0.66)	0.087	1.74
Headache ≥1 time in week after hit	2.07 (1.15)	2.43 (1.27)	2.12 (1.06)	2.19 (1.21)	2.28 (1.28)	1.86 (1.04)	1.17 (0.66)	2.27 (1.07)	1.81 (0.99)	1.65 (0.89)	<0.001[f]	6.55
Concentration difficulties	1.47 (0.89)	1.66 (1.09)	1.57 (0.86)	1.53 (1.00)	1.56 (0.92)	1.25 (0.65)	1.17 (0.66)	1.56 (0.90)	1.35 (0.69)	1.35 (0.89)	0.004[g]	2.85

[a]Symptom frequency was measured on a 6-point scale ranging from 1 = never to 6 = more than once per day; higher mean scores indicate increased symptom frequency.
[b]Reflects differences in symptom and symptom reporting outcomes between position groups as measured by a one-way analysis of variance.
[c]Dizziness significant positional differences from Tukey's post-hoc tests: (TE, OL) > (DB, WR, ST); (LB, DL) > ST.
[d]Bell rung significant positional differences from Tukey's post-hoc tests: (TE, OL, LB) > (DB, ST); ST < (TE, OL, LB, DL, WR, RB, QB, DB).
[e]Saw stars significant positional differences from Tukey's post-hoc tests: LB > (DB, WR, ST); (OL, DL) > ST.
[f]Headache ≥1 time in week after hit significant positional differences from Tukey's post-hoc tests: OL > (DB, WR, QB, ST); LB > (QB, ST); (TE, RB, DL) > ST.
[g]Concentration difficulties significant positional differences from Tukey's post-hoc tests: OL > DB.
OL, offensive linemen; DL, defensive linemen; RB, running backs; DB, defensive backs; ST, special teams; TE, tight end; WR, wide receiver; QB, quarterback; SD, standard deviation.

Table 5. Regression: Positional Differences in Frequency of Postimpact Symptoms

	χ^2 (p value)	B (p value)									χ^2 (p value)		
	Overall	OL	DL	RB	LB	DB	ST	TE	WR	QB	Position	Team	Duration
Dizziness	72.62 (<0.001)	Ref	−0.29 (0.038)	−0.47 (0.003)	−0.21 (0.118)	−0.59 (<0.001)	−1.09 (<0.001)	0.04 (0.851)	−0.64 (<0.001)	−0.56 (0.003)	51.92 (<0.001)	21.22 (0.012)	0.93 (0.336)
Bell rung	113.93 (<0.001)	Ref	−0.37 (0.008)	−0.44 (0.005)	−0.09 (0.500)	−0.69 (<0.001)	−1.42 (<0.001)	0.00 (0.985)	−0.45 (0.003)	−0.49 (0.010)	68.81 (<0.001)	41.05 (<0.001)	7.56 (0.006)
Loss of consciousness	28.95 (0.049)	Ref	−0.04 (0.442)	−0.07 (0.228)	0.02 (0.764)	0.01 (0.916)	−0.11 (0.173)	−0.06 (0.447)	0.10 (0.091)	−0.07 (0.340)	11.87 (0.157)	17.15 (0.046)	0.16 (0.687)
Saw stars	68.47 (<0.001)	Ref	−0.12 (0.364)	−0.31 (0.032)	0.12 (0.343)	−0.34 (0.005)	−0.65 (0.001)	−0.22 (0.208)	−0.39 (0.003)	−0.22 (0.209)	31.99 (<0.001)	18.58 (0.029)	15.08 (<0.001)
Vomited or felt nauseous	42.15 (0.001)	Ref	−0.06 (0.291)	−0.09 (0.166)	−0.07 (0.236)	−0.10 (0.076)	−0.21 (0.022)	−0.16 (0.044)	−0.11 (0.078)	−0.18 (0.028)	10.78 (0.215)	32.53 (<0.001)	0.00 (0.959)
Forgot what to do on the field	36.90 (0.005)	Ref	0.03 (0.768)	−0.08 (0.378)	0.14 (0.093)	−0.10 (0.219)	−0.18 (0.179)	−0.12 (0.289)	−0.05 (0.579)	0.04 (0.737)	13.41 (0.098)	20.97 (0.013)	1.72 (0.189)
Headache ≥1 time in week after hit	76.25 (<0.001)	Ref	−0.30 (0.037)	−0.27 (0.098)	−0.16 (0.271)	−0.60 (<0.001)	−1.24 (<0.001)	−0.20 (0.303)	−0.62 (<0.001)	−0.80 (<0.001)	54.37 (<0.001)	24.35 (0.004)	0.99 (0.319)
Concentration difficulties	47.97 (<0.001)	Ref	−0.07 (0.533)	−0.14 (0.292)	−0.13 (0.248)	−0.43 (<0.001)	−0.47 (0.009)	−0.13 (0.392)	−0.33 (0.006)	−0.34 (0.030)	25.06 (0.002)	23.84 (0.005)	1.18 (0.278)

Reflects differences in postimpact symptom frequency outcomes, based on GLM regression including position, team membership, and duration of football career.
OL, offensive linemen; DL, defensive linemen; RB, running backs; DB, defensive backs; ST, special teams; TE, tight end; WR, wide receiver; QB, quarterback.

($F(8,715) = 5.29$; $p < 0.001$), and experiencing symptoms the day after a hit and not reporting them ($F(8,716) = 4.01$; $p < 0.001$) in the 2012 football season were all significantly different between position groups in ANOVA analyses. GLM regressions examining these outcomes, controlling for career duration and team membership, were significant overall (all omnibus p values < 0.001), and offensive linemen reported the highest frequencies in all categories, compared to all other position groups, reaching statistical significance in most cases. Kruskal-Wallis' H tests showed significant differences between position groups in returning to play while symptomatic in the 2 weeks preceding survey administration ($\chi^2(8) = 21.61$; $p = 0.006$), the 2012 football season ($\chi^2(8) = 34.46$; $p < 0.001$), and over the course of their football career ($\chi^2(8) = 32.31$; $p < 0.001$). In GLM regressions, controlling for team membership and duration of football career, these return-to-play outcomes remained significant for the 2 weeks preceding the survey and the 2012 football season. Offensive linemen reported returning to play while symptomatic during the 2012 football season significantly more frequently than all other positions except running backs. Full details of positional differences in intention to report concussions and returning to play with symptoms can be found in Tables 6 and 7.

Contact practice

There were significant differences in frequencies of types of practice by position group. Based on one-way ANOVAs, there were significant differences in full-contact ($F(8,641) = 4.80$; $p < 0.001$), half-pads ($F(8,667) = 2.24$; $p = 0.023$), and helmets-only–style practices ($F(8,665) = 2.62$; $p = 0.008$) between groups. Means and ANOVA results for positional differences in practice style can be found in Table 8. In GLM regressions, controlling for team membership, there were significant differences in all practice style frequencies (all omnibus test p values < 0.001). Notably, offensive linemen reported the highest frequency of full-contact practices, and significantly higher frequency of full-contact practices, compared to all position groups other than defensive linemen and tight ends. In all GLM regressions examining practice, team was a significant predictor ($p < 0.001$). Regression analyses examining practice style by position group are presented in Table 9.

Discussion

This study provides novel findings of positional differences in the frequency of some postimpact symptoms in NCAA Division I football players. Importantly, the symptoms that differed significantly across primary playing positions were those that are unlikely to be externally visible (e.g., headache, concentration difficulties, and dizziness), whereas externally visible symptoms (e.g., LOC and vomiting) were not different between position groups. Where there were position-based symptom differences, offensive linemen reported more-frequent symptoms than most other position groups. One possible interpretation of this finding is that the frequency of the impacts, linearity of forces, or total cumulative g force of the impacts sustained by linemen result in more-frequent symptoms. This could be consistent with previous research demonstrating a small, but measurable, increase in neurological symptoms associated with increased total impacts.[60] Alternatively, symptom recognition or willingness to report symptoms to researchers may vary systematically by primary playing position. An important consideration is the fact that many of the symptoms that varied by position could be a result of causes other than head impacts. As such, this finding should be replicated in studies using on-site

Table 6. Concussion and Concussion-Symptom Reporting Intention by Primary Football Position

	Mean[a] (SD)											
	Overall	*OL*	*DL*	*RB*	*LB*	*DB*	*ST*	*TE*	*WR*	*QB*	p *value*[d]	*F*[d]
Intention to report concussion symptoms[a]	5.00 (1.87)	4.52 (1.90)	4.85 (1.95)	5.10 (1.89)	5.00 (1.89)	5.20 (1.86)	5.27 (1.95)	5.05 (1.66)	5.09 (1.82)	5.63 (1.58)	0.046[e]	1.98
Experienced symptoms posthit, continued to play[b]	1.99 (1.23)	2.35 (1.41)	2.15 (1.15)	2.00 (1.39)	2.28 (1.32)	1.66 (0.98)	1.21 (0.77)	2.02 (1.24)	1.71 (1.00)	1.73 (1.01)	<0.001[f]	6.10
Experienced symptoms posthit, but did not tell coach or AT[b]	1.93 (1.16)	2.23 (1.32)	2.14 (1.30)	1.76 (1.11)	2.18 (1.19)	1.73 (1.04)	1.21 (0.77)	2.02 (1.13)	1.69 (0.89)	1.60 (0.87)	<0.001[g]	5.29
Experienced symptoms day after hit but did not report[b]	1.70 (1.07)	1.97 (1.32)	1.88 (1.10)	1.56 (0.90)	1.85 (1.15)	1.50 (0.86)	1.21 (0.77)	1.83 (1.14)	1.59 (0.98)	1.33 (0.62)	<0.001[h]	4.01
											p *value*[i]	*Kruskal-Wallis H*[i]
RTP with symptoms during football career[c]	6.65 (36.66)	6.97 (11.83)	5.68 (8.88)	21.06 (113.37)	6.95 (13.01)	2.72 (4.86)	1.43 (3.33)	5.35 (9.06)	3.93 (8.25)	5.19 (7.47)	<0.001	32.31
RTP with symptoms during 2012 football season[c]	1.74 (3.95)	2.95 (4.86)	1.77 (3.00)	2.22 (7.65)	2.09 (3.85)	1.08 (2.47)	0.25 (1.32)	1.37 (2.35)	1.11 (2.08)	0.94 (1.64)	<0.001	34.46
RTP with symptoms in 2 weeks preceding survey[c]	0.51 (1.40)	0.79 (1.70)	0.56 (1.32)	0.86 (2.57)	0.62 (1.53)	0.26 (0.72)	0.00 (0.00)	0.45 (0.77)	0.29 (0.62)	0.28 (0.89)	0.006	21.61

[a]Responses to intention outcomes were measured on a 7-point Likert scale, 1 = strongly disagree and 7 = strongly agree; higher mean scores indicate higher average agreement.
[b]Frequencies were measured on a 6-point scale, 1 = never to 6 = more than once per day during the 2012 football season; higher mean scores indicate increased symptom frequency.
[c]Return to play with symptoms following an impact measures were free response.
[d]Reflects differences in intention outcome between position groups, as measured by a one-way analysis of variance.
[e]Intention to report concussion symptoms significant positional differences from Tukey's post-hoc tests: OL > QB.
[f]Experienced symptoms posthit, continued to play significant positional differences from Tukey's post-hoc tests: (OL, LB) > (WR, DB, ST), DL > ST.
[g]Experienced symptoms posthit, but did not tell coach or AT significant positional differences from Tukey's post-hoc tests: OL > (DB, WR, ST); (LB, DL) > ST.
[h]Experienced symptoms day after hit, but did not report significant positional differences from Tukey's post-hoc tests: OL > (DB, QB, ST).
[i]Reflects differences in free-response RTP outcomes as measured by Kruskal-Wallis' test.
OL, offensive linemen; DL, defensive linemen; RB, running backs; DB, defensive backs; ST, special teams; TE, tight end; WR, wide receiver; QB, quarterback; SD, standard deviation; AT, athletic trainer; RTP, return to play.

Table 7. Regression: Concussion and Concussion-Symptom Reporting Intention by Primary Football Position

	χ^2 (p *value*)	*B* (p *value*)									χ^2 (p *value*)		
	Overall	*OL*	*DL*	*RB*	*LB*	*DB*	*ST*	*TE*	*WR*	*QB*	*Position*	*Team*	*Duration*
Intention to report concussion symptoms	25.97 (0.100)	Ref	0.30 (0.219)	0.58 (0.037)	0.55 (0.023)	0.74 (0.002)	0.61 (0.106)	0.52 (0.116)	0.63 (0.016)	1.14 (0.001)	17.75 (0.023)	4.70 (0.859)	5.44 (0.020)
Experienced symptoms posthit, continued to play	81.23 (<0.001)	Ref	−0.19 (0.222)	−0.36 (0.043)	−0.09 (0.554)	−0.72 (<0.001)	−1.12 (<0.001)	−0.36 (0.082)	−0.68 (<0.001)	−0.65 (0.002)	52.67 (<0.001)	32.82 (<0.001)	0.97 (0.324)
Experienced symptoms posthit, but did not tell coach or AT	76.87 (<0.001)	Ref	−0.07 (0.651)	−0.48 (0.004)	−0.08 (0.607)	−0.53 (<0.001)	−0.98 (<0.001)	−0.24 (0.232)	−0.57 (<0.001)	−0.66 (0.001)	45.82 (<0.001)	32.54 (<0.001)	2.85 (0.092)
Experienced symptoms day after hit, but did not report	55.53 (<0.001)	Ref	−0.06 (0.676)	−0.40 (0.010)	−0.12 (0.359)	−0.49 (<0.001)	−0.74 (0.001)	−0.17 (0.372)	−0.40 (0.006)	−0.66 (<0.001)	35.02 (<0.001)	23.00 (0.006)	1.09 (0.297)
RTP with symptoms during football career	27.05 (0.078)	Ref	−1.53 (0.765)	13.89 (0.016)	−1.51 (0.768)	−5.43 (0.272)	−4.95 (0.522)	−2.73 (0.684)	−4.55 (0.407)	−2.82 (0.683)	13.42 (0.098)	13.29 (0.150)	0.44 (0.508)
RTP with symptoms during 2012 football season	46.21 (<0.001)	Ref	−1.20 (0.022)	−0.79 (0.180)	−1.03 (0.049)	−1.94 (<0.001)	−2.59 (0.001)	−1.74 (0.012)	−1.90 (0.001)	−2.10 (0.003)	26.05 (0.001)	20.84 (0.013)	0.26 (0.609)
RTP with symptoms in two weeks preceding survey	39.59 (0.002)	Ref	−0.20 (0.284)	0.09 (0.664)	−0.18 (0.322)	−0.56 (0.002)	−0.77 (0.007)	−0.38 (0.121)	−0.53 (0.007)	−0.52 (0.041)	23.31 (0.003)	17.73 (0.038)	0.16 (0.689)

Reflects differences in intention and RTP outcomes, based on GLM regression including position, team membership, and duration of football career.
OL, offensive linemen; DL, defensive linemen; RB, running backs; DB, defensive backs; ST, special teams; TE, tight end; WR, wide receiver; QB, quarterback; AT, athletic trainer; RTP, return to play.

Table 8. Practice Style by Position Group

	Mean[a] *(SD)*											
	Overall	*OL*	*DL*	*RB*	*LB*	*DB*	*ST*	*TE*	*WR*	*QB*	p *value*[b]	*F*[b]
Full contact	0.96 (1.14)	1.35 (1.35)	1.23 (1.16)	0.89 (1.10)	0.81 (0.95)	0.56 (0.90)	1.00 (1.33)	1.08 (1.22)	0.87 (0.99)	0.64 (1.10)	<0.001[c]	4.80
Full pads	1.28 (1.06)	1.01 (1.06)	1.24 (1.22)	1.32 (0.87)	1.23 (1.00)	1.45 (1.05)	1.56 (1.05)	1.31 (1.20)	1.33 (0.98)	1.42 (1.00)	0.10	1.67
Half pads	1.68 (0.94)	1.42 (0.82)	1.63 (0.91)	1.60 (0.83)	1.68 (0.92)	1.80 (1.10)	1.64 (1.16)	1.85 (0.99)	1.90 (0.88)	1.80 (0.97)	0.02[d]	2.24
Helmets only	1.16 (0.61)	1.10 (0.52)	1.11 (0.62)	1.08 (0.41)	1.12 (0.45)	1.15 (0.50)	1.61 (1.37)	1.10 (0.37)	1.21 (0.59)	1.27 (0.93)	0.008[e]	2.62

[a]Response to practice style questions were free response.
[b]Reflects differences in practice type outcomes between position groups as measured by a one-way analysis of variance.
[c]Full contact significant positional differences from Tukey's post-hoc tests: OL > (LB, QB, DB); DL > DB.
[d]Half pads significant positional differences from Tukey's post-hoc tests: WR > OL.
[e]Helmets only significant positional differences from Tukey's post-hoc tests: ST > (DB, LB, DL, OL, TE, RB).
OL, offensive linemen; DL, defensive linemen; RB, running backs; DB, defensive backs; ST, special teams; TE, tight end; WR, wide receiver; QB, quarterback; SD, standard deviation.

Table 9. Regression: Practice Style by Position Group

	χ^2 (p value)	B (p value)									χ^2 (p value)	
	Overall	*OL*	*DL*	*RB*	*LB*	*DB*	*ST*	*TE*	*WR*	*QB*	*Position*	*Team*
Full contact	138.52	Ref	−0.12	−0.46	−0.49	−0.80	−0.37	−0.28	−0.48	−0.72	44.04	108.95
	(<0.001)		(0.385)	(0.004)	(<0.001)	(<0.001)	(0.100)	(0.144)	(0.001)	(<0.001)	(<0.001)	(<0.001)
Full pads	209.40	Ref	0.31	0.36	0.24	0.41	0.48	0.37	0.30	0.41	16.56	228.33
	(<0.001)		(0.014)	(0.011)	(0.051)	(0.001)	(0.014)	(0.028)	(0.024)	(0.016)	(0.035)	(<0.001)
Half pads	407.54	Ref	0.20	0.14	0.25	0.41	0.29	0.33	0.46	0.39	31.64	526.10
	(<0.001)		(0.041)	(0.180)	(0.007)	(<0.001)	(0.050)	(0.010)	(<0.001)	(0.003)	(<0.001)	(<0.001)
Helmets only	90.67	Ref	0.01	−0.03	0.04	0.05	0.46	0.00	0.08	0.18	19.99	73.53
	(<0.001)		(0.893)	(0.704)	(0.635)	(0.480)	(<0.001)	(0.992)	(0.349)	(0.092)	(0.010)	(<0.001)

Reflects differences in practice style outcomes across position group, measured by GLM regression including team membership and position.
OL, offensive linemen; DL, defensive linemen; RB, running backs; DB, defensive backs; ST, special teams; TE, tight end; WR, wide receiver; QB, quarterback.

clinical evaluation and helmet sensor data, taking into account primary playing position.

This study also adds novel findings regarding differences in undiagnosed concussions and ''dings'' between position groups. There were no significant differences in diagnosed concussions across position groups. In this study, position groups that indicated that they sustained more-frequent, less externally visible postimpact symptoms (e.g., offensive linemen) also indicated that they sustained more impacts that they suspected were concussions, but went undiagnosed, and more ''dings.'' Finding no significant differences in diagnosed concussion across position groups is in contrast to the results of previous studies[30,31] and highlights the complex nature of the concussion diagnosis process,[41] which often relies on honest athlete report of symptoms. It is also possible that there are position-based differences in accepted reporting behavior. Previous research has discussed motivational aspects of concussion reporting and has utilized models of rational behavior to analyze athlete report and nonreport of symptoms.[43–45,52–54] However, these models have not yet incorporated differences based on playing position or specific concussion symptoms.

One factor that may contribute to the differences in symptom frequency, undiagnosed concussions, and ''dings'' is the difference between positions in contact sustained during practice. Offensive linemen reported participating in more full-contact practices on a weekly basis than all other position groups and significantly more than all position groups other than tight ends and defensive linemen. Additionally, offensive linemen reported participating in fewer ''full pads, limited contact'' practices than other position groups. These differences may be attributable, in part, to purposeful coach decisions (e.g., choosing more full-contact drills for these positions) and, in part, to differences in positional responsibilities (e.g., skill positions can practice route running and coverage without contact, whereas linemen cannot practicing blocking and rushing the quarterback without contact). It is important to note that athletes may experience a different level of contact in a given practice dependent on their primary playing position. Examining the extent to which practices may be modified to minimize contact is an important step and one that has been taken by NCAA conferences, such as the Ivy League and PAC-12,[62,63] and that has recently been suggested for implementation at all institutions by the NCAA's recent Concussion Management Best Practice Guidelines.[64] However, understanding that the seemingly routine contact experienced by linemen may be leading to symptoms, it is important that these rules clearly define what is meant by contact practices in order to reduce the brain trauma experienced by all athletes, including linemen.

Given the known difference in impacts experienced across playing positions, it is possible that athletes experiencing more-frequent impacts begin to consider them a routine or normative aspect of their positional role and feel less compelled to report symptoms that may result. This is supported by this study's finding that offensive linemen report returning to play while experiencing postimpact symptoms significantly more frequently than almost all other position groups during the 2012 football season. One of the most important individual-level predictors of the likelihood that an individual performs a behavior is their intention to perform that behavior.[56] In this study, 67.0% of football players indicated that they intended to report their concussion symptoms, whereas 23.4% indicated that they did not intend to report concussion symptoms, and 9.6% neither agreed nor disagreed that they intended to report symptoms. Although intention to report concussion symptoms was different between position groups in initial ANOVA analysis, when

controlling for team membership and duration of football career, the differences between positions were no longer significant. Though position-based differences are important, there are other contextual factors, such as perceived support from the coach for concussion reporting,[57] that may contribute to concussion reporting and concussion reporting intention in this population. Further research is needed to examine factors influencing the concussion reporting decisions made by football players and whether rationales for reporting (or nonreporting) vary systematically by playing position.

Although concussions and other brain trauma are an important area of scientific inquiry, terminology used to describe head impact phenomena are not wholly agreed upon or used uniformly. There are several definitions regularly used to describe concussion, such as those set forth by the AMSSM,[26] American Academy of Neurology,[65] National Athletic Trainer's Association,[3] and Zurich Concussion Conference.[9] Although use of terms such as ''ding'' and ''bell ringer'' has been discouraged,[3] these colloquialisms are still commonly used in the athletic community to indicate an impact that results in transient symptoms. Subconcussive head impacts have become part of the discussion surrounding head trauma, particularly with regard to the possible long-term outcomes, such as CTE.[11,12,66] In its earliest uses in the literature, subconcussive impact was meant to describe a head impact that did not result in severe, noticeable symptoms, particularly LOC.[67] Today, this term is sometimes used to mean an impact that is asymptomatic[11,68,69] and other times more generally used to mean an impact that is not concussive.[60,66,70–72] The findings of this study indicate that the regular hits taken by offensive linemen are leading to more-frequent postimpact symptoms than other positions, but are more frequently left unreported, possibly owing to their routine nature. Symptom frequency differences are prominent for those symptoms that may not be outwardly visible (e.g. dizziness and headache). Understanding the extent to which an impact leads to, or does not lead to, symptoms is not always possible without athlete honesty. Thus, it may be the case that many of the impacts that have been referred to as ''subconcussive'' in the modern literature, with the intention of representing impacts that did not result in acute symptoms, may have actually been symptomatic impacts left unreported. This is not just a semantic distinction; measuring impact frequency or magnitude is a very different activity than measuring postimpact symptoms. Understanding the extent to which the overall head impact exposure (including both symptomatic and asymptomatic impacts), as opposed to solely the symptomatic head impacts, affect short-term cognitive and neurological outcomes as well as later-life neurodegenerative outcomes is critical and warrants future investigation. Further, insofar as the terms ''subconcussive impacts'' or ''subconcussion'' continue to be utilized in the dialog surrounding brain trauma, it is important to recognize that the lack of concussion diagnosis does not necessarily mean that an impact was asymptomatic.

In recent years, football leagues, including the NFL and the NCAA, have adopted rules to improve concussion safety. These rule changes have most often attempted to penalize or reduce the frequency of large noticeable hits (e.g., eliminating the wedge to reduce concussion frequency on kick-off return and penalizing hitting defenseless players). The results of this study indicate that the routine impacts sustained by lineman may cause them to experience postimpact symptoms more frequently during a football season, when compared to skill players. However, the types of impacts routinely sustained by linemen have not been addressed by existing rule changes. As Bailes and colleagues[66] have previously noted, although the literature on subconcussion is growing, there is not yet sufficient evidence to create recommendations regarding a safe or unsafe number of these impacts. However, this study's findings should be considered as future rule changes are made, in order to improve sport safety and reduce the short- and long-term risks associated with repetitive head impacts for all football players.

Limitations

A primary limitation of this study is its generalizability. Team participation required coach and/or athletic trainer endorsement, and consequently the participating teams may have been different from those declining participation in ways potentially related to concussion risk and reporting. Additionally, although teams came from multiple states and regions of the United States, they include only a small fraction of NCAA Division I FCS teams or athletes and thus may not be representative of NCAA Division I FCS as a whole or generalizable to other levels of competition. The use of retrospective self-report survey data introduces the possibility of inaccurate or biased recall of the experience of concussion diagnosis, postimpact symptoms, or return-to-play frequency. Given the potentially sensitive nature of the topics, there is also the possibility of social desirability bias having influenced the results. Although 730 athletes participated in this study, not all athletes provided responses to all questions. The questions with write-in responses had the additional limitation of noncodeable/nonquantifiable responses (e.g., writing ''lots'' as a response to the number of undiagnosed concussions). However, chi-squared tests of independence indicated that there were no significant differences between responders, nonresponders, and those who provided unquantifiable responses on diagnosed concussion, undiagnosed concussion, ''ding,'' and return-to-play questions with write-in responses, across primary playing position. In addition, because the larger study sought to examine athlete knowledge of concussion signs and symptoms, no formal definition of concussion was provided. It is possible that there were systematic differences between participants' concepts of concussion, and these differences may have impacted responses to questions regarding number of diagnosed or undiagnosed concussions.[73] This survey asked about symptom frequency, but not symptom duration or severity; future research should investigate whether these other symptom metrics vary by playing position. Although this study found significant differences between position groups in a variety of outcomes, it is unclear whether the differences on this self-report survey translate into clinically measurable health differences in these athletes. The symptoms reported are associated with concussion; importantly, these symptoms are nonspecific to concussion and could be the result of a variety of factors, such as stress or dehydration. Future studies that combine the self-report methodology used in the present study with more objective assessments of postimpact symptoms across position groups are needed, as is prospective and longitudinal study in this area.

Conclusion

Collegiate football athletes playing positions that experience more-frequent, but lower-intensity, hits, based on previous helmet sensor studies (e.g., offensive linemen), report experiencing more-frequent postimpact symptoms, more undiagnosed concussions, and report that they more frequently continued to play despite concussion symptoms. This suggests that these more routine, but lower-magnitude, impacts may have clinically relevant, yet undiagnosed, manifestations, and that athletes incurring these regular symptomatic impacts may see postimpact symptoms as

routine and not worthy of reporting to a medical professional. Strategies for risk reduction consistent with these findings include position-targeted concussion education for athletes, increased awareness by sports medicine clinicians about between-position variability in symptoms and symptom reporting, and, ultimately, rule changes to reduce the frequency of these types of impacts. Given the known short- and long-term health consequences of concussions and other brain trauma, it is imperative that we work toward protecting the health of all athletes, and results of this study provide critical evidence to inform appropriate strategy.

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