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Injuries to High School Football Athletes in California

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Background: Among all high school sports, football has the highest rate of injury. Prior research has been limited primarily because of challenges in surveillance, defining injuries, and measuring exposures.

Hypothesis: Football injury patterns differ across player and session characteristics.

Study Design: Descriptive epidemiology study.

Methods: More than 5000 football players from 87 high schools in California were observed for 2 seasons (2001 and 2002). School representatives were trained to collect data on injuries, player characteristics, and daily exposures. Data were analyzed using descriptive statistics and clustered Poisson regression.

Results: Players sustained 25.5 injuries per 100 players, 9.3 injuries per 10 000 player-hours, and 8.4 injuries per 100 session-hours. Session rates were highest during games, on artificial turf (13.8 of 100), during foggy weather (25.1 of 100), and on clear evenings (21 of 100). Offensive and defensive backfielders had about a 20% increased rate of injury compared with linemen. The adjusted injury rate for starters was 60% higher than the rate for nonstarters (relative rate, 1.6; 95% confidence interval, 1.4-1.9).

Conclusion: Risk profiles differed by experience, playing position, and surface types. We recommend future sports injury research that measures time-dependent exposures at the individual level and for various types of environmental playing conditions.

Keywords: injury; football; high school sports; epidemiology; risks

According to the National Federation of State High School Associations, 1.5 million preadolescent and adolescent boys participate in high school football.[29] In California, football is the most popular boys' sport among high schools, with approximately 97 000 players during the 2001-2002 school year.[6] Although involvement in sports is associated with self-reported mental and physical health benefits, it is also related to injury.[31] With the increase of participation in varsity football each year, there has been an increase in the number of injuries.[36] Approximately 300 000 to 1 215 000 boys sustain football injuries each year,[4,17,22,23] and this sport has the highest rate of fatal and nonfatal injuries. Between 1977 and 1998, the death rate was 0.70 per 100 000 football players, and the rate of catastrophic injuries, defined as those resulting in severe neurologic disability, was 1.65 of 100 000 players.[7]

Most adolescent injuries seen in hospitals, emergency rooms, and primary care visits have been attributed to high school sports, with 25% to 50% of injuries sustained while playing football requiring hospitalization.[5,8,16] In 1977, the estimated cost per football injury was $177.95,[28] and a later study in 1986 estimated the average cost of each football injury to be $211.09.[33]

To prevent these injuries, well-designed surveillance should be conducted to obtain accurate risk profiles. One significant challenge in conducting surveillance is the lack of a consensus among experts in defining injury.[27,32] For example, most researchers have defined injuries as events resulting in lost time from practices or games,[13,32] whereas others defined injuries as events requiring some type of medical treatment.[24] The various mechanisms of reporting injuries also complicate surveillance and include direct interviews, school-generated reports, medical records, questionnaires, and insurance claims.[28,32] A further limitation in earlier studies of football injury is that measures of injury

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frequency are rarely, if ever, expressed as a function of time exposed to an activity.[15,32,35]

A cohort study in California was undertaken to describe the epidemiology of high school football injuries. The specific aims of this project were to determine the types and body locations of these injuries and to calculate rates by selected player characteristics and exposure conditions. It was hypothesized that football injuries among high school athletes follow different patterns by player and session characteristics.

MATERIALS AND METHODS

Study Population and Recruitment

In 2001, we attempted to obtain a representative sample of 100 of 1212 California Interscholastic Federation (CIF) high schools in California through telephone and mail recruitment. When a representative sample of schools could not be achieved in this manner, "snowball sampling" was implemented; that is, schools that had already committed to participate assisted with the recruitment of additional schools in their districts. Of 1212 CIF schools, we enrolled a total of 91 high schools into the study, but by the end of the 2001 season, only 48 high schools completed data collection.

All 91 schools from 2001 were invited to re-enroll in the second season, 2002. To recruit additional schools to increase the sample size, our enrollment efforts focused on 3 CIF sections geographically close to the researchers, sections VIII and IX in Los Angeles County and section X in San Diego County. Members of the research team conducted recruitment meetings, mass mailings, and telephone calls to schools from these 3 sections. Of 1217 CIF high schools in 2002, 678 high schools were invited to enroll in the 2002 season. Of the 678 invited schools, a total of 98 schools enrolled. At the end of the season, a total of 64 high schools completed data collection, and 34 dropped from the study for a drop rate of 35%. The final sample for the 2 seasons was a heterogeneous group of public and private schools of different student population sizes from various geographic communities in California. Together, for 2001 and 2002, a total of 87 schools enrolled into the study, with 48 schools in 2001 and 64 in 2002. A total of 25 schools participated in both seasons.

Data Collection

Coaching staff, certified athletic trainers, team managers, or student volunteers collected data. Because of differing levels of medical knowledge and skill, we made attempts to standardize data collection efforts through training and intense follow-up. Furthermore, a coach or athletic trainer supervised student data collectors, and research personnel conducted follow-up with both supervising school staff and student trainees. Research personnel also provided a training session for data collection either by telephone or in person. Each participant was provided an instruction manual, 3 data collection forms, and prepaid self-addressed envelopes. Definitions of terms including body locations and injury classifications were included in the instruction manual. Data were submitted to researchers biweekly throughout the season, and all schools were contacted periodically by telephone or site visit. A toll-free number was provided to contact study researchers for any questions.

Definitions. Injuries were defined as (1) physical trauma to a player resulting in the player either leaving a game or practice session or missing the next subsequent game or practice session or (2) a concussion, fracture, or dislocation sustained by a player, regardless of time lost. Concussions were defined as head injuries resulting in brain function disruptions. Because of potential difficulty in assessing concussions, data collectors were further asked to describe the presence and duration of loss of consciousness, memory loss, repetitive questioning, confusion, and dizziness. Injuries that did not result in lost time, for example, athletes with chronic injuries or minor injuries who were taped or braced and then returned immediately to play, were not included as an injury case, as this study focused on injuries resulting in significant lost time and/or use of medical resources (ie, fractures, dislocations, concussions). Injured players were defined as players who sustained 1 or more injuries during the season of play. Injury events were defined as the incidents in which an injury occurred. Player injury rates were defined as the number of injured players per 100 players. Player-hour injury rates were defined as the number of injured players per 10 000 player-hours. Session injury rates were defined as the number of injury events per 100 session hours of game or practice play. The relative rate (RR) is the ratio of 2 incidence rates.

Player Characteristics. A trained school representative was asked to complete a team roster of all eligible varsity players form at 3 different times during the season. The first roster was completed at the beginning of the football season and included each player's height, weight, date of birth, year in school, position, and whether he was a starter. Starters are players who start games and play a significant amount of time during games. School data collectors reported height and weight by abstracting the information from existing school athletic records. Body mass index (BMI) was calculated by dividing weight (in kilograms) by height squared (in meters) obtained from the first roster. Two additional rosters were used to collect data in the middle and end of the season to monitor any changes, including position, starter status, and the loss or addition of new players. The coach, athletic trainer, or athletic director generally completed the rosters.

In the second year, the project was expanded to collect additional preseason information on players. Members of the research team attended 1 practice session for each team within the first month of the season to administer a baseline questionnaire on all football players. Players present during this session self-reported their year in school, weight, height, current football playing position, history of any medically attended injury in high school, sports-playing experience (both school-sponsored and community), and high school exercise regiment. For this report, baseline player characteristics were collected primarily from rosters; in cases in which roster data from 2002 were missing, data from all rosters and player questionnaires were combined to obtain a complete player profile.

Team-Level Exposures. School representatives were also asked to complete a daily activity tracking form to describe each activity session (eg, conditioning, practice, away or home games). Data were also collected on weather, playing surface composition, and time duration of each playing session. It was not feasible to gather player exposure hours at the individual level, as our school representatives had limited time to collect additional detailed data. Hence, under assumptions of a stable population, player exposure hours were calculated from these team level estimates (see Analysis section below). Exposure data were collected by all school representatives (ie, coaches, athletic trainers, student managers or volunteers).

Injuries. A systematic injury reporting system was implemented to identify and describe all injuries occurring during the study period. Each high school representative (ie, coach, athletic trainer, student manager, or student volunteer supervised by an adult) was requested to provide biweekly reports on injuries sustained by the football players. The data collected included the nature and severity of injury, mechanism, activity at time of injury, player's position, and type of medical treatment received. Injuries were validated by seeking other in-house reporting mechanisms for documenting injuries at schools. However, most schools did not have any other available system used for routinely reporting sports injuries. For a subset of schools, primarily those with certified athletic trainers and student volunteers supervised by certified athletic trainers, overall agreement was calculated by dividing the number of cases ascertained through our reporting mechanism by the number of cases reported in-house at school sites.

For the second season of data collection, 2002, additional information about lost time and the treatment of injuries was collected. Data collectors were asked to report the number of missed practice or game days, the number of school days lost, and if the player quit the team because of the injury. For medical treatment, data collectors reported whether players with injuries were immediately transported to a hospital or were referred to a physician for further medical care.

Study staff screened all data forms for nonsense errors or missing data. Forms with questionable entries were sent back to school representatives for corrections. After screening and editing, data were entered into a Paradox (Corel Corporation, Ottawa, Ontario, Canada) electronic database, examined for data entry errors, and coded by staff. Player questionnaires, rosters, and injury forms used a unique player identification code devised by the school representative, whereas exposure forms had a school code and data ascribed to each activity day. Data were linked first across player questionnaires, rosters, and injuries using the player identification code. Then, exposure data were aggregated by school and linked to each player from that school. Injuries were also linked to exposure data by matching schools and date of injury to the corresponding exposure activity day.

The project was initially designed as a 1-season study and then was expanded with supplemental funds. Changes in staff and school representatives at the respective schools posed challenges in locating prior season paperwork. Furthermore, the keys linking identification codes to individual subjects were not available to the researchers as stipulated by the Institutional Review Board at the University of California, Los Angeles (UCLA). Injury cases not linked to exposure and roster data were excluded from analysis. A total of 25 schools participated in both seasons, and data were combined across the 2 playing seasons (2001 and 2002).

This study was approved by the UCLA Committee for Human Subjects Protection. Parents or guardians of all players on all teams consented before enrollment into the study. There were no refusals to participation.

Analysis

Data were imported into Statistical Analysis Software (SAS version 8.1, SAS Institute, Cary, NC). Univariate and bivariate distributions, rates, and RRs were estimated using SAS.

Data were combined from the 2 seasons to calculate 3 types of average rates: player rates, player-hour rates, and session rates. The numerator to calculate the player rates is the number of injured players suffering 1 or more injuries during the season of play, and the denominator is the number of players.

For player-hour rates, the numerator is the number of injured players. Player hours per season, the denominator, was estimated for all players using the individual roster and daily team exposure data at the beginning, middle, and end of the season rosters. It was assumed that players listed on a specific roster were exposed to the same amount of playing or game time. Each roster was assigned an estimated amount of game or practice exposure time, representing a segment of time for the season. Hence, players present in the beginning roster were assumed, on average, to be exposed to one quarter of the total amount of hours played by his team for the entire season. Players present on the middle roster (the more stable roster) were allocated one half of the total amount of team hours; players in the end of the season roster, which is likewise subject to change, were given one quarter total hours played by his team. Because individual level information on playing time and absenteeism was unavailable, exposure estimates did not account for time loss due to injury or other reasons, for example, illness or unexcused absenteeism. Player-hour rates were calculated by position, starter or nonstarter status, and year in school.

Session rates were injury events per 100 session hours of play. The denominator was an accruement of exposure minutes played during each playing session by each team and hence captures exposure time at the team level. The numerator is the sum of all injuries occurring within an exposure session of interest. Rates were then calculated across characteristics of sessions, such as weather conditions.

Because exposure time was not measured individually, a sensitivity analysis was conducted whereby rates were adjusted to account for potential differences in playing time by player characteristics. We asked coaches and CIF section representatives to provide best estimates of relative playing time for starters and nonstarters. Game exposure time, where exposure time was reported to be differential, was then weighted accordingly to establish adjusted game rates for starters and nonstarters.

Relative ratios and 95% CIs were estimated for player, player-hour, and session rates.

Clustered Poisson Regression

Relative ratios were modeled to describe relative risk, and they were calculated for player characteristics, seasons of experience, year in school, age, position, and BMI. Position types were grouped according to function on the team. Three sets of positions were formed and tested. In set 1, positions were categorized into defense (defensive lineman, defensive back, defensive end, linebacker), offense (offensive lineman, center, quarterback, running back, fullback), and special teams or other (kicker, punter, other). In set 2, positions were grouped into lineman (offensive lineman, center, defensive lineman, defensive end, tight end), offensive backfield (quarterback, running back, fullback, wide receiver), defensive backfield (defensive back, linebacker), and special teams or other. In the third set, positions were categorized as lineman, running backfield (wide receiver, defensive back, running back, fullback), nonrunning backfield (quarterback, linebacker), and special teams or other. Exposure time was accrued across all 3 position groupings before modeling. Body mass index was also categorized according to standardized intervals used in prior studies, where 0 to 18.5 kg/m^2 was defined as underweight, 18.6 to 24.9 kg/m^2 as normal weight, 25 to 29.9 kg/m^2 as overweight, and more than 30 kg/m^2 as obese.[12,25] In our multivariate models, relative rates were mutually adjusted for all covariates in the model and also clustered across schools. Individual subjects could not be linked across the 2 seasons, which limited our ability to account for repeated measures. However, school clustering captured random group effects and hence addressed some of the lack of independence among observations.

RESULTS

Eighty-seven different schools enrolled their football teams into the study during the 2-season study period. Forty-eight schools enrolled in the 2001 season, whereas 64 enrolled in the 2002 season. A total of 25 schools enrolled in both seasons. One school that reported no football injuries, which was highly unlikely, was excluded from analyses.

From the 86 schools, 5118 male athletes were included in the study. Of these, 2200 played in 2001 and 2918 played in 2002 (Table 1). Data on the playing and physical characteristics of these athletes were combined for both seasons. The majority of players were either 16 (41.9%, n = 2008) or 17 years old (37.8%, n = 1813), and players were, on average, 70.9 inches tall with a mean weight of 190.2 lb and average BMI of 26.5 kg/m^2. Most players either had no (36.9%) or only 1 previous year (34.8%) of varsity football experience. Almost three fourths played on offense compared with 20% who were defensive players and 6% who were on special teams or unspecified positions. Overall, more players were offensive linemen (28.8%) than any other position, and approximately 48% of players were starters.

Injured Players

Of the 5118 players, 1501 were injured 2008 times during the study period, and 1700 injury events were linked to game or practice exposure data. These 1700 injury events were experienced by 1307 players, with 577 players injured during the 2001 season and 730 injured during the 2002 season. The player rate in 2001 was 44.1 injured players per 100 players, and the rate in 2002 was 55.9 of 100. Data on the injured players were combined because there was no difference in the rate of injury for the 2001 and 2002 seasons ($\chi^2 = 0.9660$, $P = .3257$). A total of 1018 players were injured once, 229 were injured twice, 53 were injured 3 times, and 16 were injured 4 or 5 times. Injured players had a mean age of 16.4 years and were, on average, 71.1 inches tall, 194.2 lb, and had a mean BMI of 26.9 kg/m^2 (Table 1). More injured players reported playing 2 or more seasons of football than uninjured players ($\chi^2 = 88.0143$, $P < .0001$). Thirty percent of injured players were offensive linemen, 19% were running backs or fullbacks, and 17% were wide receivers. More than 60% of injured players were starters.

Injury Rates

Overall, the average injury rate per season was 25.5 per 100 players (Table 1). Player rates were highest among 18+-year-olds (34.9 per 100 players) who had 1.9 times the rate of 13- to 15-year-olds (RR, 1.9; 95% CI, 1.1-3.4). Player rates increased with the number of seasons of experience, with the highest rates among players with 4 seasons of experience (50 per 100 players). Among all playing positions, running backs or fullbacks had the highest rates (32.0 per 100 players), whereas the lowest rates were found among kickers or punters (10.0 per 100 players). Rates were also elevated among starters, who had rates that were 1.8 times that of nonstarters (RR, 1.8; 95% CI, 1.0-3.1).

During 1 401 184 player-hours, 1307 players were injured at least once, corresponding to an overall rate of 9.3 injured players per 10 000 player-hours (Table 2). The highest player-hour rates were reported among running backs or fullbacks, players with the most number of years of experience, starters, and high school seniors.

The 1700 separate injury events sustained during 20 274 session-hours correspond to an overall session-rate of 8.4 injuries per 100 session-hours of play (Table 3). The highest rates were reported during games (away games, 29.2 per 100 session-hours; home games, 27.7 per 100 session-hours) and scrimmages (25.4 per 100 session-hours). These rates are about 5 times greater than the injury rate reported for regular practice sessions. Through our sensitivity analysis, we also estimated adjusted game rates for starters and nonstarters adjusted using reported prior information about relative playing time. Coaches and CIF section representatives reported that starters play anywhere from 70% to 90% of game time, depending on a variety of conditions such as score, play-off schedule, and size of the opposing team. In contrast, nonstarters play substantially less game time, ranging from 10% to 30% of game time. Using these prior data, we calculated game rates for starters ranging from 23.1 to 29.7 injuries per 100

TABLE 1
Characteristics of All Football Players (N = 5118 Players) and Injured Players (n = 1307), Player Injury Rates, Relative Rates, and 95% Confidence Intervals[a]

	All Players (N = 5118)[b]	Injured Players (n = 1307)[c]	Player Injury Rate[d] (per 100 Players)	Relative Rate (95% Confidence Interval)
Season				
2001	2200 (43.0)	577 (26.2)	44.1	
2002	2918 (57.0)	730 (25.0)	55.9	
Age, y[e]				
13-15	762 (15.9)	138 (10.9)	18.1	ref.
16	2008 (41.9)	513 (40.6)	25.5	1.4 (0.8-2.6)
17	1813 (37.8)	539 (42.6)	29.7	1.6 (0.9-2.9)
18+	215 (4.5)	75 (5.9)	34.9	1.9 (1.1-3.4)
Height, in	70.9 ± 2.8 (60-83)	71.1 ± 2.8 (61-83)		
Weight, lb	190.2 ± 36.9 (105-380)	194.2 ± 36.9 (109-355)		
Body mass index, kg/m^2	26.5 ± 4.5 (16- 51)	26.9 ± 4.4 (18-46)		
No. of seasons of experience				
0	1614 (36.9)	331 (27.4)	20.5	ref.
1	1521 (34.8)	432 (35.8)	28.4	1.4 (0.8-2.4)
2	812 (18.6)	286 (23.7)	35.2	1.7 (1.0-3.0)
3	384 (8.8)	136 (11.3)	35.4	1.7 (1.0-3.0)
4	46 (1.1)	23 (1.9)	50.0	2.4 (1.5-4.1)
Position				
Offense				
Offensive line	1391 (28.8)	389 (29.9)	28.0	ref.
Quarterback	246 (5.1)	67 (5.2)	27.2	1.0 (0.6-1.7)
Running back/fullback	773 (16.0)	247 (19.0)	32.0	1.1 (0.7-1.9)
Wide receiver	864 (17.9)	215 (16.5)	24.9	0.9 (0.5-1.5)
Tight end	313 (6.5)	75 (5.8)	24.0	0.9 (0.5-1.5)
Defensive				
Defensive line	398 (8.3)	98 (7.5)	24.6	0.9 (0.5-1.5)
Linebacker	364 (7.6)	109 (8.4)	29.9	1.1 (0.6-1.8)
Defensive back	200 (4.2)	53 (4.1)	26.5	0.9 (0.6-1.6)
Special teams/other				
Kicker/punter	80 (1.7)	8 (0.6)	10.0	0.4 (0.2-0.7)
Unspecified	194 (4.0)	39 (3.0)	20.1	0.7 (0.4-1.3)
Starter				
Yes	2229 (47.7)	794 (62.2)	35.6	1.8 (1.0-3.1)
No	2445 (52.3)	482 (37.8)	19.7	ref.
Total	5118	1307	25.5	

[a]ref, reference.
[b]Data presented as no. (%), except for height, weight, and body mass index, which are presented as mean ± SD (range). Total of all categories may not add up to 5118 because of missing data.
[c]Data presented as no. (%), except for height, weight, and body mass index, which are presented as mean ± SD (range). Total of all categories may not add up to 1307 because of missing data.
[d]Rates are averaged across 2 seasons. Repeated measures of players in 2 seasons are not independent but could not be identified.
[e]Mean age for all players is 16.3 ± 0.84 years; mean age for injured players is 16.4 ± 0.80 years.

session-hours and game rates for nonstarters from 23.1 to 69.5 injuries per 100 session-hours.

Rates were 1.6 times more common on artificial turf compared with grass surfaces (95% CI, 1.3-1.9). Injury rates were also highest during foggy weather (25.1 of 100) and clear evenings (20.7 of 100).

Injury Events

Eighty-four percent of injury events involved first-time or acute injuries, and almost 14% were reinjuries from earlier seasons (Table 4). More than 78% of injuries involved some type of contact with another player. Sixty-eight percent of injuries involved collisions with persons, with most being nonhead collisions (64.1%) and head collisions (4.4%). The most common types of activities reported during injury were running (34.2%), tackling (29.0%), and blocking (23.4%). Overall, 38% of all injuries occurred to offensive and defensive linemen, followed by running backs and fullbacks (13.9%), linebackers (13.0%), and wide receivers (11.7%). More than 93% of players were reported to have worn full equipment when injured. To validate these injuries, we estimated an overall agreement of 79% between injuries reported by schools using their in-house reporting system and those reported using our instruments.

TABLE 2
Player-Hour Injury Rates per 10 000 Player-Hours, Relative Rates, and 95% Confidence Intervals by Selected Player Characteristics[a]

	No. of Injured Players	Player-Hours	Rate per 10 000 Player-Hours	Relative Rate (95% Confidence Intervals)
Player position				
Offense				
Offensive line	389	391 889	9.9	ref.
Quarterback	67	69 949	9.6	0.9 (0.7-1.3)
Running back/fullback	247	220 245	11.2	1.1 (1.0-1.3)
Wide receiver	215	245 486	8.8	0.9 (0.7-1.0)
Tight end	75	84 301	8.9	0.9 (0.7-1.1)
Defensive				
Defensive line	98	113 514	8.6	0.9 (0.7-1.1)
Linebacker	109	109 758	9.9	1.0 (0.8-1.2)
Defensive back	53	62 822	8.4	0.8 (0.6-1.1)
Special teams/other				
Kicker/punter	8	23 769	3.4	0.3 (0.2-0.7)
Other	39	49 591	7.9	0.8 (0.6-1.1)
No. of seasons of experience				
0	331	451 101	7.3	ref.
1	432	453 613	9.5	1.3 (1.1-1.5)
2	286	242 618	11.8	1.6 (1.4-1.9)
3	136	114 986	11.8	1.6 (1.3-2.0)
4	23	10 258	22.4	3.1 (2.0-4.7)
Starter				
Yes	794	661 327	12.0	1.7 (1.5-1.9)
No	482	675 983	7.1	ref.
Year in school				
Freshman	5	5678	8.8	ref.
Sophomore	93	119 603	7.8	0.9 (0.4-2.2)
Junior	543	606 696	9.0	1.0 (0.4-2.5)
Senior	654	63 582	102.9	11.7 (4.8-28.2)
Overall	1307[b]	1 401 184[b]	9.3	

[a]ref, reference.
[b]Total of all categories may not add up because of missing data.

Physical Injuries

The 1700 injury events involved 1900 different injury diagnoses to 1724 body regions. Multiple injuries were sustained during 194 separate injury events. Two or 3 body regions were affected during 37 separate injury events, but the overwhelming majority of incidents (n = 1648) involved only 1 body region. Overall, the lower extremity (45.1%) was the most common region of injury followed by the upper extremity (23.2%) and the head (12.4%) (Table 5). The knee and the ankle were most commonly injured, whereas the shoulder and wrist, hand, or fingers were the most frequently injured in the lower and upper extremities, respectively. Sprains and strains composed 46.1% of all injury types, followed by skin contusions, abrasions or lacerations (16.9%), and concussions (10.8%). About 7% of injuries were fractures, and 5% were dislocations or subluxations. Sprains, strains, and tears occurred most often to the ankle (n = 144) and knee (n = 105) (Table 6). Fractures were sustained primarily in the wrist, hand, thumb, and fingers (n = 24), and dislocations and subluxations were common to the shoulder (n = 24).

For injuries from the 2002 season, we had additional information on lost playing or game time and treatments. One third of injuries (n = 266) resulted in no lost practice or game days. For 87% of these injuries, players left a game or session because of the injury but did not miss a complete session of play. Most of these injuries were sprains (29%), contusions (24%), and muscle strains (19%), whereas 9% were concussions and 3% were fractures. However, more than 50% of injuries resulted in 1 to 7 days of missed practice or game time. Fifteen percent of injuries (n = 137) resulted in 8 or more lost practice or game days, with as many as 42 days missed. About 5% of injuries resulted in 1 to 8 days of lost school time, and only 3% of injuries resulted in the player quitting the football team. Eight percent of injured players were immediately transported to the hospital, whereas 33% (n = 564) were referred to a physician.

Measures of Association

Adjusted RRs control for player position, starting status, year in school, number of seasons of experience, and BMI.

TABLE 3
Session Injury Rates per 100 Hours, Relative Rates, and 95% Confidence Intervals[a]

	No. of Injury Cases	Session-Hours	Session Rate per 100 Session-Hours	Relative Rate (95% Confidence Intervals)
Type of session				
Regular practice, full equipment	640	11 968	5.3	ref.
Light practice	70	3600	1.9	0.4 (0.3-0.5)
Conditioning	61	1285	4.7	0.9 (0.7-1.2)
Home game	399	1438	27.7	5.2 (4.6-5.9)
Away game	459	1570	29.2	5.5 (4.8-6.1)
Scrimmage	64	252	25.4	4.7 (3.7-6.1)
Not specified	—	160	—	—
Playing surface				
Dirt	14	303	4.6	0.5 (0.3-0.9)
Grass	1235	14 085	8.8	ref.
Mixed dirt/grass	290	4558	6.4	0.7 (0.6-0.8)
Artificial turf	118	857	13.8	1.6 (1.3-1.9)
Other	14	426	3.3	0.4 (0.2-0.6)
Playing surface condition				
Normal	1437	17 167	8.4	ref.
Wet or muddy	96	956	10.0	1.2 (1.0-1.5)
Irregular	107	1715	6.2	0.7 (0.6-0.9)
Other	29	370	7.8	0.9 (0.6-1.4)
Weather condition				
Sunny	954	14 574	6.5	ref.
Overcast	181	2699	6.7	1.0 (0.9-1.2)
Foggy	84	335	25.1	3.8 (3.1-4.8)
Drizzle	22	277	7.9	1.2 (0.8-1.9)
Rain	28	222	12.6	1.9 (1.3-2.8)
Clear night	278	1344	20.7	3.2 (2.8-3.6)
Other	124	627	19.8	3.0 (2.5-3.6)
Overall	1700[b]	20 274[b]	8.4	

[a]ref, reference.
[b]Total of all categories may not add up because of missing data.

We used 3 types of groupings of position to explore how position is associated with the rate of injury (Table 7). Overall, there was no significant difference in injury rates comparing offense and defense positions. However, offensive backfield (quarterback, running back, fullback, wide receiver) and defensive backfield (cornerback, defensive back, linebacker, safety) compared with linemen had a 20% increase in the injury rate (offensive backfield: RR, 1.2; 95% CI, 1.1-1.4; defensive backfield: RR, 1.2; 95% CI, 1.0-1.5). In another model of position groupings, compared with linemen, running backfield (wide receiver, cornerback, defensive back, safety running back, fullback) had a 20% increased rate of injury (RR, 1.2; 95% CI, 1.1-1.4), while nonrunning backfield (quarterback, linebacker) had a 10% increased injury rate (RR, 1.1; 95% CI, 1.0-1.3). Starters had an adjusted injury rate 60% higher (95% CI, 1.4-1.9) than that of nonstarters. Although year in school did not appear to be related to injury, there was a positive relationship between the number of years of experience and injury rates. Players with 1 year of experience had a rate 30% greater, players with 2 to 3 years of experience had a rate 50% higher, and those with 4 years of experience had a rate 120% greater than rates among players with no experience. Both BMI and year in school had no clear effect on injury rates.

DISCUSSION

In this study, we present injury rates in 3 dimensions of exposure-time, that is, rates per players, rates per session-hours, and rates per player-hours. Overall, we observed an injury rate of 25.5 per 100 players, which is in the range reported in prior studies (22 per 100 players to 51 per 100 players).[4,11,15,19,27,35] We also estimated a player-hour rate of 9 per 10 000 player-hours, which compares with the rates reported by DeLee and Farney.[11] Finally, we estimate an overall session rate of 8.4 injuries per 100 session-hours.

By presenting 3 types of injury rates, we allow for adequate comparison of rates across studies, but caution should be used when interpreting these rates. Each rate measures exposure in different units, has different numerator definitions, and hence carries its own assumptions and limitations regarding the at-risk population. Player rates estimated using conventional exposure accruement methods assume equal exposure among all players in a

TABLE 4
Description of 1700 Injury Events[a]

	No. (%)
Season	
2001	746 (33.9)
2002	954 (32.7)
Time of injury	
New/acute	1422 (84.1)
Reinjury this season	109 (6.5)
Reinjury other season	125 (7.4)
Not specified	34 (2.0)
Session type	
Regular practice, full equipment	637 (37.5)
Light practice	101 (5.9)
Conditioning	47 (2.8)
Home game	399 (23.5)
Away game	459 (27.0)
Scrimmage	56 (3.3)
Not specified	1 (0.6)
Physical contact with another player	
Yes	724 (78.3)
No	201 (21.7)
Mechanism of injury	
Collision with object	73 (4.4)
Nonhead collision with other person	1057 (64.1)
Head-to-head collision with other person	71 (4.3)
Fall	84 (5.1)
Overexertion	147 (8.9)
Twisting	114 (6.9)
Other	60 (3.6)
Not recorded	44 (2.7)
Activity at time of injury	
Running	563 (34.2)
Tackling	476 (29.0)
Blocking	385 (23.4)
Drills	72 (4.4)
Catching ball	38 (2.3)
Throwing/passing ball	29 (1.8)
Other	50 (3.0)
Not recorded/unknown	31 (1.9)
Player was…	
Playing offense	870 (53.4)
Playing defense	669 (41.0)
Conditioning	91 (5.6)
Position of player at time of injury	
Offense	
Offensive line	330 (20.0)
Quarterback	70 (4.2)
Running back/fullback	230 (13.9)
Wide receiver	193 (11.7)
Tight end	52 (3.1)
Defensive	
Defensive line	292 (17.7)
Linebacker	214 (13.0)
Defensive back	127 (7.7)
Special teams/other	
Kicker/punter	56 (3.4)
Other	87 (5.3)
Wearing full equipment when injured	
Yes	1538 (93.7)
No	104 (6.3)

[a]Total of all categories may not add up to 1700 because of missing data.

TABLE 5
Number and Percentage of Injuries by Body Location and Type

	No. (%)
Body regions	
Lower extremity	778 (45.1)
Upper extremity	400 (23.2)
Head	213 (12.4)
Abdomen/pelvis	114 (6.6)
Back/spine	86 (5.0)
Neck	88 (5.1)
Chest	24 (1.4)
Face	21 (1.2)
Total body regions injured	1724
Injury types	
Sprains/strains	876 (46.1)
Skin contusions	268 (14.1)
Concussions	204 (10.8)
Fractures	135 (7.1)
Tears	115 (6.1)
Dislocations/subluxations	94 (4.9)
Skin lacerations or abrasions	53 (2.8)
Other	53 (2.7)
Nerve damage	42 (2.2)
Tendinitis	31 (1.6)
Heat exhaustion	18 (0.9)
Spasms	11 (0.6)
Total physical injuries	1900

TABLE 6
Number and Percentage of Most Common Anatomical Regions for 5 Common Diagnoses

Diagnoses and Anatomical Regions	No. (%)
Sprains, strains, and tears	892 (52.4)
Ankle	144
Knee	105
Abdomen/pelvis	79
Neck	55
Contusions, abrasions, lacerations	305 (17.9)
Knee	32
Abdomen/pelvis	24
Concussions—head	204 (12.0)
Fractures	118 (6.9)
Wrist/hand/fingers	24
Lower leg	9
Dislocations, subluxations	79 (4.6)
Shoulder	24
Knee	9

team throughout a season.[20] Identical exposure across players is unlikely, as players are subject to variation in practice or playing time. Earlier studies do not account for differential exposure time and only present rates per numbers of players.[9,10,13,19,27,33] Other investigators have used rates per number of games using the total number of sessions in a season as a denominator,[1] but this type of rate

TABLE 7
Crude and Adjusted Injury Relative Rates and 95% Confidence Intervals for Player Features[a]

	Crude Relative Rates (95% Confidence Intervals)	Adjusted Relative Rates (95% Confidence Intervals) Model 1[b]	Adjusted Relative Rates (95% Confidence Intervals) Model 2[b]	Adjusted Relative Rates (95% Confidence Intervals) Model 3[b]
Player position				
Grouping 1				
Special teams/other	0.7 (0.5-1.0)	0.7 (0.5-1.0)		
Offense	1.0 (0.9-1.2)	1.0 (0.9-1.2)		
Defensive	ref.	ref.		
Grouping 2				
Special teams/other	0.7 (0.5-1.0)		0.8 (0.6-1.1)	
Offensive backfield (quarterback, running back, fullback, wide receiver)	1.1 (1.0-1.2)		1.2 (1.1-1.4)	
Defensive backfield (defensive back, linebacker)	1.1 (0.9-1.3)		1.2 (1.0-1.5)	
Linemen	ref.		ref.	
Grouping 3				
Special teams/other	0.7 (0.5-1.0)			0.8 (0.6-1.1)
Running backfield (wide receiver, defensive back, running back, fullback)	1.1 (1.0-1.2)			1.2 (1.1-1.4)
Nonrunning backfield (quarterback, linebacker)	1.1 (0.9-1.2)			1.1 (1.0-1.3)
Linemen	ref.			ref.
Starter				
Yes	1.8 (1.7-2.1)	1.6 (1.4-1.9)	1.6 (1.4-1.9)	1.6 (1.4-1.9)
No	ref.	ref.	ref.	ref.
Year in school				
Freshman	0.9 (0.3-2.4)	1.5 (0.6-4.0)	1.6 (0.6-4.1)	1.6 (0.6-4.1)
Sophomore	0.8 (0.6-1.0)	1.1 (0.9-1.4)	1.1 (0.9-1.4)	1.1 (0.9-1.4)
Junior	0.8 (0.7-0.9)	1.1 (1.0-1.3)	1.1 (1.0-1.3)	1.1 (1.0-1.3)
Senior	ref.	ref.	ref.	ref.
No. of seasons of experience				
0	ref.	ref.	ref.	ref.
1	1.4 (1.2-1.6)	1.3 (1.1-1.5)	1.3 (1.1-1.5)	1.3 (1.1-1.5)
2	1.7 (1.4-2.1)	1.5 (1.2-1.9)	1.5 (1.2-1.9)	1.5 (1.2-1.9)
3	1.9 (1.4-2.5)	1.5 (1.1-2.2)	1.5 (1.1-2.1)	1.5 (1.1-2.1)
4	2.5 (2.0-3.0)	2.2 (1.6-2.9)	2.2 (1.6-2.9)	2.2 (1.6-2.9)
Body mass index, kg/m^2				
0-18.5	ref.	ref.	ref.	ref.
18.6-24.9	1.3 (0.4-3.5)	1.1 (0.4-3.2)	1.1 (0.4-3.3)	1.1 (0.4-3.3)
25-29.9	1.6 (0.6-4.4)	1.3 (0.5-3.6)	1.4 (0.5-3.9)	1.4 (0.5-4.0)
30+	1.5 (0.6-4.3)	1.3 (0.4-3.5)	1.4 (0.5-4.1)	1.5 (0.5-4.2)

[a] ref, reference.
[b] Poisson Model. Model adjusts for player position, starting status, year in school, seasons of experience, and body mass index and includes clustering across schools.

does not account for differences in numbers of sessions by players.

In contrast, injury rates per session measure differences in exposure time by characteristics of sessions such as game or practice, weather, and playing surface. Such rates provide some information about risk of injury by the quality of practices and games. For example, we found injury rates highest during games, on artificial turf, on wet or muddy surfaces, during foggy days, and during evening sessions. This information may be important for determining underlying causes as well as for future policies on game or practice restrictions and for identifying appropriate types of playing surfaces. These rates, however, do not account for differences in exposure time among the players in a session.

The player-hour rate is the ideal measure, and to estimate this rate, the total exposure time of sessions is multiplied by the number of players on a team.[11] Although players are not exposed to the same number of minutes in a session, it is a feasible approach for estimating exposure time when monitoring each player's time is resource intensive.

However, the reality is that all athletes do not play the same number of minutes, particularly during game situations and by starting status, experience, and playing position. For example, starters and experienced players have substantially more playing time than nonstarters and less experienced players during games, particularly close scoring games and during play-offs. This assumption could have led to underestimated or overestimated rates. In examining potential bias through a sensitivity analysis, we found game rates of injury for nonstarters could be similar or up to 3 times the rate of starters. Although our study could not measure individual differences in playing time, we call for future work that specifically analyzes exposure time for environmental characteristics such as type of session (games vs practices vs scrimmages) or time of season (playoff vs regular season) and individual characteristics (eg, position, starting status, experience).

Consistent with the literature, most injuries were sprains and strains, occurred during games, and were sustained to the lower extremity.[11,15,27,35] We also found that game starters, players in certain football positions, and experienced players were at the greatest risk of injury.

Several reasons may explain why vulnerability to injury follows this particular pattern. First, degree of competitiveness or aggressiveness likely increases with longer exposure to football and starting status. Furthermore, at the biologic level, starting players may be exposed to repetitive, cumulative trauma over time.[35] Other psychological components such as adult or peer-imposed pressures and life-event stressors could also be elevated among starters. The football athlete pressured to succeed may seek visibility and recognition in his quest for the college football scholarship. The reality is that only a very small percentage of high school players advance to the college level. When desire to achieve outweighs talent, the highly aggressive athlete may be at risk for severe and multiple injuries over time.

Others have also reported that players with more total and negative life change measures such as familial instability are at higher risk of injury.[9,14] Andersen and Williams[2,37] proposed a model that relates stressful events to injury; that is, stress can lead to constant tensing of muscles leading to greater vulnerability to injury, particularly strains.[14]

Future study of starting players is warranted to understand what places them at risk and to develop appropriate interventions. One approach could involve partnering with behavioral scientists to study the pressures experienced by high school athletes and their ability to cope and seek social support.[9,14]

Starters and experienced players may also be exposed to life stressors and repeated cumulative trauma to the body, both of which may increase risk of football injury. On the other hand, experienced players should be more familiar with techniques and protected against injury compared with the novice player.[35] To resolve these potential conflicting theories, we examined whether our findings were confounded by some unaccounted variable. Injury in the previous season has been reported as an important risk factor for subsequent injury.[35] Although we were unfortunately unable to link injured players across seasons, we collected any self-reported injuries sustained in high school resulting in medical attention. These data were collected as part of the baseline assessment for the 2002 season but not for the 2001 season. For a subset of the population, we reconstructed our regression models and included the prior injury variable. We found that most estimates, except for seasons of experience and year in school, did not change substantially. In the subsample, the effect of playing experience on injury dissipated, there was an increased risk of injury among freshmen players, and prior injury was independently associated with injury (RR, 1.6; 95% CI, 1.4-1.9). We cannot confirm this issue for the entire sample, given our available data, but based on this sensitivity analysis, we recommend that future football injury research address prior injury as a confounder and as an independent risk factor.

We attempted to test different groups of positions to identify how players with similar activities may be more or less prone to injury. We found that running backfielders (wide receiver, cornerback, defensive back, safety, running back, fullback) were at greatest risk of injury compared with linemen. The level of physical activity required in a specified position coupled with the physique of a player is an important marker for risk. Offensive linemen, often larger in size, station their bodies to block or tackle, whereas backfielders move with greater speed. The transmittal of energy forces from larger linemen to backfielders may increase the risk of injury to backfielders. Our findings contradict those of Turbeville et al[35] who reported linemen at greatest risk of injury but are supported by Prager[27] and Andresen[3] who found backfielders and halfbacks with greater injury rates primarily because of being tackled rather than blocking. Hence, it would be beneficial for future research to measure force transmittal, anthropometry, and physical activities by playing position. This information could help determine position-specific drills and conditioning exercises to prevent and reduce injuries to backfielders.

The higher injury rate on artificial turf is particularly alarming given the growing number of high school football fields now being built or redesigned with new synthetic surfaces. Several earlier studies have found higher rates of injury, particularly less severe injuries, on artificial surfaces compared with grass.[1,21,26] Specific types of injuries, such as muscle-tendon overload injuries and epidermal injuries from noncontact running and injuries to certain playing positions, that is, special teams, have been reported more frequently on artificial turf than on grass.[21] It has been hypothesized that the consistent elastic surface enhances acceleration, speed, and torque, which leads to overextension and muscle fatigue and hence greater risk of injury.[18,21,30] Furthermore, football shoes, particularly those with longer cleats, are more likely to get caught in artificial surfaces when players' legs rotate.[3] Therefore, it has been suggested that soccer-style football shoes be used to reduce injuries on artificial turf.[1,34] To examine these issues, future analyses of our data will include comparisons of various types of injuries across surface types and conditions.

Limitations

As in all field studies, data may be subject to data recording errors and reporting biases. In particular, the level of prior medical knowledge and training likely differs across school representatives, which could lead to nondifferential misclassification and underestimated results. To minimize this, we conducted extensive training and follow-up with data collectors. Furthermore, we screened each data sheet and contacted teams with discrepancies or missing data. To reduce underreporting or overreporting, we reminded schools to report injuries meeting only our study criteria.

In addition, although we account for clustering across football teams in our multivariate models, we expect some amount of unaccounted dependence among athletes who played multiple seasons. Point estimates should not be affected, but CIs may be narrow. Results could also be confounded by other unmeasured variables, particularly prior injury as discussed above. Finally, because exposure time was measured at the team level, we could not account for differences in playing time at the individual level, for example, by playing position, starting status, or amount of experience, which could have led to underestimated or overestimated rates.

CONCLUSION

We recommend that future sports injury research consider time-dependent exposure measures in the design and conduct of studies. This recommendation includes using methods to capture the best estimates of exposure time at the individual level and for various kinds of environmental playing conditions. Future preventive efforts should also focus on high-risk groups of players, including experienced athletes, game starters, backfielders, and high-risk conditions such as evening time, foggy weather, or wet games played on artificial turf. This undoubtedly involves additional research on both intrinsic and extrinsic factors that affect injury risk, how risk patterns change during the career of a football player who matures from a novice to an experienced starter, and understanding risk-taking patterns and activities specific to these high-risk young men.

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