Context The potential seriousness of mild traumatic brain injury (MTBI) is increasingly recognized; however, information on the frequency of MTBI among high school athletes is limited.

Objective To identify the type, frequency, and severity of MTBI in selected high school sports activities.

Design Observational cohort study.

Setting and Participants Two hundred forty-six certified athletic trainers recorded injury and exposure data for high school varsity athletes participating in boys' football, wrestling, baseball and field hockey, girls' volleyball and softball, boys' and girls' basketball, and boys' and girls' soccer at 235 US high schools during 1 or more of the 1995-1997 academic years.

Main Outcome Measures Rates of reported MTBI, defined as a head-injured player who was removed from participation and evaluated by an athletic trainer or physician prior to returning to participation. National incidence figures for MTBI also were estimated.

Results Of 23,566 reported injuries in the 10 sports during the 3-year study period, 1219 (5.5%) were MTBIs. Of the MTBIs, football accounted for 773 (63.4%) of cases; wrestling, 128 (10.5%); girls' soccer, 76 (6.2%); boys' soccer, 69 (5.7%); girls' basketball, 63 (5.2%); boys' basketball, 51 (4.2%); softball, 25 (2.1%); baseball, 15 (1.2%); field hockey, 13 (1.1%); and volleyball, 6 (0.5%). The injury rates per 100 player-seasons were 3.66 for football, 1.58 for wrestling, 1.14 for girls' soccer, 1.04 for girls' basketball, 0.92 for boys' soccer, 0.75 for boys' basketball, 0.46 for softball, 0.46 for field hockey, 0.23 for baseball, and 0.14 for volleyball. The median time lost from participation for all MTBIs was 3 days. There were 6 cases of subdural hematoma and intracranial injury reported in football. Based on these data, an estimated 62,816 cases of MTBI occur annually among high school varsity athletes participating in these sports, with football accounting for about 63% of cases.

Conclusions Rates of MTBI vary among sports and none of the 10 popular high school sports we studied is without the occurrence of an MTBI. Continued involvement of high school sports sponsors, researchers, medical professionals, coaches, and sports participants is essential to help minimize the risk of MTBI.

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See also pp 954, 964, 971, 974, and 989.
jury/illness reporting systems, the 1986-1988 NATA study and injury surveillance systems in place for the National Collegiate Athletic Association, the National Football League, and the National Hockey League.8,9

**Schools and Subjects**

From the 350 NATA-certified athletic trainers who volunteered to participate in the project, 246 were selected to participate. For athletic trainers to participate, they had to (1) work directly with high school sports programs on a daily basis, (2) work within a geographic distribution among the 50 states, and (3) fit a broad representation from different-sized schools within the various parts of the country. These procedures created a stratified cluster sample representing high schools with different-sized student enrollments.

The distribution of the NATA study sample by size of school enrollment was similar to size of school distribution reported by the National Center for Education Statistics in 1994.10 Compared with National Center for Education Statistics data, the study had less representation in schools with enrollments of fewer than 500 (11.9% vs 15.3%) and 500 to 1000 (20% vs 30.2%), higher representation in schools with enrollment of 1001 to 1500 (31.9% vs 24.7%) and 1501 vs 2000 (22.6% vs 14.5%), and similar representation for schools with more than 2000 students (13.6% vs 14.4%).

A total of 114 high schools participated for 3 years of the study, 42 recorded data for 2 of the 3 school years, and 79 (27 in 1995, 20 in 1996, and 32 in 1997) contributed complete data for only 1 school year. Because not all schools offered all sports, the number of team-seasons (1 team in 1 season) for each sport varied. For the majority of schools, 1 athletic trainer recorded data for all sports. As new athletic trainers entered the study, special emphasis was given to them to provide a smooth transition into the recording process and the system requirements.

The subjects in the study are athletes who were included as participants on the varsity sports rosters at the study schools. No effort was made to manipulate or control the athlete’s participation in sports. All references to the player’s data that were submitted to the research office were coded by the participating athletic trainers so that the player could not be identified. The project did not place players at risk, but only observed and recorded the experiences of this population of athletes as they participated in their chosen sport. The certified athletic trainers were required to submit to the research office a written permission to participate statement from their school’s athletic director prior to submitting data.

**Definitions and Data Reporting**

Prior to the beginning of the study, the operational definitions and reporting requirements were included in a user’s manual and distributed to all athletic trainers. Data were recorded by the athletic trainers using a customized version of the Sports Injury Monitoring System (Med Sports Systems, Iowa City, Iowa) and were transferred to the central database using manual or electronic procedures. Schools without access to computers provided data using paper forms that paralleled the software. All reported data were subject to specific procedures for verification. Data collected included player height, weight, age; type of session (game or practice); number of participants; player position and player activity; team activity; playing surface at the time of injury; and time lost from participation.

A reportable injury in the NATA study included an incident that caused cessation of customary participation in the current session (game or practice) or on the day following the day of injury onset. A reportable injury was also any fracture or dental injury that occurred, even though the athlete might not have missed a scheduled session.

A reportable MTBI in the NATA study was identified by the certified athletic trainer when the injury required the cessation of a player’s participation for initial observation and evaluation of the injury signs and symptoms before returning to play, either in the current session or subsequent sessions. By using this definition of MTBI, athletic trainers were able to report cases that they observed or were reported to them for which they conducted an evaluation for MTBI. Athletic trainers were not asked to grade the injury, but only to report that the player’s participation was suspended while an evaluation for MTBI was conducted.

The days lost from participation following an MTBI was used as an indicator of the relative effect the injury had on the player’s participation in sports. Players were classified as having injuries that resulted in loss of participation for fewer than 8 days, between 8 and 21 days, or more than 21 days.1,8,9,11,12

**Data Analysis**

Injury rates per 100 player-seasons reflect the number of injuries reported divided by the number of players who were subjects in the study. Using the case rates per 100 player-seasons, the individual season data were statistically tested to determine if the year of recording showed variation in the injury rates.13 The results identified homogeneity among the seasons for each sport. The 95% confidence intervals for the injury rates were calculated using statistical software (EpiCalc 2000, Version 1.0, Brixton Health, Llanidloes, Powys, Wales) using methods described by Kirkwood.14

Athlete exposure or opportunities for injury are calculated by aggregating the number of participants for each game or practice. For example, 100 players in each of 5 practices would equal 500 athlete exposures. Only those persons who played in the game accumulated game exposures. Injury rates for the aggregate of the 3 study years are compared with a reference base of 1000 athlete exposures.

The incidence density ratio (IDR) was used to compare injury rates among sports and within the conditions of the sport. The IDR was based on the injury rates per 1000 athlete exposures and used as an estimate of the relative risk of injury. For example, the IDR that compares practices and games was cal-

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culated by dividing the injury rate in games by the injury rates for practice and describes the relative risk of injury for games compared with practices. To test the null hypothesis of no difference between the 2 injury rates, a procedure that uses a standard normal approximation to the binomial distribution was used.15 Test-based 95% confidence intervals were calculated according to the methods of Miettinen.16

Subdural hematoma and episodes of intracerebral bleeding are included in the patterns of injury and removed from the analysis when time lost consideration is presented. These more serious brain injuries are described separately.

To estimate national incidence of MTBI in these 10 sports, the number of players in the United States was estimated from the participation data obtained from the National Federation of State High School Association’s hand-

### RESULTS

For the 10 high school sports we studied during the 1995, 1996, and 1997 academic years, the NATA project documented 74,298 player-seasons from 3195 team-seasons, 23,566 reportable injuries, and more than 4.4 million opportunities to be injured (athlete exposures). Of the reported injuries, 1219 (5.5%) were MTBIs. The median time loss for reported MTBI was 3 days. In 89% of the cases, the injured player was removed from the session and 54.8% of the injured players were referred to a physician, medical clinic, or hospital for additional evaluation. (The findings of these medical evaluations are not included in this study.) Data on rates of MTBI for the 10 study sports are shown in Table 1 and Table 2.

#### Table 1. Mild Traumatic Brain Injury Cases, Injury Rates, and Rates per 1000 Athlete Exposures

<table>
<thead>
<tr>
<th>Boys’ Sports</th>
<th>Baseball</th>
<th>Basketball</th>
<th>Football</th>
<th>Soccer</th>
<th>Wrestling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team-seasons</td>
<td>324</td>
<td>406</td>
<td>400</td>
<td>315</td>
<td>328</td>
</tr>
<tr>
<td>Player-seasons</td>
<td>6502</td>
<td>6831</td>
<td>21122</td>
<td>7539</td>
<td>8117</td>
</tr>
<tr>
<td>No. of MTBI cases (% of all MTBI)</td>
<td>15 (1.2)</td>
<td>51 (4.2)</td>
<td>773 (63.4)</td>
<td>69 (5.7)</td>
<td>128 (10.5)</td>
</tr>
<tr>
<td>Percentage of all reported injuries (95% CI)</td>
<td>1.7 (1.0-2.9)</td>
<td>2.6 (2.0-3.5)</td>
<td>7.3 (7.1-8.1)</td>
<td>3.9 (3.1-4.9)</td>
<td>4.4 (3.7-5.2)</td>
</tr>
<tr>
<td>Injury rate (95% CI) per 100 player-season exposures</td>
<td>0.23 (0.11-0.35)</td>
<td>0.75 (0.54-0.95)</td>
<td>3.66 (3.40-3.92)</td>
<td>0.92 (0.70-1.13)</td>
<td>1.58 (1.30-1.85)</td>
</tr>
<tr>
<td>1000 athlete exposures</td>
<td>0.05 (0.02-0.07)</td>
<td>0.11 (0.08-0.15)</td>
<td>0.59 (0.19-1.04)</td>
<td>0.18 (0.14-0.22)</td>
<td>0.25 (0.24-0.29)</td>
</tr>
<tr>
<td>1000 practice exposures</td>
<td>0.03 (0.01-0.05)</td>
<td>0.06 (0.03-0.08)</td>
<td>0.25 (0.16-0.34)</td>
<td>0.04 (0.01-0.06)</td>
<td>0.17 (0.13-0.21)</td>
</tr>
<tr>
<td>1000 game exposures</td>
<td>0.12 (0.04-0.19)</td>
<td>0.28 (0.18-0.38)</td>
<td>2.82 (2.58-3.07)</td>
<td>0.57 (0.43-0.72)</td>
<td>0.51 (0.38-0.64)</td>
</tr>
<tr>
<td>Incidence density ratio (95% CI)†</td>
<td>4.5 (1.76-11.5)</td>
<td>4.9 (2.9-8.1)</td>
<td>11.4 (10.1-12.8)</td>
<td>16.2 (9.9-26.6)</td>
<td>3.1 (2.2-4.2)</td>
</tr>
</tbody>
</table>

*CI indicates confidence interval.
†Calculated as game divided by practice.

#### Table 2. Relative Frequency and Injury Rates Based on Time Lost From Participation Following Mild Traumatic Brain Injury (MTBI), 1995-1997

<table>
<thead>
<tr>
<th>Boys’ Sports</th>
<th>Baseball</th>
<th>Basketball</th>
<th>Football</th>
<th>Soccer</th>
<th>Wrestling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Lost From Participation</td>
<td>&lt;8 d</td>
<td>8-21 d</td>
<td>&gt;21 d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTBI cases, %</td>
<td>53.3</td>
<td>46</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury rate (95% CI)*</td>
<td>0.12 (0.04-0.21)</td>
<td>0.67 (0.47-0.85)</td>
<td>2.92 (2.70-3.17)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-21 d</td>
<td>7</td>
<td>5</td>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTBI cases, %</td>
<td>46.7</td>
<td>9.8</td>
<td>17.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury rate (95% CI)*</td>
<td>0.11 (0.03-0.19)</td>
<td>0.07 (0.01-0.14)</td>
<td>0.66 (0.55-0.77)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;21 d</td>
<td>0</td>
<td>1</td>
<td>37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTBI cases, %</td>
<td>0</td>
<td>2.0</td>
<td>4.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury rate (95% CI)*</td>
<td>0</td>
<td>0.01 (0-0.04)</td>
<td>0.17 (0.12-0.23)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Per 100 player-seasons; CI indicates confidence interval.
The highest injury rate per 100 team-game positions (ie, the number of team games multiplied by the number of players in the various positions [1 quarterback, 1 tight end, 2 running backs, 2 wide receivers, 3 linebackers, 4 defensive linemen, 5 offensive linemen]) was for the quarterback (1.3) compared with running backs (0.74) and linebackers (0.52).

During the study, 693 different players sustained an MTBI while playing football, including 621 (89.6%) who sustained only 1 injury, 65 players who had 2 MTBs, 6 players who had 3 MTBs, and 1 player who had 4 MTBs. Of the 72 players who were reinjured, 47 had a second MTBI in the same season and 14 had a second MTBI in the next season. One person had 3 MTBs in 1 season and 1 person had 4 MTBs in 1 season. There were 4 cases of subdural hematoma and 2 cases of intracerebral bleeding reported in the 3 seasons of football and none in any of the other sports. Of these 6 players, 3 returned to football the following season and 3 did not but did return to participate in other types of sports and physical activities. There were no deaths.

**Wrestling**

More than half of the cases of MTBI in wrestling (53%) occurred during practices. The injury rate for MTBI in matches is 3.1 times higher than practice sessions. The MTBI cases were fairly evenly distributed among the various weight classes for both matches and practices. Player activity most often associated with MTBI was the takedown or attempted takedown both in practice (64.6%) and in matches (70.0%). During the 3 study years, 115 different players sustained an MTBI, and 11 players had a second MTBI. The median time lost due to an MTBI was 2 days.

**Basketball**

Games accounted for 62.8% of the reported MTBIs in boys' basketball, with an IDR 4.9 times the MTBI injury rate for games compared with practices. The MTBI occurred most often as a result of collisions between players in both practices (42.1%) and games (53.1%). Players designated as guards accounted for 62.5% of the game-related MTBIs whereas forwards sustained 68.4% of the practice-related MTBIs. The median time lost due to an MTBI was 2 days. There were 51 different players who sustained an MTBI. One person sustained an MTBI in 1 season followed by 1 in the next season.

In girls' basketball, 68.3% of MTBIs occurred in games with an IDR 6.1 times the injury rate for practices. The injury pattern shows MTBIs occurring in guards accounting for 56.4% of the game-related cases with 62.5% of practice-related MTBIs occurring in forwards. In games, 41.3% of the MTBIs occurred during rebounding and 46.5% of the cases resulted from collisions with players. The median time lost due to an MTBI was 2 days. Fifty-nine different players sustained an MTBI, and 4 players sustained a second episode.

**Soccer**

Boys' soccer games accounted for 85.5% of the injuries and the injury rate was 16.2 times greater for a game than a practice. Players on the forward line and the halfbacks sustained 66.1% of the injuries and the goalkeeper accounted for 11.9% of MTBIs. The MTBI most often occurred from collisions while heading the ball (59.3%). The second most frequent cases of MTBI occurred from collisions with other players (30.5%). The median time lost due to an MTBI was 3 days. There were 67 different players who sustained an MTBI and 2 sustaining a second occurrence.

For girls' soccer, games had an IDR 14.4 times higher than practice sessions. Players on the forward line and
the halfbacks had 70.3% of the injuries and the goalkeeper accounted for 18.8% of the MTBI cases. The MTBI most often occurred from collisions while heading the ball (40.6%) and from collisions with other players (42.2%). The median time lost due to an MTBI was 3 days. Sixty-seven players sustained an MTBI and 9 players sustained a second episode. Of the 9 reinjured players, 5 were reinjured in the same season, 1 was reinjured in the next season, and 3 were reinjured 2 seasons after the first MTBI.

**Baseball and Softball**

The baseball game injury rate was 4.5 times higher than for practice. Among the 15 MTBIs, 9 occurred from collisions between players, 3 from collisions with a bat, 2 from being hit by a pitch, and 1 from sliding. The median time lost due to an MTBI was 3 days with 53.3% of the MTBI cases requiring fewer than 8 days and none requiring more than 21 days to return to participation. In the 3 seasons, 15 different players sustained an MTBI.

Among the 25 MTBIs in girls’ softball, 13 occurred as a result of collisions with other players. There was 1 MTBI from being hit with a bat and 2 from being hit by a batted ball. Six MTBIs occurred from collisions during a sliding activity and 3 MTBIs occurred from being hit by a pitch. The median time lost due to an MTBI was 2 days. Twenty-three different players sustained an MTBI with 2 players being reinjured.

**Field Hockey**

Games had an injury rate 14.4 times higher than practices. Of the 13 cases of MTBI, 4 occurred from being hit with a stick and 4 occurred from being hit with the ball. The remaining 5 cases resulted from collisions with other players. The median time lost due to an MTBI was 3 days. There were 12 different players injured with 1 person sustaining a second MTBI.

**Volleyball**

Four of the 6 MTBI cases reported in volleyball occurred in practice and 2 in games. Collision with a ball accounted for 3 cases, digging for 2 cases, and collision with a player for 1 case. The median time lost due to an MTBI was 1 day. Six different players sustained an MTBI in 3 seasons.

**National Estimates**

The annual national estimate of MTBIs among the 10 high school sports is 62,816 cases, with football accounting for nearly 63% of the injuries (Table 3). Based on the frequency reported in the NATA study and the number of participating teams, the expected number of cases of MTBI per team per season is projected in Table 3. For instance, a football team can expect an average of 2 MTBI cases per year, whereas in volleyball, 2 cases of MTBI in 100 team-seasons are expected.

**COMMENT**

Recent research efforts have begun to investigate the incidence, prevalence, and management of MTBIs. For example, the National Football League (Elliot Pellman, MD, oral communication, September 1998) and the National Hockey League (Charles Burke, MD, oral communication, September 1998) have initiated projects to document the natural history of MTBI. Other programs include systematic sideline evaluation procedures, neuropsychological measurements to assess the head-injured player’s ability to process information, biomechanical studies of balance as an evaluation tool, and the neurobiology of the MTBI. Incidence data are important in designing research programs and for evaluating the success of intervention programs.

The difference in the current study are limited to injuries, specifically MTBIs that were reported by NATA-certified athletic trainers who were on-site at the study schools on a daily basis. Within this group of certified athletic trainers, 55% had graduate degrees and 73% were employed as full-time members of the school’s faculty.

The definition used to record incidence data will change the frequency of reported cases and the magnitude of estimated injury. While the athletic trainer did not question every player after every session, we assume that events reported to or observed by the athletic trainer were reported in the study data.

Gerberich et al. estimated the magnitude of concussions in high school football in the late 1970s and found an injury rate of 19 concussions per 100 players with 24% of all injuries listed as concussions. These injuries occurred prior to the implementation of the National Operating Committee for Safety in Athletic Equipment helmet protection standards in 1980, which may have an impact on their injury rates compared with current football injuries nearly 20 years after the introduction of the rule. In a prospective study of college football players from 1982 through 1986, Barth et al. found 195 injuries among 182 different players in a population of 2350 athletes; 7.7% of the study group had sustained a reportable mild head injury. In our study us-


<table>
<thead>
<tr>
<th>Boys’ Sports</th>
<th>Girls’ Sports</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of players</strong></td>
<td><strong>No. of players</strong></td>
</tr>
<tr>
<td>Baseball</td>
<td>Basketball</td>
</tr>
<tr>
<td>501 356</td>
<td>504 836</td>
</tr>
<tr>
<td>Estimated</td>
<td>1153</td>
</tr>
<tr>
<td>Expected per team*</td>
<td>0.05</td>
</tr>
</tbody>
</table>

*Calculated as injury rate per athlete exposures multiplied by the average number of exposures per school.
ing NATA data, 693 athletes (3.9%) had MTBIs in a population of 17 815 athletes. The difference may reflect differences in the population (college vs high school), the period (1982-1986 vs 1995-1997), the study design, and mechanisms of documentation. McCrea et al recently reported 33 concussions (5.8%) among a group of 353 high school and 215 college football players. The article also reports high school data for 1995 as 6 concussions in 141 players (4.3%), which is comparable with the current study at 3.9%.

The findings of our study highlight the importance of collisions, in all forms, as a contributing factor for MTBI in sports. Football, a sport characterized by collisions, compared with girls' volleyball represent opposite ends of the continuum. In basketball, the collisions seem to occur between players in the open court not necessarily under the basket. In soccer, the collisions occur between players and during heading of the ball. However, the current data are unable to clearly differentiate an MTBI from head-to-ball contact vs head-to-body or ground contact during the heading process. The data on field hockey point to collisions with objects, such as the stick or the ball, as well as player collisions as risk factors. The potential for collision among players as well as with bats and balls is low in baseball and softball. Even with the low potential, there are MTBIs that result from these collisions.

Given the close association of MTBI with a variety of different types of collisions, prevention strategies may be most successful when interventions are aimed at controlling the participation environment. Modifications in player skills, teaching techniques, and playing rules may be required to reduce the potential risk from different types of collisions in sports. In addition, sports medicine professionals should focus on accurate identification of MTBIs and consistent management throughout the recovery period. Players and coaches must be encouraged to report all suspected head injuries to athletic trainers and team physicians.

Clearly identifying the MTBI, carefully documenting the signs and symptoms at the time of injury, reevaluation of the signs and symptoms until they disappear, and monitoring of brain function through neuropsychological profiles may lead to greater success in prevention of reinjury. While not all MTBIs can be prevented, accurate and consistent medical management of those that occur will minimize the potential for reinjury and subsequently reduce the potential for the long-term effects that have been associated with MTBI. Modifications of player skills, rule changes, and protective equipment can only go so far in the prevention of MTBI. Only through the continued cooperation of sports sponsors, researchers, medical professionals, coaches, and sports participants can the goal of minimizing the risk of MTBI and its long-term disability be achieved.

**Funding/Support:** The development, implementation, and data analysis for this project were sponsored by the National Athletic Trainers Association Inc (Dallas, Tex) in the form of a contract with Med Sports Systems. The computer software used by the athletic trainers in this project was customized to meet the needs of the project from the Sports Injury Monitoring System produced by Med Sports Systems.

**Acknowledgment:** We appreciate the hard work and dedication of the certified athletic trainers who volunteered to participate in this project. Their patience and professionalism made the process of collecting and maintaining the project data efficient. Without their dedication, the project could not have been done. We also thank Mario Schootman, PhD, epidemiologist for the Iowa Public Health Department; Mark Lovell, PhD, chairman of neuropsychology at Henry Ford Health Systems, and Kenneth S. Clarke, PhD, senior vice president of risk analysis at SLE Worldwide Inc for their counsel regarding the analysis and presentation of the findings in this report.

**REFERENCES**