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Sports- and Recreation-Related Concussions in US Youth

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abstract

OBJECTIVE: The incidence of sports- and recreation-related concussions (SRRCs) in the United States is unknown. More than 44 million youth participate in sports annually, thus understanding the frequency of SRRCs in children is important on a population level. Our objective was to determine the number of SRRCs occurring annually among US youth ≤18 years old.

METHODS: We identified SRRCs using 3 national databases: MarketScan, National Electronic Injury Surveillance System, and National High School Sports Related Injury Surveillance System, Reporting Injury Online. We determined the number of SRRCs seen in health care settings (outpatient, inpatient, and emergency department) and SRRCs reported to certified high school athletic trainers (ATCs). We used these data and findings in recently published literature to generate a national estimate of SRRCs.

RESULTS: We estimate that between 1.1 and 1.9 million SRRCs occur annually in US children aged ≤18 years. Most children with SRRCs, 511 590 to 1 240 972, were not seen in health care settings. Of children with SRRCs seen in health care settings, most were seen as outpatients with 377 978 visits, compared with between 115 479 and 166 929 ED visits, and between 2886 and 4936 hospitalizations.

CONCLUSIONS: This study provides the most accurate and precise estimate to date of the number of concussions among US children annually. SRRCs are a common injury in children. Providers in all health care settings need to be trained in concussion care. There is a need for better surveillance to enhance our understanding of the epidemiology of concussions in youth.

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WHAT'S KNOWN ON THIS SUBJECT: Sports- and recreation-related concussions (SRRCs) are a common source of morbidity in children. Many of these injuries are not treated within health care settings. It is unknown how many SRRCs occur annually in the US.

WHAT THIS STUDY ADDS: We estimate between 1.1 and 1.9 million SRRCs occur annually in US children ≤18 years old. The magnitude of this number emphasizes the need for better national injury surveillance of the incidence of SRRCs.

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Concussions, a form of traumatic brain injury (TBI), are common in children, with sports and recreation as a leading cause in this age group.[1,2] The incidence of sports- and recreation-related concussions (SRRCs) in the United States is unknown; however, most epidemiologic studies indicate that a large number of SRRCs occur each year.[3–7] More than 44 million youth participate in sports annually, and thus understanding the frequency of SRRCs in children and adolescents is important on a population level.[1,8]

One challenge in calculating the incidence of SRRCs is that injured youth may not receive treatment, or may receive care from a variety of providers including certified athletic trainers (ATCs), primary care, and emergency medicine physicians. Few studies have examined SRRCs across multiple care settings.[5,8] Population-based studies on the incidence of SRRCs often focus only on sport-specific injuries in high school and college athletes. These estimates frequently omit recreational activities, a major source of SRRCs in younger children. Thus, existing estimates do not provide comprehensive assessments of SRRC prevalence.[6,9]

The most commonly cited estimate is that between 1.6 and 3.8 million sports- and recreation-related TBIs occur annually in the United States.[5] This estimate was based on the Injury Supplement to the 1991 National Health Interview Survey, which defined TBI as a head injury with loss of consciousness, then inflated the number using the estimated proportion of concussions without loss of consciousness.[3,10] In addition to being based on self-reported data from assessments >2 decades ago, the range is wide. Despite these profound methodologic limitations, this estimate is widely cited by numerous authors. We sought to generate an updated and more accurate national estimate of SRRCs in children ≤18 years old from available population-based data.

METHODS

Data Sources

Multiple data sources were used to generate a national estimate for 2013, the year for which most recent data were available. Because only anonymized data were used, the study was exempt from human subjects committee review.

We used the conceptual framework in Fig 1 to comprehensively identify all children ≤18 years old with SRRCs. The National Electronic Injury Surveillance System (NEISS) and MarketScan databases contain information on all emergency department (ED) visits and inpatient hospitalizations for SRRCs (cells A–F in Fig 1). Office visits for both primary and subspecialty care are contained within MarketScan (cells A–C in Fig 1). For treatment locations with data from multiple sources, such as the ED, the estimates from each source were included separately, which created a range for the final estimate but prevented double counting of cases.

From the narrative review of NEISS, concussions were considered sports-related if there was any mention of a sport, regardless of injury mechanism (eg, hit by player, fell while playing); concussions were determined to be recreation-related if the narrative reported any recreational activities such as bicycling or if the injury occurred in a recreational setting, such as playgrounds. The Supplemental Information contains a comprehensive list of the sports, recreational activities and locations included. Our method of determining SRRCs was more inclusive than many previous studies, which excluded specific causes or required sports- and recreation-related E-codes for inclusion.[4,11,12] Because MarketScan is dependent on *International Classification of Disease, Ninth Revision, Clinical Modification* (ICD-9-CM) codes and the presence of E-codes for injuries is variable, we used an exclusion method for classification of SRRCs in MarketScan. Sports and recreation, motor vehicle collisions, and falls account for ~80% of concussions in children.[11,13] We excluded concussions due to motor vehicle collisions (ICD-9-CM codes E810-E819) and falls (ICD-9-CM codes E880.×, E881.×, E882, E883.×, E884.×, E885.9, E888.×) to count only SRRCs. However, by excluding all concussions coded due to falls, we may have underestimated the true number of SRRCs by not counting concussions from falls

<table>
<tr><th colspan="3">Office-based and inpatient care[a,b]</th><th colspan="3">Emergency Department care[a,b]</th><th>Seen by athletic trainer only[c]</th><th colspan="3">Not seen by any health care provider[d]</th></tr>
<tr><td>School sports</td><td>Non-school sports</td><td>Recreational</td><td>School sports</td><td>Non-school sports</td><td>Recreational</td><td>School sports</td><td>School sports</td><td>Non-school sports</td><td>Recreational</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>G</td><td>H</td><td>I</td><td>J</td></tr>
<tr><td colspan="3">Office visits[a] 377 978
Inpatient hospitalizations[a,b] 2 886–4 936</td><td colspan="3">115 479–166 929</td><td>85 885</td><td colspan="3">511 590–1 240 972</td></tr>
</table>

FIGURE 1

Conceptual framework for settings where children and adolescents experience SRRCs and receive care for SRRCs. [a]Information from MarketScan database. [b]Information from NEISS database. [c]Information from RIO database. [d]Information derived from literature sources.

during sports and recreational activities. Conversely, we may have overestimated the number of SRRCs by misclassifying concussions as SRRCs that were from "other causes," such as falling objects, assault, or unknown circumstances. To adjust for this potential misclassification, we excluded an additional 15% from the original number of concussion visits based on previous studies that have identified ~15% of concussion being due to other causes.[11,14]

MarketScan

To identify SRRCs that resulted in health care encounters, we queried the Truven Health Analytics MarketScan Research Database for 2013. This database contains health care claims of individuals who have commercial health insurance, covering ~30 million individuals in the United States annually.[15] It contains information on outpatient, ED, and inpatient claims. We used ICD-9-CM codes for concussion (850.xx and 854.09). Because we aimed to identify visits for incident concussions, we excluded claims if there had been a previous claim for concussion within the preceding 1 month to minimize the likelihood of including follow-up visits from the same injury. This time period was chosen because symptoms resolve within 1 month in 70% to 90% of youth with SRRCs.[6,16–19] We conducted a sensitivity analysis using alternate exclusion periods of 2 weeks and 3 months to determine how different time periods affected the estimate. We used 2 weeks as the shortest period based on typical symptom resolution. The 3-month period was based on the definition of postconcussive syndrome (PCS) in the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition*, which differs from the *ICD-9-CM* definition of 1 month.

Incidence rates were calculated on the basis of the number of claims divided by the number of enrollees (11 533 618 children ≤18 years during 2013). Age was categorized in years: 0 to 5, 6 to 10, 11 to 13, and 14 to 18 to reflect preschool, elementary, middle school, and high school ages. We multiplied incidence rates by population estimates from the Centers for Disease Control and Prevention Web-based Injury Statistic Query and Reporting System to determine concussion counts by age category. We constructed 95% confidence intervals using a Poisson distribution. These calculations are based on the assumption that MarketScan is representative of the US population. We believe this is reasonable as MarketScan contains a substantial sample of the US population (15%).

NEISS

To estimate the number of ED visits and hospitalizations from SRRCs, we analyzed data from NEISS.[20] NEISS, a database operated by the US Consumer Product Safety Commission, consists of data on all ED visits including a brief description of the event and disposition for a probability sample of 100 hospitals. The number of inpatient hospitalizations was determined by the number of patients who were admitted from the ED. We conducted a narrative review of all concussion cases to determine the proportion of concussions that were SRRCs. We classified SRRCs as occurring during school sports using binary yes/no, and whether it was 1 of the 9 sports included in the National High School Sports Related Injury Surveillance System (High School Reporting Injury Online [RIO]), described subsequently.

Estimates of the annual number of SRRCs nationally treated in the ED and admitted from the ED were generated using weights based on the probability sampling of hospitals in NEISS. We constructed 95% confidence intervals using the coefficient of variation by age category provided in NEISS.

National High School Sports-Related Injury Surveillance System, High School RIO

Certified ATCs are qualified health professionals for diagnosis and treatment of concussions.[21] Previous studies have demonstrated that student athletes often report SRRCs to ATCs. Many of these SRRCs do not result in an encounter with additional health care providers and would not be included in the previously described databases.[16,22,23] To determine the number of high school athletes who receive care exclusively from ATCs, we used data from High School RIO.[24] High School RIO is an Internet-based sports injury surveillance system that records sports-related injuries reported by high school ATCs for a random sample of 100 US high schools. These 100 schools with a National Athletic Trainers' Association–affiliated ATC are randomly selected based on school population and geographic location to create a nationally representative sample. Data are reported for 9 sports: boys' football, boys' and girls' soccer, girls' volleyball, boys' and girls' basketball, boys' wrestling, boys' baseball, and girls' softball.

We examined all concussions included in High School RIO for 2013. Data collected in RIO included types of health care providers seen by concussed athletes: ATCs, physicians, and other providers (nurse practitioners, physician assistants, etc). To eliminate overlap between SRRCs from High School RIO and those in MarketScan and NEISS, we only included students seen exclusively by ATCs; we believed this represented SRRCs in high school athletes that were not captured by our other data sources. Using weight-based probability sampling provided by High School RIO, we generated a national estimate of the number of

SRRCs in high school students who participated in the sports in High School RIO and were treated by ATCs exclusively.

SRRCs Not Captured by Previous Databases

The most challenging number to determine was the number of children with concussions who were not seen in health care settings captured by our databases, namely, children who sought care from ATCs or did not receive care. From High School RIO, we determined the number of SRRCs from the 9 high school sports covered by RIO and the proportion of these that were reported only to ATCs. To create an estimate that included all high school SRRCs seen exclusively by ATCs, we used NEISS to determine the proportion of high school sports injuries from sports covered by High School RIO because NEISS was the only other data source that included data on the activity that resulted in injury. We inversely weighted the High School RIO data by this proportion to estimate the number of SRRCs from all high school sports that were treated exclusively by ATCs (cell G in Fig 1).

Estimates in the literature of the proportion of untreated SRRCs in high school athletes range between 22.5% and 52.7%.[22,23,25] To generate an estimated number of untreated SRRCs from high school sports (cell H), we applied this range (22.5%–52.7%) to the number of concussions from High School RIO (Figs 2 and 3).

There are major gaps in the literature regarding treatment of children who experience concussions during nonschool sports and recreation. In 1 ED-based study of concussions, 53% of SRRCs in adolescents aged between 14 and 19 years were not school sport–related.[27] To determine the number of untreated SRRCs that occurred in nonschool (cell I) and recreation settings (cell J) for high school age youth, we applied that 53% to the estimated number of SRRCs in high school sports (cell H; Fig 3).

There are limited data on untreated SRRCs occurring in children <14 years for all sports- and recreation-related activities (cells H–J). A prospective cohort study of middle school female soccer players found that 55.9% of players with symptoms of concussion were never evaluated.[26] We applied this proportion (55.9%) to the number of concussions from MarketScan and NEISS data to estimate the number of SRRCs that go untreated in children <14 years of age (Figs 2 and 3). Because there have been so few studies in young children, we conducted a sensitivity analysis to vary the percentage of untreated SRRCs for children <14 years. For this analysis, we used the range of percentages of unreported concussions in high school athletes (22.5%–52.7%) applied to younger children.[22,23,25]

Calculations to determine concussions in high school sports that did not result in a healthcare encounter, ages 14–18 years
All high school concussions seen in a formal health care setting based on RIO: 394 520
Range of concussions not reported to healthcare providers: 22.5–52.7%[22,23,25].
To determine the range of total concussions in high school sports: 394 520/(1–.225) = 509 058 to 394 520/(1–.527) = 834 080
Estimate of concussions in high school age (14–18 years) not seen in a healthcare setting:
509 058–394 520 = **114 538** 834 080–394 520 = **439 560**

Calculations to determine all SRRCs for children <14 years that did not result in a healthcare encounter
Total concussions MarketScan Inpatient, Outpatient, and ED:241 199
Total concussions MarketScan Inpatient and Outpatient and NEISS ED: 211 342
55.9% concussions not seen in healthcare setting among middle school soccer players[26]
To determine the range of total SRRCs in children <14 years: 211 342/(1–.559) = 479 234 to 241 199 /(1–.559) = 546 937
Estimate of SRRCs in children <14 years untreated in healthcare setting
479 234 –211 342 = **267 892** 546 937–241 199 = **305 738**

FIGURE 2
Calculations of the number of 0- to 18-year-olds with concussions not treated in health care settings.

RESULTS

Treated by Health Care Providers (Cells A–G)

Outpatient visits accounted for 68.7% of MarketScan claims and an incidence of 485 SRRCs per 100 000 children per year. Inpatient hospitalizations and ED visits represented 0.9% and 30.4% of MarketScan claims for SRRCs, respectively (Table 1). On the basis of data from NEISS and MarketScan, we estimated a population incidence between 4 and 6 hospitalizations and between 148 and 214 ED visits for SRRCs per 100 000 US children per year.

Using alternate exclusion periods of 2 weeks and 3 months for MarketScan claims, we identified 11.6% more SRRCs and 6.6% fewer SRRCs, respectively (Table 2).

From High School RIO, we estimated 335 342 SRRCs annually from the 9 included high school sports (95% confidence interval 321 628–349 056). Of these, 21.8% were seen exclusively by ATCs (Table 1). On the basis of review of NEISS cases, 85% of SRRCs from school sports in adolescents 14 to 18 years old occurred during sports in High School RIO. Thus, we estimated 394 520 SRRCs occurred in all high school athletes, of which 85 885 were treated only by ATCs (Cell G for ages 14–18; Fig 3). The remaining 308 636 concussions are captured in cells A and D. Because information for youth <14 years is not captured in RIO, there are no contributions to cell G from younger children.

We estimated between 582 228 and 635 728 SRRCs are treated annually by health care providers in the United States for an incidence between 748 and 816 SRRCs per 100 000 US children per year.

Not Treated by Any Health Care Provider (Cells H, I, and J)

Between 22.5% and 52.7% of SRRCs from high school sports are not reported to any provider. Applying this range to the 394 520 concussions

TABLE 1 Concussion Counts by Age Group Based on 3 Databases

Age (y)	MarketScan[a]			RIO[b]	NEISS[c]	
	Outpatient (95% CI)	Inpatient (95% CI)	ED (95% CI)	ATC only (95% CI)	Inpatient (95% CI)	ED (95% CI)
0–5	24 071 (23 270–24 887)	756 (621–914)	19 037 (18 326–19 765)	—	—	4540 (3116–5964)
6–10	48 798 (47 656–49 961)	622 (497–763)	28 059 (27 194–28 942)	—	—	20 252 (15 092–25 412)
11–13	83 224 (81 775–84 693)	687 (563–835)	35 945 (34 992–36 911)	—	—	28 392 (22 270–34 512
14–18	208 724 (206 483–210 989)	2722 (2472–2993)	79 525 (78 141–80 925)	73 002 (59 450–86 555)	—	62 296 (48 865–75 727)
Total	377 978 (374 858–381 126)	4936 (4587–5303)	166 929 (164 854–169 020)	—	2886 (1160–2783)	115 479 (89 343–141 615)

CI, confidence interval.

[a] MarketScan includes data from outpatient, inpatient, and ED visits.

[b] RIO includes all reported concussions documented by athletic trainers for high school students only. No data available for children <14 y old.

[c] Sample size too small to provide population estimates and CIs for age categories.

estimated from High School RIO, we estimated an additional 114 538 to 439 560 untreated SRRCs among high school athletes (cell H; Fig 3). On the basis of an estimated 53% of concussions in this age group not related to school sports, we estimated an additional 129 160 to 495 674 untreated SRRCs occurring in nonschool sport and recreational settings (cells I and J). In children <14 years, we estimated between 267 892 and 305 738 untreated SRRCs based on the estimate of 55.9% of SRRCs in this age group that were not evaluated by a health care provider (Fig 3). The results of our sensitivity analysis varying the percentage of

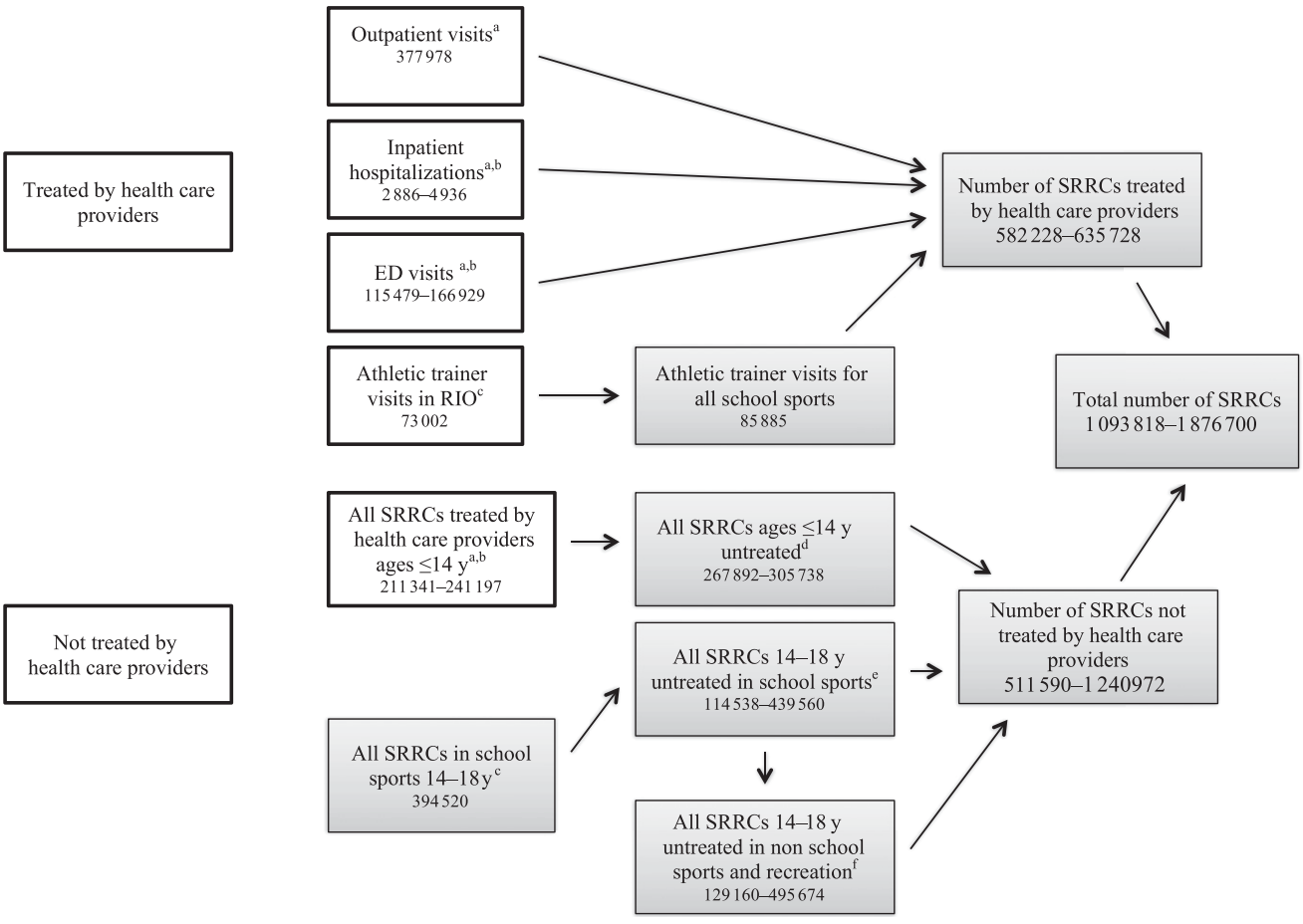

FIGURE 3

Flowchart of process to calculate total number of sports- and recreation-related concussions in children ≤18 years. Shaded boxes indicate transformations of data. [a]Data from MarketScan. [b]Data from NEISS. [c]Data from RIO. [d]The 55.9% unreported in O'Kane et al[26] article applied to total number of SRCs with health care encounters by age group. Lower number is MarketScan outpatient, NEISS inpatient, and NEISS ED number of visits. Upper number is based on total MarketScan visits. Sample calculation in Figure 2. [e]From 22.5% to 52.7% of concussions in high school sports are unreported in health care settings.[22,23,25] [f]Based on percentage of non–team-related concussions by age group.[27]

untreated SRRCs in children <14 years estimate between 59 772 and 216 483 untreated SRRCs.

In children ≤18 years old, we estimated between 511 590 and 1 240 972 SRRCs are untreated each year. (Fig 3)

In total, we estimated between 1 093 818 and 1 876 700 SRRCs occur annually in US children ≤18 years old, for an incidence between 1405 and 2410 per 100 000 children in 2013.

TABLE 2 Sensitivity Analysis of the Effect of Varied Visit Exclusion Time Frames on Number of SRRCs in MarketScan

Age (y)	1 mo (95% CI)	2 wk (95% CI)	3 mo (95% CI)
0–5	43 863 (42 781–44 962)	45 369 (44 269–46 485)	42 780 (41 716–43 870)
6–10	77 478 (76 040–78 942)	82 866 (81 372–84 374)	74 554 (73 143–75 987)
11–13	119 856 (118 116–121 615)	134 844 (133 000–136 711)	112 806 (111 120–114 515)
14–18	290 971 (228 321–293 643)	330 132 (327 311–332 976)	267 428 (264 890–269 990)
Total	549 843 (546 066–552 627)	613 601 (609 617–617 607)	513 641 (509 996–517 308)

CI, confidence interval.

DISCUSSION

Our estimate of 1.1 to 1.9 million SRRCs annually in US children ≤18 years old includes population estimates for SRRCs diagnosed by health care providers and those who are undiagnosed. We estimate more than half a million children use health care services annually for treatment of SRRCs. This number emphasizes the need to improve primary prevention efforts aimed at children, parents, and coaches.

Our estimate is substantially lower than the previous estimate of 1.6 to 3.8 million TBIs annually.[5] This difference is expected because we focused on children ≤18 years old. A previous population-based study found ~61% of SRRCs occur in youth 0 to 18 years.[4] Applying this percentage to the Langlois estimate, we would expect between 980 800 and 2.3 million SRRCs annually, which is in reasonable accordance with our estimate.

The difference in the ED estimates from the NEISS and MarketScan databases likely stems from 2 sources. Our query of MarketScan was more inclusive with ICD-9-CM codes for both concussion (850) and unspecified intracranial injury (854), whereas we queried NEISS exclusively based on concussion diagnosis because NEISS does not use ICD codes. We conducted a narrative review of NEISS concussions to determine SRRCs. Because MarketScan does not contain narrative information, we used an exclusion method to eliminate other common causes. The true estimate of ED visits from SRRCs likely lies between these 2 values. The NEISS data may be an underestimate because of nonspecific coding and narrative information, whereas the MarketScan data may be overly inclusive by counting some concussions from non-SRRC causes as SRRCs.

Many previous population-based studies of concussion have focused on reporting concussion rates by athletic exposure, which are difficult to compare with our results of the count and incidence of SRRCs across the population.[7,9,28–32] The number of athletic exposures per individual is variable by age and challenging to quantify for recreational activities. Many studies examining underreporting of concussions are sport-specific and focus only on older youth. Despite this limitation, we sought to include children of all ages with untreated SRRCs because previous studies have consistently identified that youth commonly do not receive care for concussions. For our estimate, we included studies from the literature with the goal of identifying the possible range of untreated SRRCs. As a result, there is variability in our estimate that is reflected in its range and the sensitivity analyses. The lack of a national surveillance system for this common injury has been identified as a major issue by the Institute of Medicine (IOM).[33,34] The large number of unreported concussions identified in our study, between 511 590 and 1 240 972, indicates a need for a cultural shift in the recognition of SRRCs. Surveillance for SRRCs must focus on recognizing and treating concussions across all age groups and include recreational activities.

There are numerous studies demonstrating that many children and adolescents do not report concussion symptoms to any health care providers, but it is unclear how many people who experience symptoms have a true concussion diagnosis.[17,22,23,25,35,36] We applied rates from studies of middle and high school students underreporting concussions across younger age groups because there is little information on SRRC reporting in younger children. There are no studies to date that examine unreported concussions for nonschool sports and recreational activities; because of this, we used reporting from school sports applied to nonschool sports and recreational activities. Our estimate is vulnerable given these assumptions and the use of reporting percentages from past literature, some of which are sport-specific, because larger more comprehensive studies have not yet been done. The MarketScan data used pertained to private insurance companies and did not include public insurance. There have been no studies evaluating differences in outpatient visits for SRRCs by insurance status, although 1 study found differences in TBI admissions.[37] The data sources

for the base estimates include SE estimates that were not included in the final estimate.

CONCLUSIONS

Our national estimate of the number of SRRC occurring to youth indicates the magnitude of these injuries in the United States. As a result of the IOM initiative, the Centers for Disease Control and Prevention is currently developing a surveillance system for SRRCs. It is critical this system includes recreational sources of concussion. The imprecision of our current estimate underscores the clinical and public health importance of the IOM's recommendation for the establishment of an accurate surveillance program.

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ABBREVIATIONS

ATCs: certified athletic trainers
ED: emergency department
ICD-9-CM: *International Classification of Disease, Ninth Revision, Clinical Modification*
IOM: Institute of Medicine
NEISS: National Electronic Injury Surveillance System
RIO: Reporting Injury Online
SRRCs: sports- and recreation-related concussions
TBI: traumatic brain injury

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