

Trends in Sports- and Recreation-Related Traumatic Brain Injuries Treated in US Emergency Departments: The National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP) 2001-2012

Victor G. Coronado, MD, MPH; Tadesse Haileyesus, MS; Tabitha A. Cheng, MD; Jeneita M. Bell, MD, MPH; Juliet Haarbauer-Krupa, PhD; Michael R. Lionbarger, MPH; Javier Flores-Herrera, MD, MPH; Lisa C. McGuire, PhD; Julie Gilchrist, MD

Importance: Sports- and recreation-related traumatic brain injuries (SRR-TBIs) are a growing public health problem affecting persons of all ages in the United States. **Objective:** To describe the trends of SRR-TBIs treated in US emergency departments (EDs) from 2001 to 2012 and to identify which sports and recreational activities and demographic groups are at higher risk for these injuries. **Design:** Data on initial ED visits for an SRR-TBI from the National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP) for 2001-2012 were analyzed. **Setting:** NEISS-AIP data are drawn from a nationally representative sample of hospital-based EDs. **Participants:** Cases of TBI were identified from approximately 500 000 annual initial visits for all causes and types of injuries treated in EDs captured by NEISS-AIP. **Main Outcome Measure(s):** Numbers and rates by age group, sex, and year were estimated. Aggregated numbers and percentages by discharge disposition were produced. **Results:** Approximately 3.42 million ED visits for an SRR-TBI occurred during 2001-2012. During this period, the rates of SRR-TBIs treated in US EDs significantly increased in both males and females regardless of age (all P s < .001). For males, significant increases ranged from a low of 45.8% (ages 5-9) to a high of 139.8 % (ages 10-14), and for females, from 25.1% (ages 0-4) to 211.5% (ages 15-19) (all P s < .001). Every year males had about twice the rates of SRR-TBIs than females. Approximately 70% of all SRR-TBIs were reported among persons aged 0 to 19 years. The largest number of SRR-TBIs among males occurred during bicycling, football, and basketball. Among females, the largest number of SRR-TBIs occurred during bicycling, playground activities, and horseback riding. Approximately 89% of males and 91% of females with an SRR-TBI were treated and released from EDs. **Conclusion and Relevance:** The rates

Author Affiliations: Division of Unintentional Injury Prevention (Drs Coronado, Cheng, Bell, Haarbauer-Krupa, and Gilchrist and Mr Lionbarger), Division of Analysis, Research Practice Integration (Mr Haileyesus), National Center for Injury Prevention and Control, and The CDC Experience Applied Epidemiology Fellowship, Division of Scientific Education and Professional Development (Dr Cheng), and Division of Nutrition Physical Activity, National Center for Chronic Disease Prevention and Health Promotion (Dr McGuire), Centers for Disease Control and Prevention, Atlanta, Georgia; and Medical Emergency Service of Madrid, SUMMA 112, Spanish Field Epidemiology Training Program, Epidemiology National Center, Madrid, Spain (Dr Flores-Herrera).

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Corresponding Author: Victor G. Coronado, MD, MPH, Division of Unintentional Injury Prevention, National Center for Injury Prevention and Control, Centers for Disease Control and Prevention, 4170 Buford Hwy NE, MS-F62, Atlanta, GA 30341 (vgc1@cdc.gov).

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of ED-treated SRR-TBIs increased during 2001-2012, affecting mainly persons aged 0 to 19 years and males in all age groups. Increases began to appear in 2004 for females and 2006 for males. Activities associated with the largest number of TBIs varied by sex and age. Reasons for the reported increases in ED visits are unknown but may be associated with increased awareness of TBI through increased media exposure and from campaigns, such as the Centers for Disease Control and Prevention's Heads Up. Prevention efforts should be targeted by sports and recreational activity, age, and sex. **Key words:** *emergency department, epidemiology, recreation, sports, traumatic brain injury*

DURING 2001-2010, the number of sports- and recreation-related (SRR) injuries treated in emergency departments (EDs) increased approximately 5% from 3.9 million to 4.1 million.^{1,2} Among these SRR injuries, traumatic brain injuries (TBIs) are a major outcome. TBIs resulting from sports and recreational activities (SRAs) have become a major public health problem in the United States.^{3,4}

Approximately 65% of all SRR-TBIs treated in EDs from 2001 to 2009 occurred among persons 19 years or younger.^{3,4} Most of these injuries were associated with bicycling, football, and playground activities and disproportionately affected 10- to 19-year-old males.^{3,4} Unlike the small increases in all SRR injuries, the number of SRR-TBIs has increased substantially (62%; from 153 375 in 2001 to 248 418 in 2009).^{3,4}

TBI has significant medical and socioeconomic consequences. Approximately 90% of SRR-TBIs were treated and released from EDs, suggesting that these injuries were mild.⁴ And yet, research indicates that 15% to 25% of all persons with mild TBI may have long-term physical, cognitive, and emotional consequences.⁵⁻⁸ The economic impact of TBI is staggering. Estimated in 2009 US dollars, the total lifetime healthcare cost of fatal, hospitalized, and nonhospitalized TBIs was approximately \$221 billion. Of this, \$57.8 billion were related to hospitalization-related costs.⁹ TBIs can be experienced by persons of any age who participate in SRAs. Therefore, information on SRR-TBIs across the entire life span is critical for prevention planning and health promotion. To our knowledge, this is the first national study that describes the magnitude of and trends in SRR-TBIs treated in US hospital EDs among all ages. In addition, this study seeks to identify population subgroups at higher risk, SRAs that are associated with the higher number of TBIs, and the number of SRR-TBIs stratified by discharge disposition (as a proxy for TBI severity).

METHODS

The National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP), an expansion of NEISS, has been cosponsored by the Centers for Disease Control and Prevention (CDC), National Center for Injury Prevention and Control, and the Consumer Prod-

uct Safety Commission since 2000.¹⁰ It collects data, on initial visits, for all types and external causes of nonfatal injuries and poisonings treated in US hospital EDs—even those not associated with consumer products. Detailed information on NEISS-AIP methods have been published elsewhere.^{1,2,4} Given that NEISS-AIP collects data on initial visits, not on unique patient data, a patient can have valid repetitive initial visits for a second or third time. To address this issue, every year, the CDC uses a computerized program to identify and delete possible (invalid) duplicates. Every year, on average, 10 records are removed. In summary, data were drawn from a nationally representative subsample of 66 of 100 NEISS hospitals selected as a stratified probability sample of hospitals in the United States and territories that have 6 or more beds and a 24-hour ED.¹⁰ Trained abstractors extract relevant information from NEISS-eligible ED records,¹¹ including, for example, the body part injured, diagnosis, external cause, and injury intent.¹¹ Abstractors may also record a brief narrative with additional details about the injury. NEISS-AIP has been used previously to estimate the incidence of SRR-TBIs treated in EDs.^{3,4}

For this study, NEISS-AIP records were examined for injuries from SRAs that were treated in the ED between January 1, 2001, and December 31, 2012. An algorithm using the consumer products involved (eg, swing sets) and the narrative description of the incident obtained from the NEISS-AIP medical record were used to identify SRAs. For this study, an SRR injury was classified as a TBI if an NEISS-AIP record documented that the primary body part injured was the head and the principal head injury diagnosis was concussion or internal organ injury. All SRR-TBIs could have occurred during organized or unorganized sports, as well as all types of recreational activities.

Initially, cases were classified into 39 mutually exclusive SRAs using an algorithm developed by the CDC and the Consumer Product Safety Commission for the consumer products involved (eg, baseball equipment), a description of events leading to the injury, injury locale, and injury diagnosis obtained from the ED medical record. Fifteen of the 39 activities with the highest occurrence of TBI were retained as separate categories: all-terrain vehicle (ATV) use, baseball, basketball,

bicycling, football, golf, gymnastics, ice hockey, horseback riding, playground activities, soccer, scooter use, softball, trampoline, and volleyball. Because of small sample sizes, selected activities that share certain characteristics were combined, including combative sports/wrestling; exercise/weight lifting; inline/roller skating; miscellaneous ball sports; moped/minicar/off-road vehicles/go-cart; snow sports (ie, snow skiing, ice skating, toboggan/sled/discovery, and snowmobile); swimming/water sports (ie, water skiing/surfing, personal watercraft, and fishing); and racket sports/tennis. Disparate activities with lower occurrence of TBI were categorized as “other sports.” Because this category is nonspecific and not conducive to identifying clear prevention implications, the results are presented but not discussed. In this report, we present the results of the most common single or combined SRAs with the highest occurrence of TBI by year, sex, age group, and discharge disposition. Patient discharge disposition was used as a proxy for TBI severity and was categorized as (1) treated and released (ie, mild TBI or concussion) and (2) hospitalized/transferred (ie, more severe TBI). The latter category includes hospitalizations following the ED visit and those transferred to other facilities for more specialized care. The “other” category includes observed, left against medical advice, left without being seen, and unknown discharge disposition. The severity of these “other” cases cannot be ascertained.

Cases of an SRR-TBI were excluded if the injury was violence-related (ie, self-harm, assault, or legal intervention). Also excluded were assault-related injuries that occurred during SRAs. Persons with an SRR-TBI who were dead on arrival or died in the ED were also excluded because of small sample size ($N = 84$).

Because the exact number of people who participate in specific SRAs in the United States is not known,^{3,4} US Census Bureau population estimates were used as the denominator to compute the overall population rates of SRR-TBIs per 100 000 population per year by sex and age group.^{3,4} Although NEISS-AIP collects data on race/ethnicity, these demographic variables were not included in this study. NEISS-AIP does not offer the option to request leading causes of injury by race/ethnicity because of the relatively high percentage of records (~17 %) with unknown race/ethnicity. Therefore, annualized national estimates presented for each race/ethnicity category will be low because they do not count cases recorded as “unknown” race/ethnicity (available at: <http://aspe.hhs.gov/datacncl/datadir/cdc5.htm>). Estimates with coefficients of variation more than 30%, a weighted estimate of less than 1200, or an unweighted count of less than 20 were considered unstable.⁵ Rates resulting from these unstable estimates were not reported; resulting numbers and percentages were reported and flagged. Analyses were conducted

using SAS 9.3; 95% confidence intervals (CIs) and statistical tests took into consideration sample weights and the complex survey design.¹⁰) Significance of trends over time was assessed using weighted rate regression analyses. Joinpoint regression version 4.1.0 was fitted to estimate annual percent change (APC) in rates and to identify possible joinpoints (ie, years at which trends may change significantly).¹² A maximum of 3 joinpoints were allowed for each estimate, and the APC for each segment was computed using log-linear models. In addition, 95% CIs were calculated for each APC estimate and were used to determine if the APC for each segment differed significantly from zero (see Tables 1 and 2). When multiple significant joinpoints occurred, the overall (full range) percent changes were reported as an average annual percent change (AAPC).

RESULTS

Overall SRR-TBI ED visits by sex

During 2001-2012, the unweighted counts for all SRR injury ED visits were 869 472, of which 71 982 (8.3%) were TBIs; weighted counts totaled 49 560 999 ED visits for all SRR injuries, of which 3 417 370 (7.0%) were TBIs (not displayed). The overall age-adjusted rate of SRR-TBI ED visits per 100 000 population significantly increased from 73.1 in 2001 to 152.0 in 2012 ($P < .0001$) (see Figure 1 and Table 1). The overall 2001-2012 AAPC in the age-adjusted rate of SRR-TBI ED visits was 7.8% (95% CI, 5.4-10.3; $P < .0001$; see Table 2). For all cases, the APC in the age-adjusted rate of SRR-TBI ED visits from 2001 to 2006 was 2.8% (95% CI, -1.9 to 7.6; $P = .2$) and then from 2006 to 2012, the APC significantly increased to 12.3% (95% CI, 8.7-15.9, $P < .0001$; see Table 2). The joinpoint for the line segments among males occurred at 2006, whereas among females it occurred at 2004 (see Table 2).

SRR-TBI ED visits by age group

On average each year during the reporting period, approximately 70% of all SRR-TBI ED visits occurred among persons 19 years or younger (see Table 1). Rates of SRR-TBI ED visits increased significantly between 2001 and 2012 for all age groups (all P s < 0.001), with persons in age groups ranging from 10 to 24 years and 45 years or older showing increases exceeding 110% (see Table 1).

Estimated rates for SRR-TBI ED visits by sex, year, and age group

Among males, the rates of SRR-TBI ED visits per 100 000 population increased significantly from 2001

TABLE 1 *Estimated numbers and rates of emergency department visits per 100 000 population of sports- and recreation-related traumatic brain injury by sex and age group, NEISS-AIP, 2001-2012, United States*

	2001		2012		2001 vs 2012	Trend
	<i>n</i>	Rate (95% CI) ^a	<i>n</i>	Rate (95% CI) ^a	rate change (%)	test <i>P</i> value
Sex						
Male	144 546	99.9 (86.1-113.7)	308 566	205.1 (181.7-228.5)	105.3	<.01
Female	63 257	45.2 (39.2-51.1)	142 157	97.1 (85.6-108.7)	114.8	<.01
Total	207 829	73.1 (63.7-82.5)	450 724	152.0 (135.1-169.0)	107.9	<.01
All age groups						
0-4	14 176	73.5 (50.9-96.1)	23 957	119.8 (84.7-154.9)	63.0	<.01
5-9	39 170	194.2 (141.2-247.2)	61 011	298.0 (227.6-368.4)	53.5	<.01
10-14	54 143	258.1 (191.4-324.7)	128 672	622.5 (462.5-782.5)	141.2	<.01
15-19	45 886	224.3 (169.1-279.5)	115 650	541.4 (410.5-672.3)	141.4	<.01
20-24	12 992	65.8 (29.4-102.2)	33 072	146.4 (99.4-193.5)	122.5	<.01
25-34	15 014	38.0 (24.0-52.0)	30 729	72.6 (52.0-93.3)	91.1	<.01
35-44	11 734	26.0 (12.2-39.9)	17 856	44.1 (30.8-57.4)	69.6	<.01
≥45	14 704	14.7 (7.4-22.0)	39 777	31.6 (21.4-41.7)	115.0	<.01
Sex and age group						
Male						
0-4	8 467	85.8 (66.0-105.6)	16 553	162.0 (111.9-212.2)	88.8	<.01
5-9	28 363	274.6 (196.9-352.3)	41 877	400.4 (302.5-498.3)	45.8	<.05
10-14	38 827	361.3 (263.2-459.3)	91 586	866.7 (637.0-1 096.0)	139.9	<.01
15-19	34 731	329.3 (260.6-397.9)	79 171	722.2 (563.3-881.0)	119.3	<.01
20-24	9 032	89.6 (41.3-137.9)	22 028	190.7 (129.1-252.3)	112.8	<.01
25-34	9 517	47.8 (28.8-66.8)	20 558	96.3 (69.6-123.1)	101.5	<.01
35-44	6 980 ^b		11 520	57.1 (38.6-75.6)	^c	...
≥45	8 621	18.7 (10.9-26.6)	25 274	42.7 (29.2-56.2)	128.3	<.01
Female						
0-4	5 709	60.5 (35.1-86.0)	7 404	75.7 (54.7-96.7)	25.1	<.01
5-9	10 807	109.8 (94.5-125.0)	19 134	191.0 (150.7-231.4)	74.0	<.01
10-14	15 316	149.7 (128.1-171.3)	37 086	367.1 (280.6-453.6)	145.2	<.01
15-19	11 155	112.6 (88.1-137.1)	36 479	350.8 (252.5-449.2)	211.5	<.01
20-24	3 960	40.9 (18.1-63.7)	11 044	100.1 (66.2-134.0)	144.7	<.01
25-34	5 498	28.1 (19.2-37.0)	10 171	48.5 (32.2-64.9)	72.6	<.05
35-44	4 755	21.0 (13.8-28.2)	63 36	31.1 (22.1-40.2)	48.1	<.01
≥45	6 057 ^b	...	14 503	21.7 (14.1-29.3)		...

Abbreviations: CI, confidence interval; NEISS-AIP, National Electronic Injury Surveillance System-All Injury Program.

^aTotal rates and rates by sex are age-adjusted rates. Rates by age group are crude rates. Rates derived from unstable estimates are not presented. Estimates are considered unstable when the number of unweighted NEISS cases is less than 20 or the national (weighted) estimate is less than 1200 or the coefficient of variation is more than 30%. 95% CI (not presented for unstable estimates).

^bThe number was derived from an unstable estimate.

to 2012 in all age groups, except for those aged 35 to 44 years whose rates were not calculated because the estimates were unstable (see Table 1). SRR-TBI ED visit rates for males were significantly higher in those aged 5 to 9, 10 to 14, and 15 to 19 years than in those in other age groups (all P s < .05; see Table 1).

Among females, the rates of SRR-TBI ED visits per 100 000 population increased significantly from 2001 to 2012 in all age groups, except for those 45 years or older whose rates were not calculated because the estimates were unstable (see Table 1). SRR-TBI ED visit rates were significantly higher among females aged 5 to 9, 10 to 14, and 15 to 19 years than in those in other age groups (P < .05; see Table 1).

Ten leading SRAs with the highest proportion of TBI ED visits by sex

Among the 10 leading SRAs comprising the highest proportion of TBI-related ED visits, the activities that accounted for the largest SRR-TBI AAPCs varied by sex and year (see Table 3). Among males, the highest number of SRR-TBI ED visits in 2001 and 2012 occurred while engaged in bicycling and football. From 2001 to 2012, the AAPC in SRR-TBI ED visits significantly increased the most in soccer (4.04%; 95% CI, 1.35-6.79; P = .0071) and football (3.29%; 95% CI, 1.70-4.90; P = .0009) (see Figure 2). In contrast, the AAPC decreased the most in skating (−2.34%; 95% CI, −4.47 to −0.17;

TABLE 2 *Estimated AAPC and period APC in sports- and recreation-related traumatic brain injury in emergency department visits by segment period and sex, NEISS-AIP, 2001-2012*

	Full range 2001-2012	Segment 1		Segment 2	
	AAPC (95% CI)	Period	APC (95% CI)	Period	APC (95% CI)
All	7.8 (5.4-10.3) ^a	2001-2006	2.8 (−1.9 to 7.6)	2006–2012	12.3 (8.7-15.9) ^a
Sex					
Male	7.5 (5.4-9.8) ^a	2001-2006	2.8 (−1.5 to 7.2)	2006-2012	11.7 (8.6-14.9) ^a
Female	7.7 (4.2-11.3) ^a	2001-2004	−2.6 (−14.1 to 10.5)	2004-2012	11.8 (8.9-14.8) ^a

Abbreviations: AAPC, average annual percent change; APC, annual percent change; CI, confidence interval; NEISS-AIP, National Electronic Injury Surveillance System-All Injury Program.

^aStatistically significant change ($P < .05$).

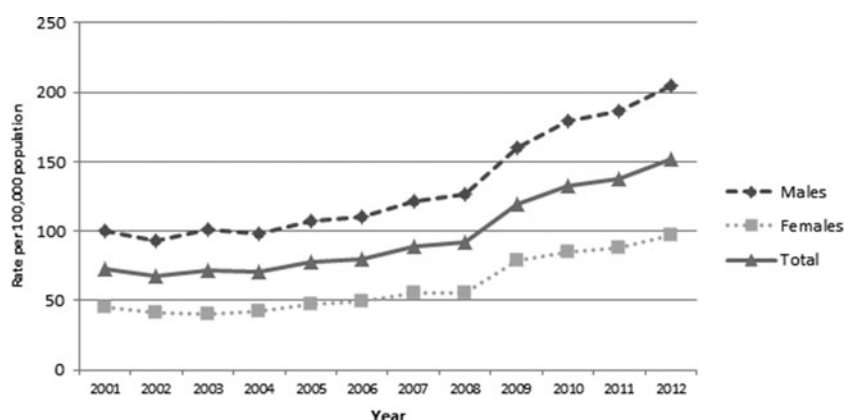


Figure 1. Age-adjusted rates of emergency department visits per 100 000 population of sports- and recreation-related traumatic brain injury, by year and sex, National Electronic Injury Surveillance System-All Injury Program, 2001-2012, United States.

$P = .0374$) and playground activities (-2.26% ; 95% CI, -4.43 to -0.04 ; $P = .0467$) (see Figure 2).

Among females, the SRAs associated with the largest number of SRR-TBI ED visits varied in 2001 and 2012 (see Table 3). In 2001, the highest number of TBI-related ED visits occurred while engaged in bicycling and horseback riding, respectively. In 2012, the second highest number of TBI-related ED visits occurred as a result of playground activities. From 2001 to 2012, the largest significant increase in the AAPC in SRR-TBI ED visits was observed in softball (5.35% ; 95% CI, 0.41 - 10.54 ; $P = .0363$) and soccer (4.80% ; 95% CI, 3.23 - 6.40 ; $P = .00004$) (see Figure 2). In contrast, the AAPC significantly decreased the most in horseback riding (-4.95% ; 95% CI, -8.69 to -1.05 ; $P = .0183$) (see Figure 2).

SRAs with the highest number and proportion of TBI ED visits by sex and age group

The 5 leading SRAs associated with TBI ED visits varied by age group and sex (see Table 4). Among males

aged 0 to 4 and 5 to 9 years, SRR-TBI ED visits occurred frequently during bicycling and playground activities. Among 10- to 14- and 15- to 19-year-old males, football and bicycling were activities in which TBI frequently occurred. Among 20- to 24-year-old men, bicycling, basketball, and ATVs were frequent activities resulting in TBI; and among men 25 years or older, bicycling and ATVs were the activities in which TBI frequently occurred.

Playground activities and bicycling were frequent SRAs resulting in TBI-related ED visits among 0- to 4- and 5- to 9-year-old females. Among 10- to 14- and 15- to 19-year-old females, soccer and basketball were activities in which TBI frequently occurred, whereas among women 20 years or older, bicycling and horseback riding were activities frequently resulting in TBI.

Five leading activities with the highest percent estimates of TBI ED visits by discharge disposition

The discharge disposition of persons with SRR-TBI ED visits varied by activity and sex (see Table 5). Of the 2 368 405 males with an SRR-TBI treated in EDs

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TABLE 3 *Number, percent, and AAPC of the 10 most common SRAs resulting in traumatic brain injury–related emergency department visits, by sex, NEISS-AIP, 2001-2012, United States*

Ten leading SRAs by sex	2001		2012		2001-2012 AAPC (95% CI) ^a	Trend test <i>P</i> value
	<i>n</i>	% (95% CI) ^a	<i>n</i>	% (95% CI) ^a		
Male						
Bicycling	29 532	20.4 (10.4-30.4)	52 077	16.9 (11.1-22.7)	− 2.04 (− 3.05 to − 1.02)	.01
Football	21 907	15.2 (13.2-17.1)	64 322	20.8 (15.5-26.2)	3.29 (1.70-4.90)	.01
Basketball	10 475	7.2 (4.9-9.6)	26 530	8.6 (6.7-10.5)	1.15 (− 1.07 to 3.42)	
Playground activities	11 042	7.6 (5.4-9.8)	17 379	5.6 (4.3-7.0)	− 2.26 (− 4.43 to − 0.04)	.05
Baseball	8 236	5.7 (4.1-7.3)	15 554	5.0 (3.5-6.6)	0.04 (− 1.70 to 1.81)	
ATV	6 930 ^b	4.8 (...)	10 957	3.6 (2.0-5.1)	...	...
Snow sports ^c	10 647 ^b	7.4 (...)	10 184	3.3 (1.4-5.2)	...	...
Skating ^d	6 720	4.6 (3.2-6.1)	11 546	3.7 (2.3-5.2)	− 2.34 (− 4.47 to − 0.17)	.05
Soccer	4 787	3.3 (1.8-4.8)	17 259	5.6 (3.7-7.5)	4.04 (1.35- 6.79)	.01
Moped ^e	3 794	2.6 (1.7-3.5)	7 965	2.6 (1.9-3.2)	− 0.18 (− 3.82 to 3.60)	
All other SRAs	30 477	21.1 (15.5-26.6)	74 793	24.2 (17.9-30.6)	1.26 (.023-2.28)	.05
Total	144 546	100.0 (73.3-126.7)	308 566	100.0 (76.5-123.5)	...	...
Female						
Bicycling	9 139	14.4 (6.8-22.1)	16 395	11.5 (7.6-15.5)	− 2.18 (− 7.79 to 3.78)	
Playground activities	6 663	10.5 (6.2-14.8)	15 041	10.6 (8.1-13.0)	− 0.83 (− 2.82 to 1.21)	
Horseback riding	7 016	11.1 (4.8-17.4)	6 340	4.5 (2.5-6.4)	− 4.95 (− 8.69 to − 1.05)	.05
Soccer	3 419	5.4 (3.9-6.9)	14 881	10.5 (6.0-14.9)	4.80 (3.23-6.40)	.01
Basketball	4 580	7.2 (5.4-9.0)	12 506	8.8 (5.9-11.7)	2.93 (0.78-5.13)	.05
Snow sports ^c	6 862 ^b	10.8 (...)	7 009	4.9 (3.2-6.7)	...	...
ATV	1 589 ^b	2.5 (...)	5 718	4.0 (1.8-6.2)	...	...
Softball	1 618	2.6 (1.3-3.8)	7 705	5.4 (3.7-7.1)	5.35 (0.41-10.54)	.05
Gymnastics	2 700	4.3 (2.8-5.8)	10 636	7.5 (4.8-10.2)	4.37 (0.88-7.99)	.05
Water sports ^f	2 580	4.1 (2.0-6.2)	6 355	4.5 (3.2-5.8)	0.17 (− 4.27 to 4.81)	
All other SRAs	17 090 ^b	27.0 (...)	39 572	27.8 (21.6-34.1)	...	...
Total	63 257	100.0 (80.5-119.5)	142 157	100.0 (77.2-122.8)	...	...

Abbreviations: AAPC, average annual percent change; ATV, all-terrain vehicle; CI, confidence interval; NEISS-AIP, National Electronic Injury Surveillance System-All Injury Program; SRA, sports and recreational activity.

^a95% CI (not presented for unstable estimates).

^bThe number was derived from an unstable estimate. Estimates are considered unstable when the number of unweighted NEISS cases is less than 20 or the national (weighted) estimate is less than 1200 or the coefficient of variation is more than 30%. No 95% CIs and no full range 2001-2012 AAPC were calculated for unstable estimates.

^cIncludes snow skiing, ice skating, toboggan/sled/discovery, and snowmobile.

^dIncludes in-line, roller, and board skating.

^eIncludes minicars/off-road vehicles/go-carts.

^fIncludes swimming, water skiing/surfing/personal watercraft, and fishing.

during 2001-2012, 89.0% were treated and released, with the remainder being hospitalized or transferred to other facilities. Hospitalization or transfers to other facilities in males were frequently associated with bicycling and ATV use, although the estimate of the latter activity was unstable.

Of the 1 048 864 females with an SRR-TBI treated in EDs during the study period, the majority (90.9%) were treated and released; all estimates of SRR-TBIs resulting in hospitalization or transfers to another facility were unstable.

DISCUSSION

This study indicates that SRR-TBIs accounted for 7.0% of all SRR injuries during 2001-2012. This latter statistic, however, represents approximately 3.4 million SRR-TBIs. Results also reveal that SRR-TBIs treated in US EDs have increased from 2001 to 2012 among males and females of all ages, particularly those aged 10 to 19 years. Overall, annual rates of SRR-TBI visits to EDs per 100 000 population significantly increased from 73.1 in 2001 to 152.0 in 2012; increases in rates were significant for all age groups and for both sexes. The leading

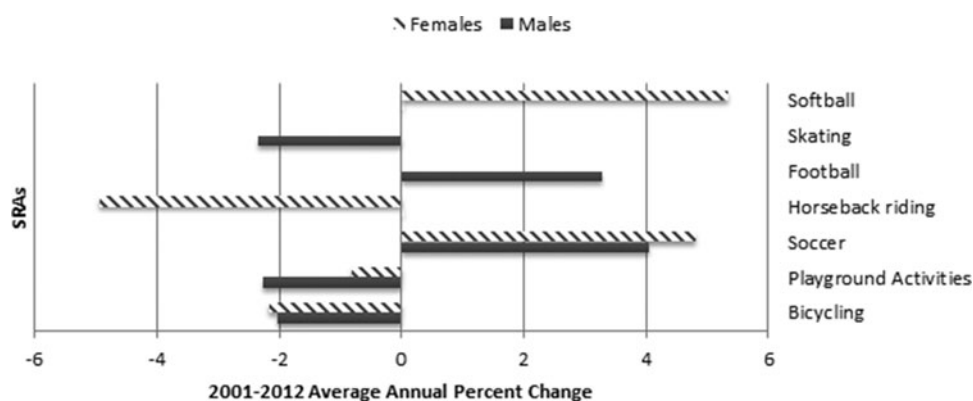


Figure 2. SRAs with the largest average annual percentage change in TBI-related emergency department visits, by sex, National Electronic Injury Surveillance System-All Injury Program, 2001-2012, United States. SRA indicates sports and recreational activity.

activities related to TBI treated in EDs varied by sex and age group and were likely related to activity popularity, ability, and choice. In general, among males, bicycling, football, and basketball were the leading activities associated with SRR-TBI ED visits; and among females, these activities were bicycling, playground activities, and horseback riding.

The significant increases observed during 2001-2012 are difficult to interpret because of limited information regarding changes over time in the numbers and demographics of persons participating in each SRA. Multiple factors might have contributed to these changes, including increased incidence, participation, or awareness of potential TBI that may have prompted injured persons to seek medical care. Previous research found ED visits for all SRR injuries among persons 19 years or younger did not increase during 2001-2009 whereas ED visits for SRR-TBIs increased.⁴ In addition, the percentage of persons with SRR-TBIs seen in EDs requiring hospitalization/transfer for further care decreased.⁴ These data suggest that the observed increase in ED-treated SRR-TBIs may not be a consequence of an actual increase in incidence in TBIs in sports and recreation. Only a portion of injuries from sports and recreation are treated in the ED.¹³ If activities actually were more dangerous, one would expect to see increases in all types of sports injuries, not just TBIs, and the hospitalization of a similar proportion of ED-treated TBI.⁴ While hospitalization rates in general have decreased, this does not explain the lack of increase in other SRR injuries treated in the ED. Finally, there also does not appear to have been a large shift in SRR participation in general as the proportion of persons 15 years or younger in the United States who were engaged in sports, exercise, and recreation activities increased from 18.5% in 2003 to 19.5% in 2010.¹⁴⁻¹⁶

These findings suggest that the significant increases in ED visits for SRR-TBIs across most age groups and in both sexes might reflect the increased knowledge of

the importance of early diagnosis and management of mild TBI among healthcare providers, sports coaches, parents, and the public. This might have prompted people, who in the past may have deemed these injuries as minimal, to seek medical care by visiting an ED.^{17,18} Several efforts might account for the potential increase in TBI awareness and knowledge. For example, in 2004, the CDC, in conjunction with many partners, launched the "Heads Up" program to improve prevention, recognition, and response to concussion in sports among clinicians.¹⁹ In 2005, the Heads Up program began engaging coaches, parents, and athletes in a similar vein (<http://www.cdc.gov/headsup/youthsports/index.html>). There also has been increased media attention related to cases of TBI observed in US troops and professional athletes in the last decade.¹⁷ Finally, the passage of youth sports concussion laws in all 50 states since 2009 may also partially explain the increase in ED visits in the present study (<http://www.ncsl.org/research/health/traumatic-brain-injury-legislation.aspx>). Joinpoint regression analyses conducted in the current study found significant increases in SRR-TBIs that began in 2004 for females and in 2006 for males. The reasons for these sex and time differences are unclear and merit further investigation.

Although the US population-based rates we report suggest that males have higher rates of SRR-TBIs than females, studies using participation- or exposure-based rates often find the reverse, with higher rates of SRR-TBIs among females within comparable activities.²⁰⁻²³ This discrepancy may have occurred because our study did not take into account participation by or exposure to SRAs; therefore, comparisons across activities between this and the other studies cannot be made. Furthermore, the SRAs in this study may not have been the same as those reported in studies that used participation or exposure information.

The large number of SRR-TBI ED visits among persons aged 0 to 19 years align with previous research^{3,4}

TABLE 4 SRAs with the highest proportion of traumatic brain injury–related emergency department visits, by sex and age group, NEISS-AIP, 2001–2012, United States

Rank order by sex	0–4 y		5–9 y		10–14 y		15–19 y		20–24 y		25–34 y		35–44 y		45+ y	
	SRA	%	SRA	%	SRA	%	SRA	%	SRA	%	SRA	%	SRA	%	SRA	%
Male	N = 128377		N = 343890		N = 638525		N = 632909		N = 171213		N = 162185		N = 111724		N = 179208	
1	Playground activities	35.6	Bicycling	21.0	Football	24.9	Football	30.6	Bicycling	18.8 ^a	Bicycling	22.0 ^a	Bicycling	35.7	Bicycling	49.5
2	Bicycling	17.5	Playground activities	19.0	Bicycling	16.1	Bicycling	9.6	Basketball	10.7	ATV	13.9	ATV	12.0	ATV	7.0 ^a
3	Baseball	6.5	Baseball	8.6	Basketball	10.0	Basketball	9.6	ATV	10.7	Snow sports ^b	6.7 ^a	Moped ^c	6.0	Horse riding	5.5 ^a
4	Scooter	5.3	Football	8.2	Baseball	7.0	Soccer	6.6	Football	8.8	Soccer	5.9	Horse riding	5.9 ^a	Snow sports ^b	5.4 ^a
5	Water sports ^d	4.3	Basketball	5.0	Skating ^e	5.8	Snow sports ^b	4.8 ^a	Moped ^c	6.6	Football	5.8	Snow sports ^b	5.8 ^a	Exercise ^f	5.0
	All other	30.8	All other	38.2	All other	36.2	All other	38.8	All other	11.2	All other	45.7	All other	34.6	All other	27.6
Female	N = 72882		N = 156235		N = 247443		N = 252600		N = 69632		N = 73848		N = 65759		N = 110304	
1	Playground activities	46.0	Playground activities	31.0	Soccer	12.8	Soccer	16.1	Bicycling	17.5 ^a	Bicycling	20.4 ^a	Horse riding	22.2	Bicycling	22.6
2	Bicycling	13.5	Bicycling	19.1	Basketball	12.2	Basketball	14.8	Horse riding	11.1	Horse riding	11.3	Bicycling	19.1	Horse riding	19.5
3	Trampoline	5.9	Water sports ^d	5.2	Bicycling	10.0	Gymnastics	9.5	ATV	10.0 ^a	Snow sports ^b	9.4	Snow sports ^b	10.3	Exercise ^f	11.8
4	Baseball	5.6	Snow sports ^b	5.0	Gymnastics	7.2	Snow sports ^b	7.2	Snow sports ^b	8.8	ATV	9.2	Water sports ^d	6.2	Snow sports ^b	6.7
5	Water sports ^d	4.8	Scooter	4.6	Softball	6.9	Softball	7.2	Water sports ^d	5.6	Softball	7.7	ATV	5.8 ^a	ATV	5.3 ^a
	All other SRAs	24.2	All other SRAs	35.1	All other SRAs	35.1	All other SRAs	45.2	All other SRAs	47.0	All other SRAs	42.0	All other SRAs	36.4	All other SRAs	34.1

Abbreviations: ATV, all-terrain vehicle; CI, confidence interval; NEISS-AIP, National Electronic Injury Surveillance System–All Injury Program; SRA, sports and recreational activity.

^aThe percentage was derived from an unstable estimate. Estimates are considered unstable when the number of unweighted NEISS cases is less than 20 or the national (weighted) estimate is less than 1200 or the coefficient of variation is more than 30%.^bIncludes snow skiing, ice skating, toboggan/sled/discovery, and snowmobile.^cIncludes minicars/off road vehicles/go-carts.^dIncludes swimming, water skiing/surfing/personal watercraft, and fishing.^eIncludes in line, roller, and board skating.^fIncludes weight lifting.

TABLE 5 Aggregated yearly numbers and percentages of 5 leading SRAs associated with the highest number and percentage of traumatic brain injury–related emergency department visits by discharge disposition and sex, NEISS-AIP, 2001–2012, United States

Rank order by sex	Treated and released		Hospitalized/transferred		Total ^a	
	SRAs	%	SRAs	%	SRAs	%
Male	N = 2 107 008		N = 216 368		N = 2 368 405	
1	Football	18.5	Bicycling	33.3	Bicycling	19.2
2	Bicycling	17.7	ATV	16.2 ^b	Football	17.3
3	Basketball	8.1	Moped ^c	7.7	Basketball	7.6
4	Playground activities	6.2	Football	6.1	Playground activities	5.8
5	Baseball	5.9	Snow sports ^b	6.0 ^b	Baseball	5.5
	All other SRAs	43.6	All other SRAs	30.7	All other SRAs	44.6
Female	N = 953 206		N = 77 385		N = 1 048 864	
1	Bicycling	12.7	Horseback riding	23.2 ^b	Bicycling	13.3
2	Playground activities	10.5	Bicycling	19.8 ^b	Playground activities	10.1
3	Soccer	8.6	ATV	16.5 ^b	Horseback riding	8.3
4	Basketball	8.3	Snow sports ^d	5.4 ^b	Soccer	8.1
5	Horseback riding	7.1	Exercise ^e	4.4 ^b	Basketball	7.8
	All other SRAs	52.8	All other SRAs	30.7	All other SRAs	52.4

Abbreviations: ATV, ATV, all-terrain vehicle; NEISS-AIP, National Electronic Injury Surveillance System-All Injury Program; SRA, sports and recreational activity.

^aIncludes unknown and other discharge dispositions.

^bUnstable estimate. Estimates are considered unstable when the number of unweighted NEISS cases is less than 20 or the national (weighted) estimate is less than 1200 or the coefficient of variation is more than 30%.

^cIncludes minicars/off-road vehicles/go-carts.

^dIncludes snow skiing, ice skating, toboggan/sled/discovery, and snowmobile.

^eIncludes weight lifting.

and may be the result of many factors. In children, participation in higher-risk activities, such as organized team sports, and increases in participants' weight and speed are positively associated with age, and this may lead to greater force of impact.²⁴ In addition, one study found that participation in team sports has a higher risk of injury than that in individual sports.²⁵ Our study found that during 2001–2012, TBIs that occurred while engaged in football was a frequent activity resulting in ED visits among males aged 10 to 19 years. Opportunities for organized team sports participation expand with age. Findings from a national survey of high school students aged 15 to 19 years found that 58.4% of students have played on at least 1 sports team, with a higher prevalence for males (64.0%).²⁶ Although scant literature exists about the practices of coaches and athletic trainers, 2 studies of coaches who were exposed to the CDC "Heads Up: Concussion in High School Sports" toolkit^{27,28} found that respondents self-reported favorable changes in knowledge, attitudes, and practices toward the prevention and management of concussions.²⁷ This, in turn, led to better prevention practices, better recognition of the injury, and better response to the injury by coaches.²⁸ Other factors that are not measured in NEISS, for example, alcohol use, may also contribute to

SRR injuries among certain age groups. A study found that almost 24% of the pedal cyclists killed in 2010 traffic crashes in the United States had a high blood alcohol concentration.²⁹ Characterizing these factors merits further research so that they can be potentially be targeted for prevention.

Despite reports finding decreases in the average number of hours spent participating in sports, exercise, and recreation per day among persons 45 years or older,^{14,16} our study found that the rates and numbers of SRR-TBI ED visits in this age group almost doubled during 2001–2012. Some of these increases also may be related to the increased knowledge and awareness of TBI described earlier. Healthcare providers who serve these populations, especially older adults (ie, 65 years or older), should be vigilant about the increasing number of comorbidities (eg, diabetes); the number and type of medications taken; and the age-related decreases in vision, hearing, coordination, strength, and cognitive function.^{30–37} All these factors may contribute to an increased risk for injuries, including TBIs, and they may even affect recovery. It is also important for healthcare providers, regardless of patient age, to inquire about a history of TBI, as those who sustain a TBI may be at risk of sustaining subsequent TBIs.^{38–40}

Our study suggests that bicycling is significantly associated with SRR-TBI ED visits in males and females and is a leading cause of hospitalization/transfer to other hospitals. NEISS, however, contains limited information regarding whether a bicycle-related injury occurred during sports or leisure riding, as opposed to bicycling for mobility purposes. Therefore, the estimates we reported likely include bicycle injuries that did not occur during a purely recreational endeavor. Regardless, our study found that bicycling was a leading activity resulting in a TBI-related ED visit. Hence, bicycle safety should be a main target for prevention, as many of bicycling injuries result from collisions or near-collisions with motor vehicles, especially those that result in death.²⁹

Various prevention efforts, such as helmet use, may help reduce the number and severity of TBI in bicyclists. Use of helmets should be encouraged, as our results indicate that riding on bicycles, horses, and ATVs resulted in a high number of SRR-TBI-related hospitalizations or transfers to other hospitals in both males and females. The higher proportion of hospitalizations we found in bicycling- and ATV-related TBIs (although this latter estimate was unstable in this study) suggest that certain biomechanical forces may be involved^{41,42}; for example, the higher velocity of impact, impact force, force impulse to injury, and the angle of impact observed in bicycle-related injury events may result in more severe injuries requiring higher levels of care, including hospitalization.⁴³ Previous research also found that at least 90% of bicycle riders⁴⁴ and 70% of ATV riders⁴⁵ who crashed and died were not wearing helmet. This suggests that despite some progress, prevention efforts can benefit by increasing helmet use for all riders. Nonetheless, TBIs can still occur, even when helmets are worn as has been reported in football.^{46,47} To be effective, appropriate helmet use requires a helmet that is appropriate for the position and activity, properly fitted, well-maintained, and used consistently and correctly.⁴⁸ Regarding ATVs, research indicates that the number of ATV-related deaths have declined since 2005.⁴⁵ Although this decline coincided with the increase in the number of states with legislation regulating ATV rider behavior (eg, helmet laws, age, and use restrictions),⁴⁹ studies of the efficacy of such legislation have produced inconclusive results.^{50–54}

Providing safer environments as recommended by the Consumer Product Safety Commission's *Public Playground Safety Handbook* (eg, using age-appropriate equipment, using shock-absorbing surfaces, adult supervision)⁵⁵ can also reduce the risk and severity of TBI such as in playground activities,⁵⁶ which are associated with high occurrence of TBI in young children of both sexes. Despite that these recommendations have been periodically updated and disseminated

since 1981,⁵⁵ NEISS-AIP data indicate that the rate of playground-related TBI per 100 000 population significantly increased from 22.7 in 2005 to 45.8 in 2011 (CDC unpublished data).

Other SRR-preventive measures include implementing and enforcing the return-to-play decision strategies and other rules/policy change¹⁹; teaching sports-specific skills and proper techniques (eg, blocking/tackling in football); encouraging good sportsmanship; and actively educating referees, coaches, trainers, parents, athletes, and the public about the consequences of TBI.^{18,19} Overall, a combination of protective measures, such as safe environments, appropriate use of helmets, and non-equipment-based protective methods (eg, good conditioning), may have the potential to reduce injury incidence and severity in SRR-TBIs.⁵⁷

Our study found that almost 90% of persons with SRR-TBI ED visits were treated and released, suggesting that these cases may have been of mild TBI. However, despite some controversy,^{58–61} the term "mild TBI" is in some cases a misnomer because up to 15% to 25% of people with this condition^{5–7} may have persistent signs and symptoms 1 year after the injury.^{54–66} Of the remainder, approximately 6% were transferred or hospitalized; an undetermined number of these may have had more severe TBI. Persons with more severe TBI may even have lifelong impairment or disability.⁶⁷

Limitations

Limitations of the NEISS-AIP have been detailed elsewhere.³ In summary, the lack of denominator data to calculate activity-specific rates in NEISS (eg, the number of people riding bicycles in the United States) limited our ability to identify activities and groups at higher risk within specific activities. Second, NEISS-AIP underestimates the number of ED-treated TBIs in SRAs. Because only the principal diagnosis and data about the primary body part injured are collected in NEISS-AIP, many TBIs that were secondary diagnoses, such as those reported in conjunction with other more severe nonbrain injuries or were listed in the narrative section of the questionnaire, may have been missed.^{3,10} In addition, certain TBI-related diagnoses, for example, skull fractures, which commonly involve TBI, are listed as fractures of the head, and not as TBIs, resulting in an underestimation of the number of ED visits due to an SRR-TBI. Also missed were cases treated in non-ED healthcare settings or those who did not seek medical care. Third, for certain surveillance years and population subgroups, small sample sizes precluded the production of stable estimates for those groups. Caution should be used when interpreting unstable estimates. Fourth, NEISS-AIP does not include information on risk or protective factors (eg, use of helmets while riding on ATVs) limiting our

understanding of the changes observed during 2001–2012. Additional information that may be missing includes the consumer products involved (eg, baseball equipment), a description of events leading to the injury, injury locale, and even details of the injury diagnosis. Much of this information can only be obtained from the NEISS records' narratives; however, it is not systematically available since patients may not share these details with providers, providers may not choose to document it in the medical record, or coders may not choose to enter the information. Finally, increases in the overall SRR-TBI rate over the study period may have resulted from increases in the knowledge of the risk of sports- and recreation-related concussion and TBI, from shifts in location of medical care, or other issues.

CONCLUSIONS

On the basis of this first nationally representative study of trends in SRR-TBIs among persons of all ages in the United States, we found that the number of SRR-TBI ED visits has increased from 2001 to 2012. Overall, 3.42 million ED visits for SRR-TBI diagnoses were identified during the study period; this figure, however,

is likely an underestimate of the true burden of SRR-TBIs because it captures only ED visits. SRR-TBIs affected mostly males, especially those aged 0 to 19 years. Our study also found that the leading activities associated with TBI-related ED visits varied by age and sex.

This information can be used to tailor prevention strategies intended to reduce the burden of SRR-TBIs in the United States by age group, sex, and SRA. Additional research that includes population-based information on participation (eg, number of participants and duration of participation) by the specific SRA is needed to better characterize risk and protective factors to prevent these injuries and determine the most effective prevention and management strategies. Special attention for prevention should be given, for example, to activities with a large number of affected participants (eg, bicycling, playground activities, and some team sports) and those with more severe injuries (eg, bicycling and riding on ATVs). Because our findings indicate that the leading types of SRAs associated with TBI-related ED visits varied by age and sex, prevention strategies should be focused on those most at risk among the activities that are more likely to result in TBI.

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