American Journal of
Preventive Medicine

RESEARCH ARTICLE

Trends in Traumatic Brain Injury Related to Consumer Products Among U.S. School-aged Children Between 2000 and 2019

Tuan D. Le, MD, DrPH,[1,2] Alan D. Cook, MD,[1,3,4] Tony T. Le[1,5], John W. Keyloun, MD,[6] Paul W. Detwiler, MD, MS,[3,4] Gerald R. Ledlow, PhD,[7] Anthony E. Pusateri, PhD,[8] Karan P. Singh, PhD[1]

Introduction: Consumer product–related traumatic brain injury in children is common, but long-term trends have not been well characterized. Understanding the long-term trends in consumer product–related traumatic brain injury may inform prevention efforts. The study objective is to examine the trends in consumer product–related traumatic brain injury in school-aged children.

Methods: Data were extracted from the National Electronic Injury Surveillance System—All Injury Program for initial emergency department visits for consumer product–related traumatic brain injury (2000-2019) in school-aged children and analyzed in 2021.

Results: Approximately 6.2 million children presented to emergency department with consumer product–related traumatic brain injury during 2000—2019. Consumer product–related traumatic brain injury increased from 4.5% of overall consumer product–emergency department visits in 2000 to 12.3% in 2019, and its incidence rate (cases per 100,000 population) was higher in males (681.2; 95% CI=611.2, 751.2) than in females (375.8; 95% CI=324.1, 427.6). The annual percentage change in consumer product–related traumatic brain injury was 3.6% from 2000 to 2008, 13.3% from 2008 to 2012, and −2.0% through 2019. Average annual percentage change was higher in females (5.1%; 95% CI=3.4, 6.8) than in males (2.8%; 95% CI=1.6, 3.9). Consumer product–related traumatic brain injury increased from 2000 to 2012 in females and then remained stable. In males, annual percentage change increased from 2008 to 2012 and then declined through 2019.

Conclusions: Traumatic brain injury incidence rate in school-aged children increased from 2000 to 2019, peaked in 2012, and then declined in males but not in females. Percentage increases were highest in females. Prevention strategies should continue, with a specific focus on reducing consumer product–related traumatic brain injury in female children.

Am J Prev Med 2022;000(000):1—9. Published by Elsevier Inc. on behalf of American Journal of Preventive Medicine.

From the [1]Department of Epidemiology and Biostatistics, School of Community and Rural Health, The University of Texas at Tyler Health Science Center, Tyler, Texas; [2]Research Directorate, U.S. Army Institute of Surgical Research, JBSA-Fort Sam Houston, Sam Houston, Texas; [3]Department of Surgery, The University of Texas at Tyler Health Science Center and UT Health East Texas, Tyler, Texas; [4]The Center for Trauma Research, The University of Texas at Tyler Health Science Center and UT Health East Texas, Tyler, Texas; [5]School of Arts and Sciences, University of Pennsylvania, Philadelphia, Pennsylvania; [6]Department of Surgery, Georgetown University Medical School, Washington, District of Columbia; [7]Department of Healthcare Policy, Economics and Management, School of Community and Rural Health, The University of Texas at Tyler Health Science Center, Tyler, Texas; and [8]Naval Medical Research Unit — San Antonio, JBSA-Fort Sam Houston, Sam Houston, Texas

Address correspondence to: Tuan D. Le, MD, DrPH, Department of Epidemiology and Biostatistics, School of Community and Rural Health, The University of Texas at Tyler Health Science Center, 11937, Highway 271, Tyler TX 75708. E-mail: tuan.le@uthct.edu.

0749-3797/$36.00
https://doi.org/10.1016/j.amepre.2022.04.011

INTRODUCTION

Traumatic brain injury (TBI) is a major public health concern[1,2] negatively affecting not only the lives of individuals and their families but also society, healthcare systems, and the economy.[3] Children have the highest rate of emergency department (ED) visits for TBI.[4] In 2014, the Centers for Disease Control and Prevention estimated that 13.5 million individuals were living with a TBI-related disability, that there were approximately 2.89 million ED visits and deaths related to TBI, and over 837,000 TBI cases in children in the U.S.[1] TBI is the leading cause of death and disability in children aged 0−4 years and 15−19 years.[5] Nonfatal TBI in children can lead to emotional, physiologic, and cognitive sequelae.[6] In 2005, an estimated 145,000 children aged 0−19 years were living with lasting cognitive, physical, or behavioral deficits because of TBI.[7] TBI resulting from sports and recreation activities are common in the U.S.,[8,9] accounting for approximately 3.4 million ED visits from 2001 to 2012.[10] A total of 65% of all sports and recreation activity–related (SRR) TBIs (SRR-TBI) presenting to the ED in 2001−2009 were among children aged ≤19 years and resulted from bicycling, football, and other playground activities.[8,9] Cheng et al.[11] (2016) reported that approximately one third of all nonfatal TBI among children aged 0−14 years in 2001−2013 occurred at places of recreation or sports and school, and TBI-related ED visits increased from 2005 to 2013. Recently, Waltzman and colleagues[12] (2020) reported that among children aged 5−18 years, TBI-ED visits increased in the U.S. from 2001 to 2012, before declining from 2012 to 2018. These findings suggest that efforts to reduce TBI have been successful. However, further examination of subgroups may reveal areas where additional focused efforts may be needed.

This study aimed to describe characteristics and trends in consumer product (CP)-related TBI (CP-TBI) incidence among school-aged children over the past 20 years (2000−2019) in a novel way. Considering the previous reports for more limited time periods, the hypothesis was that ED visits for pediatric CP-TBI would increase initially and then decline before stabilizing for all age groups in males and females.

METHODS

Study Population

This was a serial cross-sectional study using data from the 2000−2019 National Electronic Injury Surveillance System (NEISS)−All Injury Program (NEISS-AIP), a surveillance system that monitors CP-related injuries presenting to participating hospital EDs. Detailed NEISS-AIP methods have been published elsewhere.[13] The database includes all ED visits for CP-related injuries (CP-ED visits) presenting to NEISS participating hospitals in the U.S. from January 1, 2000 to December 31, 2019. Data were abstracted with a weighted national estimation from 5 strata and 100 clusters from 66 of 100 NEISS hospital EDs selected from all (>5,300) U.S. hospitals. The study population included children aged 5–18 years who presented to an ED for CP-injury care and met inclusion and exclusion criteria (Appendix Table 1, available online). This study was conducted under a protocol reviewed and exempted by the IRB of The University of Texas Health Science Center at Tyler, Texas.

Measures

TBI cases were identified on the basis of the NEISS criteria if a patient had a head injury (body part injured code: 75) related to CPs and diagnosis codes of 52 for concussion, 57 for skull fracture, 58 for hematoma, and 62 for internal head injury that includes subdural hematoma, cerebral contusion, and head injury not otherwise specified (Appendix Table 1, available online). The NEISS criteria are reliable as compared with the International Classification of Diseases, Ninth Revision/ICD-10-CM code.[14,15]

School-aged children aged 5–18 years were stratified by age groups as 5−10, 11−13, and 14−18 years for elementary, middle-, and high-school students, respectively.[16] Injury locales were a priori categorized as at home, in school, in sporting and recreational areas, on streets and highways, and other.[14] Mortality included dead on arrival, death in the ED, and death after admission.

Numbers of reported CP-TBI cases were first calculated as the percentage among CP-ED visits, and then *estimated (weighted) national CP-TBI cases with incidence rates* were defined as CP-TBI cases per 100,000 population (TBI-IR), overall and then by sex and age groups. The TBI-IR was used as a primary outcome measure for trends, related causes, and locales by sex and age groups.

Statistical Analysis

To illustrate national trends in CP-TBI over time, incidence rates of CP-TBI were used. The data were weighted to represent the U.S. population. National injury estimates were calculated using established statistical weights.[13] TBI-IR was standardized using the U.S. Census population as the denominator to estimate CP-TBI incidence rates per 100,000 population for each corresponding year by age groups and sex. Temporal trends in TBI-IR were evaluated using Joinpoint regression analysis.[17] Joinpoints identified years at which trends in magnitude and direction of CP-TBI changed significantly and are illustrated by annual percentage changes (APC) and then estimated average APCs (AAPC) overall, by age groups, by sex, and by locales. Logarithmic transformation of the TBI-IR was applied, and the heteroscedastic errors option was assumed as SEs. Estimates of APC and AAPC (with 95% CI) were calculated and investigated to determine whether the APC for each segment and the AAPC within groups and overall were statistically significant. Linear regression was used to determine changes in the incidence rates and the odds of CP-TBI over time. Rao-Scott chi-square analysis was also performed to test the differences between years for secular trends and to calculate the relative risk with 95% CI.

Data reported were national estimates with weighted cases unless specified as unweighted. Descriptive statistics characterized

Table 1. Estimated Numbers and Incidence Rates of Consumer Products–Related ED Visits in School-Aged Children by Age and Sex

Variables	Estimated N (95% CI), millions[a]	%	Incidence rate (95% CI)[b]
All age			
CP-ED visits	273.4 (238.7, 307.9)	100	4,455.5 (4,397.2, 4,513.9)
TBI care	22.8 (18.1, 27.5)	8.3	365.3 (315.3, 415.3)
Age 5−18 years ED visits (all)			
CP-ED visits	76.6 (66.0, 87.2)	28.0	—
Annual average	3.8 (3.2, 4.5)	—	6,609.9 (6,410.5, 6,809.3)
Sex			
Male	48.0 (41.4, 54.6)	62.6	8,089.3 (7,783.7, 8,394.8)
Female	28.6 (24.5, 32.7)	37.3	5,056.6 (4,956.2, 5,156.9)
Unknown	0.009 (0.006, 0.013)	0.1	—
Age 5−18 years ED visits (TBI)			
CP-ED visits	6.2 (4.9, 7.4)	8.1	—
Annual average, thousands	308.5 (237.2, 379.8)	—	532.1 (471.5, 592.7)
Age group, years (TBI)			
5−10	2.4 (1.5, 2.9)	33.8	492.8 (444.8, 540.9)
11−13	1.4 (1.1, 1.6)	22.1	544.7 (476.6, 612.8)
14−18	2.4 (1.9, 2.9)	39.1	569.8 (497.8, 641.8)
Age group by sex (TBI)[c]			
Male	4.0 (3.2, 4.8)	65.5	681.2 (611.3, 751.2)
5−10 years	1.6 (1.2, 1.9)	39.2	637.9 (577.2, 698.6)
11−13 years	0.9 (0.8, 1.1)	23.2	734.0 (648.7, 819.4)
14−18 years	1.5 (1.2, 1.8)	37.6	699.5 (624.2, 774.7)
Female	2.1 (1.7, 2.6)	34.5	375.8 (324.1, 427.6)
5−10 years	0.8 (0.6, 1.0)	38.1	341.1 (305.8, 376.5)
11−13 years	0.4 (0.3, 0.5)	19.9	346.8 (295.1, 398.5)
14−18 years	0.9 (0.7, 1.1)	42.0	433.3 (361.7, 505.0)
Overall mortality, counts	2,264 (1,296, 3.233)	0.04	36.4 (26.4, 43.5)

Note: Percentages and 95% CIs are estimated using weighted method.
[a]Estimated numbers are presented in millions unless otherwise indicated.
[b]Incidence rate is calculated as the number of ED visits per 100,000 population.
[c]Unknown sex is very small: n=13 (unweighted 0.06%) and estimated 257 (weighted 0.04%).
CP, consumer product; ED, emergency department; TBI, traumatic brain injury.

patient demographics. Categorical variables were presented as frequencies and percentages. Continuous variables were expressed as means and SDs or medians and IQRs, where appropriate. Statistical significance was determined at the 2-sided $p<0.05$ level. Data analyses were performed in 2021 using SAS, version 9.4 (SAS Institute, Inc.).

RESULTS

From 2000 to 2019, the weighted estimate for all initial ED visits was 76.6 (95% CI=66.0, 87.2) million, with an estimated average of 3.8 (95% CI=3.2, 4.5) million ED visits yearly. Of these, ED visits for CP-TBI care were estimated at 6.2 (95% CI=4.9, 7.4) million, accounting for 8.1% (95% CI=7.4, 8.5) of CP-ED visits. Males accounted for 65.5% of all school-aged TBI cases (n=4,040,593) and a higher proportion of CP-TBI to CP-ED visits than females, 8.4% (4,040,593/47,978,963) vs 7.4% (2,129.059/28,609,156), ($p<0.001$) (Table 1 and Appendix Tables 2−3, available online).

The annual average was 308,496 CP-TBI cases (95% CI=237,241, 379,750) with the lowest frequency in 2000 (n=188,710) and highest frequency in 2012 (n=420,066). Percentage of CP-TBI−related visits increased from 4.5% in 2000 to 6.8% in 2008, then increased sharply to 12.3% (2019) (Figure 1A; Appendix Figures 1−3, available online; and Appendix Tables 2−3, available online).

The overall incidence rate of CP-TBI shows a similar trend (Figure 1B), with a TBI-IR of 532.1 (95% CI=471.5, 592.7) cases per 100,000 person-year. Two joinpoints of CP-TBI incidence were identified: at the years 2007 and 2012 (Appendix Figure 2A, available online); therefore, the trend in TBI-IR was segmented into 3 periods (2000−2007; 2007−2012, and 2012 −2019) (Table 2). Overall TBI-IR increased over time with an AAPC of 3.6% (95% CI=2.3, 4.9). Detailed

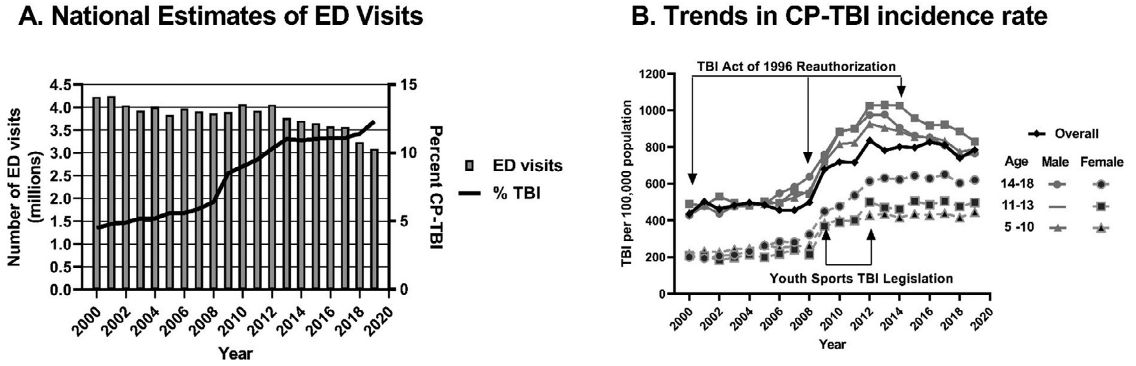

Figure 1. National estimated numbers and trends in CP-related TBI among school-aged children by age and sex, 2000−2019.
Note: Figure 1 shows annually nationally estimated (weighted) numbers of school-aged children who arrived at ED for CP-related injuries (CP-injury; Panel A, black bars; left Y-axis) and trends in the percentage of ED visits for CP-related TBI (CP-TBI; Panel A, black solid line; right Y-axis). Panel B illustrates the trends in incidence rates of CP-TBI over time from 2000 to 2019 by age group and sex defined as shown. The arrows indicate the timelines of policy implementation.
CP, consumer product; ED, emergency department; TBI, traumatic brain injury.

examination of segments illustrated a slight increase in segment 1 with an APC of 2.7% (95% CI=0.8, 4.5), a large increase in segment 2 with an APC of 13.3% (95% CI=8.6, 18.2), and a gradual decrease in segment 3 with an APC of–2.0% (95% CI= −3.8, −0.2) (Table 2).

Incidence rate of CP-TBI was highest in children aged 14−18 years (569.8; 95% CI=497.8, 641.8), followed by those aged 11−13 years (544.7; 95% CI=476.6, 612.8) and those aged 5−10 years (492.8, 95% CI=444.8, 540.9) (Table 1). TBI-IR was higher in males than in females:

Table 2. APC in TBI Incidence in ED TBI Care Visits of School-Aged Children by Age and Sex Using Joinpoint Regression

Variables	All	Segment 1		Segment 2		Segment 3	
	AAPC (95% CI)	Period	APC (95% CI)	Period	APC (95% CI)	Period	APC (95% CI)
Age 5−18 years, all	**3.6 (2.3, 4.9)**	2000−2007	**2.7 (0.8, 4.5)**	2007−2012	**13.3 (8.6, 18.2)**	2012−2019	**−2.0 (−3.8, −0.2)**
Male	**2.8 (1.6, 3.9)**	2000−2006	1.0 (−1.1, 3.1)	2006−2012	**11.4 (8.4, 14.6)**	2012−2019	**−2.7 (−4.3, −1.0)**
Female	**5.1 (3.4, 6.8)**	2000−2007	**3.7 (1.7, 5.7)**	2007−2011	**17.3 (9.2, 26.0)**	2011−2019	0.7 (−0.9, 2.3)
Age 5−10 years, all	**3.1 (0.9, 5.3)**	2000−2007	0.5 (−1.4, 2.3)	2007−2010	**17.5 (2.5, 34.7)**	2010−2019	0.7 (−0.6, 1.9)
Male	**2.8 (0.2, 5.5)**	2000−2007	−0.4 (−2.6, 1.9)	2007−2010	18.0 (−0.2, 39.5)	2010−2019	0.6 (−0.9, 2.2)
Female	**3.6 (2.1, 5.2)**	2000−2007	**2.1 (0.8, 3.5)**	2007−2010	**16.7 (5.6, 28.9)**	2010−2019	0.8 (−0.2, 1.7)
Age 11−13 years, all	**3.5 (1.8, 5.1)**	2000−2006	−0.03 (−3.1, 2.8)	2006−2012	**14.3 (9.9, 18.9)**	2012−2019	−2.0 (−4.3, 0.4)
Male	**2.8 (1.3, 4.4)**	2000−2006	−0.5 (−3.2, 2.3)	2006−2012	**13.8 (9.7, 18.1)**	2012−2019	**−3.0 (−5.2, −0.9)**
Female	**4.8 (2.1, 7.7)**	2000−2006	0.3 (−4.5, 5.4)	2006−2012	**15.6 (8.3, 23.4)**	2012−2019	0.2 (−3.7, 4.2)
Age 14−18 years, all	**4.1 (3.0, 5.1)**	2000−2005	**2.8 (0.2, 5.5)**	2005−2012	**12.1 (10.0, 14.3)**	2012−2019	**−2.5 (−4.0, −1.0)**
Male	**2.8 (1.7, 3.9)**	2000−2005	2.1 (−0.6, 4.9)	2005−2012	**10.9 (8.6, 13.2)**	2012−2019	**−4.3 (−5.8, −2.7)**
Female	**6.6 (4.9, 8.3)**	2000−2007	**6.6 (4.3, 8.9)**	2007−2012	**17.0 (11.2, 23.2)**	2012−2019	−0.4 (−2.5, 1.8)

Note: Boldface indicates statistical significance ($p<0.05$).
AAPC, average annual percentage change; APC, annual percentage change; ED, emergency department; TBI, traumatic brain injury.

681.2 (95% CI=611.3, 751.2) and 375.8 (95% CI=324.1, 427.6), respectively (Table 1).

TBI-IR (Figure 1B) increased over time in all age groups and both sexes. TBI-IR was highest in males aged 11−13 years (734.0; 95% CI=648.7, 819.4), followed by males aged 14−18 years (699.5; 95% CI=624.2, 774.7) and males aged 5−10 years (637.9; 95% CI=577.2, 698.6). In females, those aged 14−18 years were highest (433.2; 95% CI=361.7, 505.0), and those aged 5−10 years were lowest (341.1; 95% CI=305.8, 376.5).

AAPC significantly increased during the study period overall and within age and sex groups. AAPCs in TBI-IR in females were higher than in males (5.1%; 95% CI=3.4, 6.8 vs 2.8%; 95% CI=1.6, 3.9), and this pattern was consistent within age groups (Table 2). The Joinpoint regression model revealed 2 Joinpoints in years 2007 and 2012 at which trends in TBI-IR significantly changed overall. Analysis of segments within specific age by sex groupings yielded slightly different Joinpoints (Table 2). In segment 1, TBI-IR in males was unchanged but significantly increased in females with an overall 3.7% APC (Table 2). In segment 2, IR-TBI increased more in females than in males in each age group and overall (overall APC of 17.3% vs 11.4%, respectively) (Table 2). In segment 3, whereas TBI-IR declined for males overall and within age groups of 11−13 and 14−18 years by −2.7%, −3.0%, and −4.3% APC, respectively, female TBI-IR was unchanged (Table 2 and Appendix Figure 4, available online).

The most common locales of CP-TBI were SRR areas (1,663,110 [27.0%]), home (1,379,355 [22.4%]), schools (1,229,919 [19.9%]), streets and highways (277,658 [4.5%]), and other (1,619,867 [26.2%]) (Figure 2A and Appendix Table 5, available online). The predominant locale for males was SRR areas (28.7 ±1.9%), whereas home was most common for females (26.9±1.4%) (Appendix Figure 5, available online).

The most common causes of CP-TBI overall were football (734,967 [11.9%]), bicycling (469,285 [7.6%]), basketball (396,613 [6.4%]), contact with floors or flooring materials (385,792 [6.3%]), and soccer (305,215 [4.9%]) (Figure 2B and Appendix Table 6, available online). The top 5 most common activities/causes of CP-TBI in males were football (17.6%), bicycling (9.0%), basketball (6.6%), contacting floors and flooring materials (5.2%), and baseball (4.4%). In females, the most common were contacting floors and flooring materials (8.3%), soccer (6.9%), basketball (6.2%), bicycling (5.0%), and contacting stairs (4.2%) (Appendix Table 7, available online). The frequency of initial ED visits for concussion and internal head injuries such as subdural hematoma and cerebral contusion increased over the study period. The proportions of TBI diagnoses remained relatively stable (Appendix Figure 6, available online).

DISCUSSION

This study found that ED visits for CP-TBI care increased in all groups from 4.5% in 2000 to 12.3% in 2019, with a sharp increase from 2008 to 2012, a period that coincided with the implementation of a number of

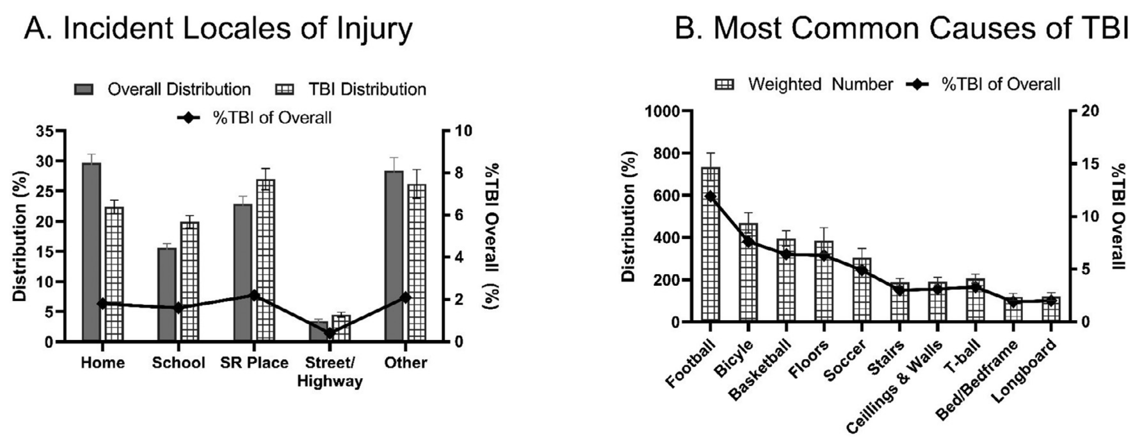

Figure 2. Distribution of ED visits for CP-injury and CP-TBI among school-aged children by locales and causes.

Note: Figure 2 shows the distribution (weighted) of the most common incident locales from all CP-related injuries (CP-injury; black bars) and CP-related TBIs (CP-TBI; crosshatched bars) and the proportion of CP-TBI to overall CP-injury (%) by locales among school-aged children presenting to NEISS EDs (Panel A). Panel B shows the distribution (weighted) of the most common causes of CP-TBI (crosshatched bars) and the percentage of CP-TBI related to the causes. Left Y-axis represents the distribution in thousands of weighted CP-injury and CP-TBI. The right Y-axis shows the proportion (%) of CP-TBI attributed to the common locales or causes.

CP, consumer product; ED, emergency department; NEISS, National electronic injury surveillance system; SR, sports and recreation; TBI, traumatic brain injury.

public policy and awareness programs. TBI-IRs in all school-aged children or specific sex and age groups were significantly segmented into 3 periods determined by 2 Joinpoints at years 2007 and 2012. An unexpected finding was that the patterns of change after 2012 differed between males and females. From 2013 to 2019, males aged 11−13 and 14−18 years exhibited a gradually decreasing incidence rate, whereas the incidence rate in females of the same ages remained unchanged. The overall incidence of SRR-TBI ED visits increased with increasing age, consistent with previous observations.[18] The overall sharp increase in incidence rate between 2007 and 2012 may reflect increased awareness and school-/sport-specific requirements for medical referral, whereas the later decline in males may reflect successes in prevention. The lack of a decline in females may have a number of contributing factors, but data suggest a need for increased emphasis on this subpopulation of school-aged children.

Increasing awareness of TBI is reflected in public health policy. The TBI Act, passed in 1996, authorized funding for programs to mitigate the incidence and impact of TBI in the U.S. This bill was expanded and reauthorized in 2000, 2008, and 2014.[19,20] A review of state-wide legislation revealed that 44 states and Washington, DC passed youth sports TBI laws between 2009 and 2012, where the Lystedt law required that high-school athletes who sustain a concussion be cleared to return to play by a medical professional.[21] During this same period, a number of military policies were implemented, which recognized the importance of awareness, prevention, and treatment of TBI and successfully addressed the issue of under-reporting.[22] Increasing awareness of TBI can also be appreciated at the intersection of scientific research and popular culture. Bennet Omalu has published extensively on repetitive head trauma; his autopsy case report on former Pittsburgh Steeler Mike Webster brought TBI and chronic traumatic encephalopathy into public focus.[23,24] Documentaries, books, and even feature films surrounding this issue have followed.[25-27] TBI exposure in popular culture has likely also increased awareness among parents and coaches and subsequently resulted in increasing incident cases of TBI among school-aged children over this time period.

Waltzman et al.[12] (2020) reported that SSR TBI-ED visits increased from 2001 to 2012 and then declined by 32% between 2012 and 2018. This was the first report indicating that TBI-related awareness, education, and safety policies had yielded a measurable decline in SRR-TBI among children. The general pattern of an increasing followed by a decreasing trend was primarily associated with contact sports and was most pronounced among those aged 10–17 years. Among males, the rate of contact sports–related TBI visits to the ED increased between 2001 and 2012, before declining by 31% by 2018. Among females, the rate increased and then fell by 38% after 2014. These patterns are generally similar to the present findings for CP-TBI. However, using a longer sampling period, the authors found 2 Joinpoints, resulting in 3 segments, with a gradual increase from 2000 to 2007, a sharp increase from 2007 to 2012, and finally a gradual decline from 2012 to 2019. Patterns differed among age groups and sexes. Among boys, rates did not statistically increase between 2000 and 2008, increased between 2008 and 2012, and then declined in middle school– and high school–aged boys (Table 2). However, among girls, the rate increased significantly for both the 2000–2008 and 2008–2012 segments and then remained stable in all age groups. Different patterns of change in sports-related TBI have previously been noted. Between 2012 and 2016, sports and recreation TBI-related ED visits declined among boys but not among girls.[28] This may reflect changes in participation in contact sports. During the past 10 years, boys' participation in football has declined considerably, whereas girls' participation in high school sports such as wrestling has increased.[29,30] In addition, girls participating in sex comparable sports tend to have a higher rate of concussions than boys.[31-33] Most pediatric patients with concussions enter the healthcare system through their primary care provider.[18,34] Therefore, it is possible that the overall reduction in CP-TBI incidence observed after 2012 reflects a shift away from ED entry. However, it seems unlikely that this could account for the differences in trends observed between girls and boys. Although it appears that efforts to decrease TBI in children's sports have been effective, our findings suggest that more focused efforts are needed among females.

The most common incident locales are at SRR places, homes, and schools. Altogether, two thirds of TBI cases occurred in places where children's activities are generally under the supervision of coaches, parents, or teachers; hence, incident TBI cases may be reduced by primary prevention (e.g., injury prevention training for coaches) and awareness campaigns targeted at coaches, parents, teachers, and even children.[12,35] Playing football or baseball and riding bicycles are the most common causes of TBI, suggesting that improved helmets may help to reduce TBI.[36,37] In addition, contacting floors and flooring materials are also involved in incident TBI at home, accounting for one fifth of all TBI cases, likely reflecting unintentional falls, highlighting the need to address the home environment safety for fall prevention. Although overall trends are promising, TBI is relatively common in a broad range of activities and occurs in many places that are presumed to be safe for children. Continued efforts are needed to further mitigate CP-TBI risk, such as removing in-home, school, and playground surface hazards (e.g., uneven surfaces); improving lighting; and installing home safety devices (e.g., stairway handrails), along with the use of appropriate protective devices (e.g., properly fitting, high-quality helmets).

Although it is not possible to determine cause and effect, the present findings are consistent with others suggesting that policies and programs that increase awareness and promote specific training and guidelines for prevention and treatment of TBI can be effective in both increasing the awareness and reducing the incidence.[12,22,28] However, further research is needed, particularly to determine the degree of effectiveness of policies in prevention. Implementation of policies related to the prevention and diagnosis of TBI at the high-school level has been variable among states in the U.S.[38-40] An evaluation of TBI-ED visits and outcomes among states may yield additional information regarding the relationship between policy implementation and outcomes.

Limitations

This study has several limitations. First, injuries and TBI reported in the NEISS-AIP relate only to CPs, so TBI-IRs in this study are not inclusive of all pediatric TBI. Second, TBI-IR in this study may be underestimated because some patients may not enter the healthcare system through the ED or may enter at non-NEISS hospitals or because some parents do not seek care for mild concussions, similar to other mild injuries.[34] Third, children with CP-TBI may not seek care in EDs because most children with SRR-TBI are asymptomatic within 4 weeks after the accident.[41] Fourth, NEISS-AIP lacks the resolution to identify specific diagnoses and severity. Fifth, before 2018, NEISS-AIP allowed 1 diagnosis and body part for injury classification. Therefore, TBI diagnoses may have been missed in the setting of multiple injuries. However, a weighted method to estimate CP-related injuries, CP-TBI cases, and incidence rates with 95% CIs was used that may reduce selection biases.

CONCLUSIONS

An average of 380,000 school-aged children suffered CP-TBI annually, and overall CP-TBI incidences increased significantly. TBI-IRs were higher among males than among females. However, percentage increases in TBI were highest among females. Among males, TBI-IRs were stable from 2000 to 2008, then increased from 2008 to 2012 before declining thereafter. In contrast, the rates of CP-TBI increased from 2008 to 2012 and then remained stable among females. Data suggest that although efforts at reducing CP-TBI have been successful, further efforts are needed, and greater emphasis should be placed specifically on reducing CP-TBI among females. The findings highlight the need for effective CP-TBI prevention strategies and policies that focus on school-aged children, their physical activities, coaches, and parents. Intervention strategies to reduce CP-TBI should be included in programs of risk mitigation and safety in areas where children are active, namely homes, schools, and sporting/recreational venues as well as in the primary healthcare setting.

ACKNOWLEDGMENTS

This study was conducted under a protocol reviewed and exempted by the IRB of The University of Texas Health Science Center at Tyler, Texas.

The views expressed in this article are those of the authors and do not represent the view or policies of the school of Community and Rural Health, The University of Texas Health Science Center at Tyler or reflect the official policy or position of the U.S. Army Medical Department, Department of the Army, U.S. Army Institute of Surgical Research, the U.S. Navy, the Department of Defense, or the U.S. Government.

No financial disclosures were reported by the authors of this paper.

CREDIT AUTHOR STATEMENT

Tuan D. Le: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Writing - original draft. Alan Cook: Conceptualization, Methodology, Writing −original draft. Tony T. Le: Investigation, Data curation, Formal analysis, Software, Visualization, Writing - original draft. John W. Keyloun: Visualization, Writing - review and editing. Paul W. Detwiler: Writing - review and editing. Gerald Ledlow: Writing - review and editing. Anthony E. Pusateri: Writing - review and editing. Karan P. Singh: Conceptualization, Methodology, Supervision, Writing - original draft.

SUPPLEMENTAL MATERIAL

Supplemental materials associated with this article can be found in the online version at https://doi.org/10.1016/j.amepre.2022.04.011.

REFERENCES

1. Centers for Disease Control and Prevention. Surveillance report of traumatic brain injury-related emergency department visits, hospitalizations, and deaths-United States. Atlanta, GA: Centers for Disease Control and Prevention; 2014. https://www.cdc.gov/traumaticbraininjury/pdf/TBI-Surveillance-Report-FINAL_508.pdf.
2. Hyder AA, Wunderlich CA, Puvanachandra P, Gururaj G, Kobusingye OC. The impact of traumatic brain injuries: a global perspective. *NeuroRehabilitation*. 2007;22(5):341–353. https://doi.org/10.3233/NRE-2007-22502.

3. Report to congress on traumatic brain injury epidemiology and rehabilitation. recommendations for addressing critical gaps. Centers for Disease Control and Prevention. https://www.cdc.gov/traumaticbraininjury/pubs/congress_epi_rehab.html. Updated January 22, 2016. Accessed October 10, 2020.
4. Report to congress: the management of TBI in children. Centers for Disease Control and Prevention. https://www.cdc.gov/traumaticbraininjury/pubs/congress-childrentbi.html. Updated January 22, 2016. Accessed December 28, 2020.
5. Faul M, Xu L, Wald MM, Coronado V, Dellinger AM. Traumatic brain injury in the United States: national estimates of prevalence and incidence, 2002−2006. *Inj Prev.* 2010;16(suppl 1):A268. https://doi.org/10.1136/ip.2010.029215.951.
6. Lumba-Brown A, Yeates KO, Sarmiento K, et al. Centers for Disease Control and Prevention guideline on the diagnosis and management of mild traumatic brain injury among children [published correction appears in *JAMA Pediatr*. 2018;172(11):1104]. *JAMA Pediatr*. 2018;172(11):e182853. https://doi.org/10.1001/jamapediatrics.2018.2853.
7. Zaloshnja E, Miller T, Langlois JA, Selassie AW. Prevalence of long-term disability from traumatic brain injury in the civilian population of the United States, 2005. *J Head Trauma Rehabil.* 2008;23(6):394–400. https://doi.org/10.1097/01.HTR.0000341435.52004.ac.
8. Centers for Disease Control and Prevention (CDC). Nonfatal traumatic brain injuries from sports and recreation activities−United States, 2001-2005. *MMWR Morb Mortal Wkly Rep.* 2007;56(29):733–737. https://www.ncbi.nlm.nih.gov/pubmed/17657206. Accessed December 8, 2021.
9. Centers for Disease Control and Prevention. Nonfatal traumatic brain injuries related to sports and recreation activities among persons aged ≤19 years−United States, 2001-2009. *MMWR Morb Mortal Wkly Rep*. 2011;60(39):1337–1342. https://www.ncbi.nlm.nih.gov/pubmed/17657206. Acceessed December 8, 2021.
10. Coronado VG, Haileyesus T, Cheng TA, et al. Trends in sports- and recreation-related traumatic brain injuries treated in U.S. emergency departments: the National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP) 2001−2012. *J Head Trauma Rehabil.* 2015;30(3):185–197. https://doi.org/10.1097/HTR.0000000000000156.
11. Cheng TA, Bell JM, Haileyesus T, Gilchrist J, Sugerman DE, Coronado VG. Nonfatal playground-related traumatic brain injuries among children, 2001-2013. *Pediatrics.* 2016;137(6):e20152721. https://doi.org/10.1542/peds.2015-2721.
12. Waltzman D, Womack LS, Thomas KE, Sarmiento K. Trends in emergency department visits for contact sports-related traumatic brain injuries among children - United States, 2001-2018. *MMWR Morb Mortal Wkly Rep.* 2020;69(27):870–874. https://doi.org/10.15585/mmwr.mm6927a4.
13. National Electronic Injury Surveillance System (NEISS). U.S. Consumer Product Safety Commission. https://www.cpsc.gov/Research−Statistics/NEISS-Injury-Data. Updated January 1, 2020. Accessed July 16, 2020.
14. U.S. Consumer Product Safety Commission. NEISS coding manual. Bethesda, MD: U.S. Consumer Product Safety Commission, 2019. https://www.cpsc.gov/s3fs-public/2019_NEISS_Coding_Manual.pdf. Published January 2019. Accessed July 13, 2020.
15. Thompson MC, Wheeler KK, Shi J, et al. Surveillance of paediatric traumatic brain injuries using the NEISS: choosing an appropriate case definition. *Brain Inj.* 2014;28(4):431–437. https://doi.org/10.3109/02699052.2014.887146.
16. School-age resources. Stanford University. https://cardinalatwork.stanford.edu/benefits-rewards/worklife/children-family/school-age-resources. Accessed December 7, 2020.
17. Joinpoint trend analysis software. Surveillance Research Program, National Cancer Institute, NIH. https://surveillance.cancer.gov/joinpoint/. Updated April 22, 2020. Accessed August 1, 2020.
18. Haarbauer-Krupa J, Arbogast KB, Metzger KB, et al. Variations in mechanisms of injury for children with concussion. *J Pediatr*. 2018;197:241–248 .e1. https://doi.org/10.1016/j.jpeds.2018.01.075.
19. Traumatic brain injury act. Brain Injury Association of America. https://www.biausa.org/public-affairs/public-policy/traumatic-brain-injury-act. Accessed November 19, 2020.
20. National Association of State Head Injury Administrators. History of traumatic brain injury (TBI) act. Alabaster, AL: National Association of State Head Injury Administrators, 2020. https://static1.squarespace.com/static/5eb2bae2bb8af12ca7ab9f12/t/5efbdcead305a44006e1025c/1593564394454/nashia_tbiact_background_2020.pdf. Published February 2020. Accessed November 19, 2020.
21. Harvey HH. Reducing traumatic brain injuries in youth sports: youth sports traumatic brain injury state laws, January 2009 - December 2012. *Am J Public Health.* 2013;103(7):1249–1254. https://doi.org/10.2105/AJPH.2012.301107.
22. Agimi Y, Regasa LE, Ivins B, Malik S, Helmick K, Marion D. Role of Department of Defense policies in identifying traumatic brain injuries among deployed U.S. service members, 2001-2016. *Am J Public Health*. 2018;108(5):683–688. https://doi.org/10.2105/AJPH.2018.304347.
23. Omalu BI, DeKosky ST, Minster RL, Kamboh MI, Hamilton RL, Wecht CH. Chronic traumatic encephalopathy in a National Football League player. *Neurosurgery*. 2005;57(1):128–134. https://doi.org/10.1227/01.neu.0000163407.92769.ed.
24. Laskas JM. Bennet Omalu, concussions, and the NFL: how one doctor changed football forever. *GQ*. 2009 September 14 https://www.gq.com/story/nfl-players-brain-dementia-study-memory-concussions.
25. Head Games: the Global Concussion Crisis [film]; 2012. https://www.imdb.com/title/tt2239400/. Accessed date December 8, 2021.
26. Fainaru-Wada M, Fainaru S. *League of Denial: The NFL, Concussions and the Battle for Truth*. New York, NY: Crown Publishing Group; 2013. https://www.penguinrandomhouse.com/books/221286/league-of-denial-by-mark-fainaru-wada-and-steve-fainaru/. Accessed December 8, 2021.
27. Passon S.Concussion [film]; 2013. https://www.imdb.com/title/tt2296697/. Accessed December 8, 2021.
28. Sarmiento K, Thomas KE, Daugherty J, et al. Emergency department visits for sports- and recreation-related traumatic brain injuries among children - United States, 2010−2016. *MMWR Morb Mortal Wkly Rep.* 2019;68(10):237–242. https://doi.org/10.15585/mmwr.mm6810a2.
29. Cook B. Examining the decade-long trends in high school sports participation. *Forbes.* 2019 August 31 https://www.forbes.com/sites/bobcook/2019/08/31/examining-the-decade-long-trends-in-high-school-sports-participation/?sh=6faa704077e5.
30. The Aspen Institute. State of play 2018: trends and development. Washington, DC: The Aspen Institute, 2021. https://assets.aspeninstitute.org/content/uploads/2018/10/StateofPlay2018_v4WEB_2-FINAL.pdf. Published October 2018. Accessed February 9, 2021.
31. Kerr ZY, Chandran A, Nedimyer AK, Arakkal A, Pierpoint LA, Zuckerman SL. Concussion incidence and trends in 20 high school sports. *Pediatrics.* 2019;144(5):e20192180. https://doi.org/10.1542/peds.2019-2180.
32. Marar M, McIlvain NM, Fields SK, Comstock RD. Epidemiology of concussions among United States high school athletes in 20 sports. *Am J Sports Med.* 2012;40(4):747–755. https://doi.org/10.1177/0363546511435626.
33. Baldwin GT, Breiding MJ, Dawn Comstock R. Epidemiology of sports concussion in the United States. *Handb Clin Neurol.* 2018;158:63–74 https://doi.org/10.1016/B978-0-444-63954-7.00007-0.
34. Arbogast KB, Curry AE, Pfeiffer MR, et al. Point of health care entry for youth with concussion within a large pediatric care network. *JAMA Pediatr.* 2016;170(7):e160294. https://doi.org/10.1001/jamapediatrics.2016.0294.
35. McKeithan L, Hibshman N, Yengo-Kahn AM, Solomon GS, Zuckerman SL. Sport-related concussion: evaluation, treatment, and future

directions. *Med Sci (Basel).* 2019;7(3):44. https://doi.org/10.3390/medsci7030044.

36. McGuine TA, Hetzel S, McCrea M, Brooks MA. Protective equipment and player characteristics associated with the incidence of sport-related concussion in high school football players: a multifactorial prospective study. *Am J Sports Med.* 2014;42(10):2470–2478. https://doi.org/10.1177/0363546514541926.
37. Zuckerman SL, Reynolds BB, Yengo-Kahn AM, et al. A football helmet prototype that reduces linear and rotational acceleration with the addition of an outer shell. *J Neurosurg.* 2019;130(5):1634–1641. https://doi.org/10.3171/2018.1.JNS172733.
38. Casa DJ, Almquist J, Anderson SA, et al. The inter-association task force for preventing sudden death in secondary school athletics programs: best-practices recommendations. *J Athl Train.* 2013;48(4):546–553. https://doi.org/10.4085/1062-6050-48.4.12.
39. Adams WM, Scarneo SE, Casa DJ. State-level implementation of health and safety policies to prevent sudden death and catastrophic injuries within secondary school athletics [published correction appears in *Orthop J Sports Med.* 2017;5(10):2325967117741461]. *Orthop J Sports Med.* 2017;5(9):2325967117727262. https://doi.org/10.1177/2325967117727262.
40. Korey Stringer Institute, University of Connecticut. Traumatic brain injury. Mansfield, CT: Korey Stringer Institute, University of Connecticut. https://ksi.uconn.edu/emergency-conditions/traumatic-brain-injury/. Accessed December 14, 2021.
41. McCrory P, Meeuwisse W, Dvořák J, et al. Consensus statement on concussion in sport - the 5th international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med.* 2017;51(11):838–847. https://doi.org/10.1136/bjsports-2017-097699.