

How Dangerous are Youth Sports for the Brain? A Review of the Evidence

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ABSTRACT

In this Article, we review over 100 studies to answer the question: How likely is it that a youth athlete will sustain a concussion? On the basis of this review, we argue that both ends of the current concussion debate are problematic. On one hand, the data clearly suggest that the vast majority of youth athletes will not sustain a concussion. Moreover, a significant proportion of those who do experience a concussion will see their post-concussion symptoms dissipate within three weeks. On the other hand, the data also clearly shows that there are serious, non-zero risks of brain injury from playing contact sports before and during high school. These risks are elevated in collision sports, and current data collection methods likely underestimate actual incidence rates. Problematically, we find that while over 100 studies have been conducted and give us credible estimates for concussion incidence, this incidence data is absent from current educational materials delivered to athletes and parents. We argue, based on this data, that concussion risk can be better communicated to athletes and parents. The data on incidence rates remains incomplete, but it is still informative. We should not hide it from youth athletes.

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INTRODUCTION

Should kids play football? Or hockey? Or soccer? Or any contact sport?

Some experts advocate for banning many youth sports altogether. Dr. Bennet Omalu, the neuropathologist portrayed by Will Smith in the movie *Concussion*, has called for an end to football.¹ Many seem to agree, as a national poll found that nearly 50% of Americans would encourage children to avoid playing contact football altogether.² Legislators in Illinois and in New York have proposed eliminating youth tackle football.³

A school board candidate in Clark County, Nevada even ran his campaign on the platform of eliminating high school football. The candidate expressed concern that, “The human brain is not designed to play the collision sport of football. We do not have an airbag between the brain and the skull.”⁴

However, there has been strong pushback to these arguments. For example, opponents to the school board candidate called him a “nanny state liberal.”⁵ In Ohio, some high school football coaches perceive their game as “under attack” and have voiced frustration towards “a society where we think everything needs to be safe.”⁶

Central to resolving policy and legal disputes, and to informing parent and student-athlete decision-making, is relevant data on concussion incidence rates. As former President Barack Obama said in 2014 at the White House Healthy Kids and Safe Sports Concussions meeting, “[w]e’ve got to have better research, better data, better safety equipment, [and] better protocols” about youth sports concussions.⁷

1. Scooby Axson, ‘Concussion’ Doctor: Letting Kids Play Football is ‘Definition of Child Abuse’ SPORTS ILLUSTRATED (Aug. 8, 2017), <https://www.si.com/nfl/2017/08/08/bennet-omaluce-football>.

2. Matthew Santoni, *More Fear ‘Tackle’ Football Too Risky for Kids*, TRIB LIVE (Dec. 17, 2014, 9:02 PM), <http://triblive.com/neighborhoods/allegHENYneighborhoods/allegHENYneighborhoodsmore/7383088-74/football-percent-contact> (“How likely would you be to encourage your child or another child to avoid playing contact football altogether? — 46.7 percent were either very or somewhat likely.”).

3. Chris Kenning, *Lawmakers in Illinois, New York Propose Tackle Football Bans For Youth*, REUTERS (Jan. 25, 2018), <https://www.reuters.com/article/us-football-youth-tackle/lawmakers-in-illinois-new-york-propose-tackle-football-bans-for-youth-idUSKBN1FF09V> (proposed bills would “ban tackle football in youth sports before age 12”).

4. Patrick Hruby, *Friday Night Lights Out: The Case for Abolishing High School Football*, VICE SPORTS (Nov. 29 2016, 8:16 AM), https://sports.vice.com/en_us/article/53xy8k/friday-night-lights-out-the-case-for-abolishing-high-school-football.

5. *Id.*

6. Zachary Holden, *As Understanding of Football Concussion Threat Grows, so Does Emphasis on Safety*, TELEGRAPH-FORUM (Aug. 25, 2017, 8:53 AM), <http://www.bucyrustelegraphforum.com/story/sports/high-school/football/2017/08/25/understand-concussion-threat-grows-so-does-emphaat-high-school-level-coaches-stress-concussion-safet/597649001/> (a coach expressing frustration with the preconceived conclusions that football is dangerous).

7. President Barack Obama, Remarks at the White House Healthy Kids and Safe Sports Concussion Summit (May 29, 2014), in DAILY COMP. PRES. DOCS., 2014 DCPD No. 00407, at 3..

In this Article we focus on the question: *how likely is it that youth participation in sports will result in a concussion?* By reviewing over 100 studies, we strive to provide the legal and policy community with a review of the current scientific literature on concussion incidence rates in youth sports.

In doing so, we uncover a disconnect between concussion research and concussion laws. As reported in our Appendix, studies in fields spanning pediatrics, sports medicine, neurology, neuroscience, neurobiology, public health, neuropsychology, athletic training, and epidemiology have followed more than 1,000,000 athletes (ages 4-22), examined over 45 different organized sports, and assessed injuries across over 40,000,000 hours of athletic activity. These studies provide us with valuable information about the contours of brain injury risk in youth sports.

Yet almost none of the legally mandated concussion education material that is delivered to parents and athletes makes any mention of the actual risk of concussion. Under current concussion laws, athletes must sign legal waivers that typically read, “I hereby acknowledge having received education about the signs, symptoms, and risks of sport related concussion.” But are athletes truly “informed” about the risks if they never receive any actual risk data? We believe the answer is no, and argue that concussion education materials should include carefully developed information about the known risks of injury from concussion and sub-concussive hits.

To be sure, we recognize that providing information on concussion risk is not easy. Our review of the literature suggests a complex picture. On one hand, the majority of youth athletes—even those in collision sports—will *not* sustain a concussion. Moreover, a vast majority of those who do experience a concussion will see their post-concussion symptoms dissipate within three weeks. In this sense, there is a problematic gap between the rhetoric of some critics and the actual incidence data. Youth sports, even youth football, wrestling, hockey and soccer, may not be as dangerous as some suggest.

On the other hand, there are serious risks of brain injury from playing contact sports before and during high school. These risks are elevated in collision sports, and current data collection methods likely underestimate actual incidence rates. For some athletes and parents, these risks may outweigh the potential benefits that those sports provide.

Making the data even more complex is the recognition that it remains incomplete. The majority of studies we review here do not examine incidence rates for youth below age 14, and the underlying neurobiology of youth brain injuries also remains unknown. The lack of reliable, objective measures of concussion make it challenging to know the extent to which current estimates are underreporting concussion, and there is a paucity of data on sub-concussive impacts, particularly their effects over the lifespan. Moreover, with but a few exceptions, there is little discussion of the benefits of contact sports.

Taken together, current data on youth sports concussion incidence supports neither extreme of the current policy debate. Policy proposals calling for the elimination of youth football, hockey, and other collision sports are overly paternalistic. Yet the data also suggests that collision sports are more dangerous than the rest. We may be significantly undercounting concussions, and the accumulation of sub-concussive incidents may also be detrimental to brain health.

Our view is that although the research is still incomplete, it is nonetheless informative. Concussion policy should encourage transparency. Specifically, concussion education—which is required by current law in most states to be provided to parents and athletes—should effectively communicate the actual concussion risk to student-athletes and parents. Concussion policy should also account for possible long-term effects of brain injury, and be more aware of how concussion care may be related to racial and socioeconomic inequality.

The Article proceeds as follows. In Part I, we briefly review how discussion of concussion incidence rates is either missing or uninformed in current policy and law. In Part II, we introduce the methods used by researchers to estimate concussion incidence in youth sports. In Part III, we review in detail this research literature on incidence rates. In Part IV, we discuss the implications of the research. We focus on emerging opportunities for improving objective measurement of youth sports concussion. We also argue that concussion education provided to athletes and parents should include information about concussion incidence risk. Part V concludes.

I. CONCUSSION INCIDENCE IN MEDIA, LEGAL SCHOLARSHIP, AND POLICY DEBATES

Legal and policy debates on sports concussions, as well as accompanying scholarly commentary, often cite to statistics about the incidence of brain injury in youth sports, especially football and hockey. But as we show in this Part, discussion of incidence rates is often misinformed—or absent altogether.

Section A briefly surveys select media coverage, Section B explores legal scholarship, and Section C examines the concussion education sheets that are provided, as mandated by state law, to prospective student-athletes and their parents.

A. Media

The public's interest in concussions has risen dramatically over the past decade. To empirically track this rise in interest, we examined the trends in Google searches for “concussion” from 2004 to the present. As shown in Figure 1, there has been a strong, steady climb in interest.

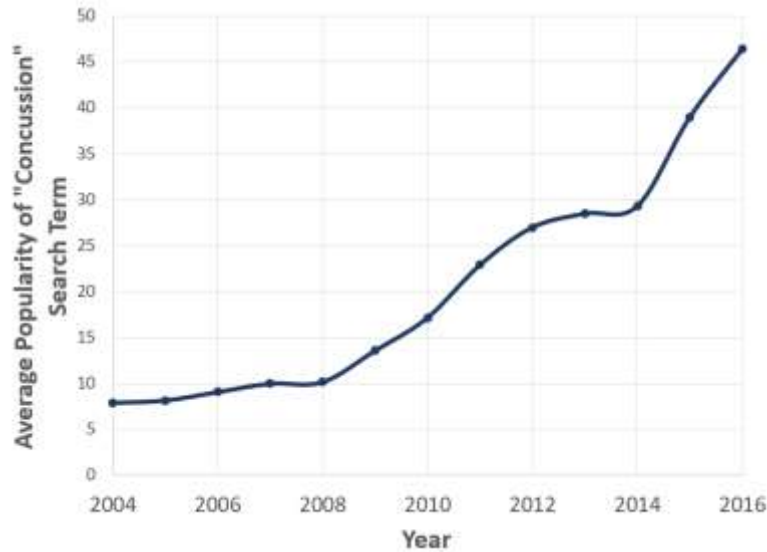
The media has played an important, if sometimes problematic, role in this

expansion of interest in sports concussions.⁸ Not surprisingly, given the media's need to attract readers and viewers, there is a general penchant for sensationalist headlines and reporting that glosses over the nuance of actual statistics.⁹

8. Rebekah Mannix et al., *Sports-Related Concussions—Media, Science and Policy*, 12 NATURE REV. NEUROLOGY 486, 486 (2016) (discussing public perception of concussions in sports and that the resulting calls to abolish collision sports like football might be “premature” without more knowledge of the harmful consequences of concussions); *See generally* T. Blake et al., *Prioritizing Concussion Prevention in Youth Ice Hockey: An Assessment of English-Language Canadian Newspapers as a Vehicle for Evidence-Based Knowledge Translation*, 48 BRIT. J. SPORTS MED. 570, 570 (2014) (study evaluating media coverage of concussions and “evidence-based injury prevention knowledge” being conveyed to the public).

9. *See generally* Katarzyna Molek-Kozakowska, *Towards A Pragma-Linguistic Framework for the Study of Sensationalism in News Headlines*, 7 DISCOURSE & COMMUNICATION 173, 173-4 (noting that “[n]ews outlets, which compete for audience attention to secure their profits from advertising, try to make their information appear relevant, urgent or unusual. For this purpose they customize news through selectivity or enhancement, generalization or simplification, emotionalism or sensationalism.”)

Figure 1. Public interest in the United States in concussions over time, measured in popularity of Google searches for concussion from 2004-2016



What to Notice in Figure 1: The most important thing to notice in Figure 1 is that there has been a steady increase in public interest in concussions over the past decade. Data for this graph was retrieved from the Google trends search engine at <https://trends.google.com/trends/>. A search was conducted on July 25, 2017 using the search key word “concussion” and the search from “2004-Present” (non-real time) parameters. The search was limited to searches made from locations within the United States. Non-real time Google trends data takes a random sample of all Google searches performed within the United States during the specified time period. Currently, data is available from 2004 through the present. This data is normalized based on the region selected. That is, the search for “concussion” in the United States presents the search interest as a proportion of all Google searches during a particular time. Thus, search interest = (# of searches for keyword) / (total Google searches). This data is further normalized such that the maximum search interest across the time period for that particular region is indexed to 100.¹⁰ Data points from each month were then averaged to demonstrate yearly trends in the popularity of the term “concussion”.

It is not hard to find provocative media statements about youth contact sports such as “enrolling a child in a contact sport could be as hazardous as giving

10. Our discussion here of Google trends methodology is based on Simon Rogers, *What Is Google Trends Data – and What Does It Mean?*, GOOGLE NEWS LAB (July 1, 2016), <https://medium.com/google-news-lab/what-is-google-trends-data-and-what-does-it-mean-b48f07342ee8>.

them cigarettes.”¹¹ News articles and television specials speak about the fact that “youth concussions are an epidemic,”¹² and feature NFL players that “advise [youth athletes] and their parents to avoid the game [football] at all costs.”¹³ A few examples include:

- A columnist in a Lancaster, Pennsylvania paper observed: “while we have little idea of the effectiveness of various treatments and safety measures, what is absolutely not in doubt is that playing tackle football is damaging to the brain. That is indisputable. The only question is the extent of the damage.”¹⁴
- After a study on chronic traumatic encephalopathy (CTE) in deceased NFL players was released in summer 2017, USA Today ran a story under the headline: “How many more dead athletes before we address CTE?”¹⁵
- At the University of Illinois, the student-run campus newspaper ran both a long form story on concussion, and an associated editorial. The editorial had the headline: “Concussion epidemic careening out of control.”¹⁶

This media coverage is important because it sparks debate about the ways in which we can make youth sports safer. But there is a balance to be struck.¹⁷ As

11. A Current Affair, *‘Don’t Risk Your Child’: Pioneer Concussion Doctor’s Blunt Message for Aussie Parents*, 9NEWS (July 6, 2017, 5:57 PM), <https://www.9news.com.au/national/2017/07/06/17/57/pioneer-concussion-doctors-blunt-message-for-aussie-parents> (statement by Dr. Bennet Omalu, a leading brain doctor and concussion expert).

12. Joe Lemire, *Ban Checking in Youth Hockey, Says NHL Great Eric Lindros*, VOCATIV (June 1, 2017, 2:11 PM), <http://www.vocativ.com/434867/ban-checking-in-youth-hockey-eric-lindros/index.html>.

13. Roxanne Jones, *Why I’m Saying Goodbye to Football*, CNN (Oct. 15, 2013, 7:52 AM), <http://www.cnn.com/2013/10/15/opinion/jones-nfl-head-injuries/index.html> (Jones discusses discouraging children from playing football, citing former NFL players who share her view).

14. John Gerdy, *The Evidence is Clear: Tackle Football is too Risky for Children*, LANCASTER ONLINE (Jan. 17, 2016), http://lancasteronline.com/opinion/columnists/the-evidence-is-clear-tackle-football-is-too-risky-for/article_be364cc6-bae2-11e5-9910-8f0f38338202.html.

15. Daniel Engber, *Inflategate*, SLATE (July 26, 2017), http://www.slate.com/articles/sports/sports_nut/2017/07/the_press_is_overhyping_the_latest_study_on_cte_in_the_nfl.html (criticizing the media coverage of this study).

16. The Daily Illini Editorial Board, *Editorial: Concussion Epidemic Careening Out of Control*, DAILY ILLINI (Jan. 26, 2017), <https://dailyillini.com/opinions/2017/01/26/editorial-editorial-concussion-epidemic-careening-out-of-control/>.

17. To be sure, there are longer form treatments that often attempt to devote more word space to the complexities. *See, e.g.*, the collection of online articles in Max Linsky, *The Longform Guide to Football in Crisis*, SLATE (Sept. 2012), http://www.slate.com/articles/sports/longform/2012/09/football_concussions_and_what_they_mean_for_the_sport_s_future_a_longform_guide.html. Moreover, a cursory search of news sites suggests to us that we may be witnessing a shift in the way that news media discusses concussion. The concussion hype seems to have peaked in 2015 and early 2016, which may be linked to the release of the movie *Concussion* as well as outspoken remarks by Dr. Bennet Omalu (the researcher at the center of the movie). Since then, the quotations directly from researchers into concussion have

concussion researcher Dr. Dawn Comstock has observed: “We should try to prevent concussions, but we should not let the fear of concussions or any sports-related injuries drive kids out of playing sports.”¹⁸ Critical to achieving that balance is careful attention to the details of concussion incidence.¹⁹

B. Legal Scholarship

The legal literature on youth sports concussions has been growing. Some commentary, such as that by law professor Hosea Harvey, explicitly recognizes the challenge of accurately measuring concussion incidence rates. Harvey observes:

“There is no comprehensive reporting mechanism at the state or national level to identify all instances of youth TBIs (Traumatic Brain Injuries) during a given year or the percentage of those caused by youth sports. Therefore, it becomes necessary to rely on estimates, anecdotes, and/or incomplete reporting systems to establish baseline population data²⁰ . . . [B]ecause specific data are lacking at both the national and state level, experts acknowledge a high degree of uncertainty notwithstanding their general agreement about the significance of the problem.”²¹

Harvey’s treatment of the data challenges is nuanced, but often in legal scholarship such careful treatment is instead replaced by a cursory glance at the statistics.

For instance, an article in the *Sports Lawyers Journal* cited the Center of Disease Control (CDC) statistic that “estimates 1.6 to 3.8 million traumatic brain injuries occur each year as a result of sports and recreation[al] activities.”²² In the next sentence, the author then concludes that “this is sufficient proof that ‘concussions from sports are an epidemic in this country.’”²³ Jumping so quickly

often spoken to the positive aspects of youth sports and the necessity of proper safety protocols, but not quitting the game. Further research might identify more systematically whether this is indeed a trend.

18. Zach Braziller & Joseph Staszewski, *Hard Knocks for Kid Grid*, NEW YORK POST (Oct. 11, 2016) (Dr. Comstock, an associate professor of epidemiology at the Colorado School of Public Health, stated that children may take longer to recover from concussions because their brains are still developing. The article also notes that the rise in concussion might be due to higher instances of reporting due to more knowledge about concussions, rather than because more concussions are occurring).

19. CTE research has also been in the news. In 2017, a group led by Bennet Omalu published an article in which they reported using positron emission tomography (PET) to identify chronic traumatic encephalopathy (CTE) in a living human. Yet the science of CTE is in need of refinement and further research. See Andrew Gardner et al., *Chronic Traumatic Encephalopathy in Sport: A Systematic Review*, 48 BRIT. J. SPORTS MED 84. (2013).

20. Hosea H. Harvey, *Refereeing the Public Health*, 14 YALE J. HEALTH POL’Y, L. & ETHICS 66, 74 (2014).

21. *Id.* at 75.

22. Kristina M. Gerardi, *Tackles that Rattle the Brain*, 18 SPORTS LAW. J. 181, 190 (2011).

23. *Id.* (quoting Study Links Concussions to Brain Disease: 60 Minutes Looks at Alarming New Research on the Longterm Effects of Concussions and Head Trauma, CBS NEWS (Oct. 11,

to such conclusions, without careful consideration of the underlying data, is problematic.²⁴ But it is something we see regularly in the scholarship. To illustrate, here are some of the ways in which legal scholars have described concussion incidence:

- “Sports concussions are *common* in young athletes.”²⁵
- “Today the sports world faces a . . . crisis from the epidemic of serious and often permanent brain injury.”²⁶
- “. . . studies show athletes between the ages of five and fourteen are far more susceptible to catastrophic brain injury resulting from the exposure to repetitive head contact, than any other age group.”²⁷
- While injuries in professional sports make headlines, “[f]or every concussion . . . occurring at the professional sports level, there are tens of thousands of injuries at the high school level and below.”²⁸

In these and other pieces of commentary, legal scholars are missing opportunities to more carefully engage with the data on youth sports concussion incidence.

C. Public Policy

Inattention to detail in scholarship is one thing; policies that don’t provide sufficiently detailed information to athletes and parents are of even greater concern. Notably, none of the concussion education material regularly made available to athletes directly addresses the question: How likely is it that you will receive a concussion playing this sport?

For instance, the CDC “Parent & Athlete Concussion Information Sheet,” a publication of their HEADS UP Concussion in Youth Sports education and

2009), available at <http://www.cbsnews.com/stories/2009/10/08/60minutes/main5371686.shtml>).

24. Moreover, attributing all of these concussions to organized sports is problematic because the “sports and recreation” category includes not only organized team sports, but also injuries sustained at the playground or biking around the neighborhood.

25. Marie-France Wilson, *Young Athletes at Risk: Preventing and Managing Consequences of Sports Concussions in Young Athletes and the Related Legal Issues*, 21 MARQ. SPORTS L. REV. 241, 246 (2010).

26. Douglas E. Abrams, *Confronting the Youth Sports Concussion Crisis: A Central Role for Responsible Local Enforcement of Playing Rules*, 2 MISS. SPORTS L. REV. 79, 75 (2013).

27. Taylor Adams, *The Repercussions of Concussions in Youth Football Leagues: An Analysis of Texas’s Concussion Law and Why Reform Is Necessary*, 18 SCHOLAR 285, 289 (2016) : ST. MARY’S L. REV. & SOC. JUST. 285, 289 (2016) (citing ROBERT CANTU & MARK HYMAN, CONCUSSIONS AND OUR KIDS: AMERICA’S LEADING EXPERT ON HOW TO PROTECT YOUNG ATHLETES AND KEEP SPORTS SAFE 11-12 (2012)).

28. Josh Hunsucker, “*When in Doubt, Sit Them Out*”: Chapter 173 Effectively Supplements California Concussion Law and Raises Awareness Among Coaches, 44 MCGEORGE L. REV. 600, 600 (2013) (international quotation marks omitted).

prevention initiative, makes no mention of the potential risks.²⁹ Not a single statistic is mentioned.³⁰ The same is true for every state concussion education fact sheet we were able to examine.³¹

To take just one illustrative example, consider the “Wisconsin Fact Sheet for Athletes.”³² The information sheet includes the following sections:

- What is a concussion?
- What are the signs and symptoms of a concussion?
- Common symptoms of a concussion.
- Anatomy of a concussion
- What should you do if you think you have a concussion?
- Why should you tell someone about your symptoms?
- Tell your teachers

All of this information about concussions is important to provide to athletes. But in Wisconsin, and in similar information sheets in other states, there is no mention of the likelihood of sustaining a concussion.

To be sure, as we discuss in Part IV, effectively communicating such information is not a simple task. But leaving the information completely absent from the educational materials creates a gap—a gap that is filled by the often-imprecise media reports we just reviewed. In other research, our Lab has found that the American general public overestimates youth concussion incidence in football.³³

In sum, what athletes, parents, coaches, and policymakers need is better, evidence-based information on the actual risks and benefits of participation in

29. See *Parent & Athlete Concussion Information Sheet*, CTRS. FOR DISEASE CONTROL & PREVENTION, https://www.cdc.gov/headsup/pdfs/custom/headsupconcussion_parent_athlete_info.pdf (last updated June 2015).

30. See *id.* The closest the form gets is stating (without a citation): “Young children and teens are more likely to get a concussion and take longer to recover than adults.”

31. For each state, we reviewed the concussion information sheets as available online. The closest that a state concussion information sheet was to identifying risk of incidence was the following statement, found in the Arizona and Maine sheets: “Based on the incidence of concussion as published by the CDC the following sports have been identified as high risk for concussion; baseball, basketball, diving, football, pole vaulting, soccer, softball, spiritline and wrestling.” New York’s sheet mentioned that “An estimated 4 million people under age 19 sustain a head injury annually. Of these approximately 52,000 die and 275,000 are hospitalized. An estimated 300,000 sports and recreation related concussions occur each year. Students who have had at least one concussion are at increased risk for another concussion. In New York State in 2009, approximately 50,500 children under the age of 19 visited the emergency room for a traumatic brain injury and of those approximately 3,000 were hospitalized.”

32. Wisconsin Dept. Pub. Instruction, *Wisconsin Fact Sheet for Athletes: Know Your Concussion ABCs*, WISCONSIN INTERSCHOLASTIC ATHLETIC ASSOCIATION, <http://www.wiaawi.org/Portals/0/PDF/Health/ConcussionAthletes.pdf> (last visited Mar. 14, 2018).

33. Francis X. Shen, *You Can Love the Brain and Football, Too*, STARTRIBUNE (Jan. 31, 2018), <http://www.startribune.com/youth-football-and-concussions-i-love-the-brain-but-think-you-can-like-football-too/472033803/>.

youth sports. Thankfully, to date there have been over 100 studies conducted that can inform our estimate of concussion risk. We review these studies in the next Part.

II. HOW DO RESEARCHERS MEASURE YOUTH SPORTS CONCUSSION INCIDENCE RATES?

In this and the next Part, we review the research literature on youth sports concussion incidence rates. Those readers who want only the summary points should skip to Part III. However, we encourage readers to review this Part, where we identify a series of cautions that must precede evaluation of the studies.

We limit our focus to “youth” by examining studies of athletes aged high school and younger. We excluded studies on NCAA athletes and professional athletes. This focus was motivated by two reasons. First, the scope of state youth sports concussion laws only reaches high school and youth sports.³⁴ Second, the majority of the nation’s athletes are high school or younger athletes.³⁵

Section A starts with a caution about the comparative lack of research on younger age cohorts. Section B discusses our search methods for identifying research studies on point. Section C summarizes the three primary types of methodologies that researchers have used to estimate concussion incidence: hospital records, surveillance studies, and athlete self-report.

A. Caution: Lack of Research on Younger Athletes

There is significantly less concussion incidence research on populations younger than highschool. Concussion in college and professional sports has been the subject of much on-going research.³⁶ In addition, there is increasing research on high school athletes, with sophisticated high school data collection systems now in place for some schools.³⁷ Comparatively little research exists on the younger age cohorts. Thus, as shown in Figure 2, there is a mismatch between the number of athletes in each age cohort and the number of research studies.

34. Francis X. Shen, *Are Youth Sports Concussion Statutes Working?*, 56 DUQ. L. REV. 7 (2018).

35. *Estimated Probability of Competing in College Athletes*, NCAA, <http://www.ncaa.org/about/resources/research/estimated-probability-competing-college-athletics> (last updated Mar. 10, 2017).

36. See, e.g., Zachary Y. Kerr et al., *National Collegiate Athletic Association Injury Surveillance System: Review of Methods for 2004–2005 Through 2013–2014 Data Collection*, 49 J. ATHLETIC TRAINING 552 (2014); Jennifer M. Hootman et al., *Epidemiology of Collegiate Injuries for 15 Sports: Summary and Recommendations for Injury Prevention Initiatives*, 42 J. ATHLETIC TRAINING 311 (2007).

37. See, e.g., *High School RIO™: Reporting Information Online*, COLORADO SCH. PUB. HEALTH, <http://www.ucdenver.edu/academics/colleges/PublicHealth/research/ResearchProjects/piper/projects/RIO/Pages/default.aspx> (last visited Mar. 14, 2018).

Less is known about athletes below high school age because it is a more difficult population to research. For instance, athletic trainers responsible for identifying concussions in high school populations “cited unfamiliarity with the youth population as the greatest challenge in assessing concussion, also noting that young children may lack understanding of concussion symptoms.”³⁸

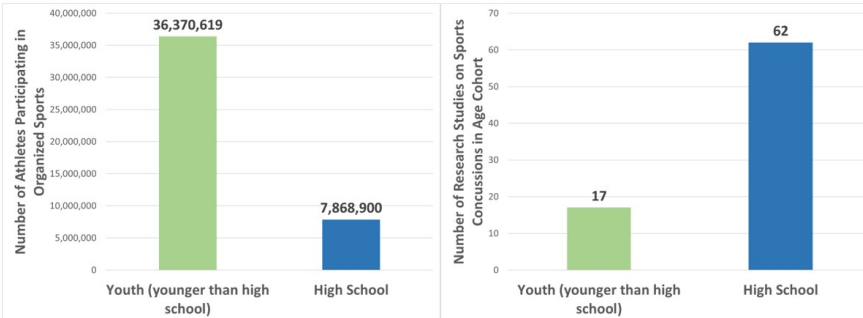
Because of this lack of research, we must proceed cautiously. In particular, we do not know how well the incidence rates derived from studies of older cohorts informs concussion incidence rates in younger cohorts. The need for research in this area is so important that the international consensus statement from the Conference on Concussion in Sport in 2016 emphasized “[t]he paucity of studies that are specific to children, especially younger children, needs to be addressed as a priority.”³⁹

38. Zachary Y. Kerr et al., *Concussion Symptoms and Return to Play Time in Youth, High School, and College American Football Athletes*, 170 J. AM. MED. ASS’N PEDIATRICS 647, 651 (2016).

39. Paul McCrory et al., *Consensus Statement on Concussion in Sport—the 5th International Conference on Concussion in Sport Held in Berlin, October 2016*, 51 BRIT. J. SPORTS MED. 838, 844 (2017).

Figure 2. Illustrating the Comparative Lack of Research on Sports Concussions in Youth Younger than High School Age: Graph of 2008-2010 Sports Participation Rates and Number of Studies, by Age Group

There are 36 million athletes younger than high school age, and 8 million high school age athletes. Yet there are 62 studies of sports concussions in high school age populations and only 17 in younger populations.



What to Notice in Figure 2: The most important thing to notice is the discrepancy between much greater participation in youth sports (younger than high school age), contrasted with much less research on sports-related concussions in that age group. Figure 2 makes two comparisons. On the left hand (A) side of the Figure, we graph the estimated number of participants in youth and in high school sports. The youth estimates are based on 2008 participation data collected and reported by the National Council of Youth Sports in 2008.⁴⁰ The high school participation data is based on 2008-2009 academic year participation collected and reported by the National Federation of State High School Associations in 2010.⁴¹ On the right hand (B) side of the Figure, we graph the number of scholarly research studies on sports concussions in both age cohorts. Appendix A discusses how studies were identified and coded, and provides a list of studies included in each column. For studies that examined both high school and younger populations we coded them in both groups.

40. *Report on Trends and Participation in Organized Youth Sports*, NAT'L COUNCIL OF YOUTH SPORTS (2008), <http://www.ncys.org/pdfs/2008/2008-ncys-market-research-report.pdf> (providing several different estimates, this graph depicts the most conservative estimates for youth sports).

41. *2008-2009 High School Athletics Participation Survey*, NAT'L FED'N ST. HIGH SCH. ASS'NS (2009), http://www.nfhs.org/ParticipationStatics/PDF/2008-09%20NFHS%20Handbook_Participation%20Survey_9_15.pdf (total high school sports participation reported by public high schools across all 50 states).

B. Identifying Studies for Inclusion in the Review

We focused our attention on studies examining concussion incidence in high school aged and younger athletes. Articles reporting the incidence of youth head injury were identified using Google Scholar, PubMed, the electronic databases of MEDLINE and Sport Discus,⁴² and the University of Minnesota library electronic catalog system. Review articles and books were consulted to capture a wide range of references. Articles were initially identified using the following search key words: youth, adolescent, pediatric, child, sport, athlete*, concussion, mild traumatic brain injury, head injury, incidence, prevalence and epidemiolog*.

Abstracts and articles were reviewed for inclusion. Our inclusion criteria were: (i) original, published research; (ii) evaluated the incidence/prevalence/epidemiology of sports-related concussion or mild traumatic brain injury; and (iii) included youth (< 19 years) as study subjects. This review excluded studies that were published in a language other than English, or were not peer-reviewed.

C. How Concussion Incidence is Measured

There are three primary sources of data for estimating sports-related concussion (SRC) incidence: medical records (primarily from hospital emergency departments), injury surveillance systems (i.e., third parties such as trainers who survey athletic activity and identify concussions), and athlete self-report data (i.e., where athletes are asked, usually retrospectively, if they have sustained a concussion). We review each of these approaches below.

One of the challenges in assessing concussion incidence is defining “concussion.” The word concussion is a derivative of the Latin word *concussus*, which means to shake violently.⁴³ Today, however, concussion is diagnosed

42. On July 26th and July 27th, 2017, 139 articles were found in MEDLINE using [exp Brain Concussion/ AND “sport* OR athlete*” AND “incidence/ or prevalence/ or epidemiological monitoring/ OR exp Epidemiology/”] when limited to English language articles and a target population of child (6 to 12 years) and adolescents (13 to 18 years). Following screening abstracts and full texts, 25 studies were included. 443 English language studies were found using [exp Brain Concussion/ AND “sport* OR athlete*” AND “incidence/ or prevalence/ or epidemiological monitoring/ OR exp Epidemiology/”]. After excluding the previous search, 345 articles remained. After screening abstracts and full texts against inclusion criteria, 15 studies were included. After removing studies identified using Google Scholar, 24 additional studies remained. On July 28th, 2017, 201 articles were found using [concussion AND (sport* OR athlete*) AND (incidence OR prevalence OR epidemiolog*) AND (scholastic OR school)]. After screening abstracts and full text, 31 articles remained. 129 articles were found using [concussion AND (sport* OR athlete*) AND (incidence OR prevalence OR epidemiolog*) AND (youth OR young OR child* OR pediatric*)]. 45 remained after removing those captured in the initial search. After screening abstracts and full text where unclear, 2 articles remained. After removing studies identified using Google Scholar or MEDLINE, 11 studies remained.

43. Robert C. Cantu, *Overview of Concussion*, 35 BRIT. J. SPORTS MED. 368, 368 (2001).

without objective physical biomarkers and thus presents the clinician with significant diagnostic challenges.⁴⁴ As a result, there is no consistent definition of concussion either within or across methodology, and there is no consistent denominator from which the incidence rate can be calculated and compared across methodologies. We must keep this in mind as we review the findings because comparisons across studies, and in particular across research methodologies, may be difficult.

1. Medical Records

One common method of estimating SRC incidence is to examine hospital records.⁴⁵ Amongst concussions treated by health care providers, the majority are outpatient or emergency department visits.⁴⁶ The CDC and the United States Consumer Product Safety Commission (CPSC) surveil hospital emergency departments from which estimates of the national incidence of medically-attended SRC can be drawn. In general, the CDC uses International Classification of Disease (ICD) diagnosis codes to identify SRC.⁴⁷ The literature based on medical record data thus frames this discussion in terms of sports and recreation-related traumatic brain injury, the broader category of brain injury into which concussions fall.⁴⁸ The CPSC's National Electronic Injury Prevention Surveillance System (NEISS)⁴⁹ matches the physician's diagnosis (usually an

44. See Paul McCrory et al., *What is the Definition of Sports-Related Concussion: A Systematic Review*, 51 BRIT. J. SPORTS MED. 877, 886 (2017) (noting that there is “no gold or reference standard for SRC diagnosis” and anticipates that “in the future, head injury and concussion may eventually be defined by the severity of clinical signs, as well as . . . biomarkers”).

45. See, e.g., Jean A. Langlois et al., *The Epidemiology and Impact of Traumatic Brain Injury: A Brief Overview*, 21 J. HEAD TRAUMA REHAB. 375, 375 (2006); MARK FAUL ET AL., *TRAUMATIC BRAIN INJURY IN THE UNITED STATES: EMERGENCY DEPARTMENT VISITS, HOSPITALIZATIONS AND DEATHS 2002-2006* (2010); Jeffrey J. Bazarian et al., *Mild Traumatic Brain Injury in the United States, 1998-2000*, 19 BRAIN INJURY 85, 86 (2005); Daniel M. Sosin et al., *Incidence of Mild and Moderate Brain Injury in the United States, 1991*, 10 BRAIN INJURY 47, 49 (1996); Thomas E. Jager et al., *Traumatic Brain Injuries Evaluated in US Emergency Departments, 1992-1994*, 7 ACADEMIC EMERGENCY MED. 134, 134 (2000).

46. Mersine A. Bryan et al., *Sports- and Recreation-Related Concussions in US Youth*, 138 PEDIATRICS, June 2016, at 1; FAUL ET AL., *supra* note 45, at 7.

47. Jeffrey J. Bazarian et al., *supra* note 45, at 86; see also *Int'l Classification of Diseases, Ninth Revision (ICD-9)*, CTRS. FOR DISEASE CONTROL & PREVENTION, <https://www.cdc.gov/nchs/icd/icd9.htm> (last visited Mar. 14, 2018).

48. In the medical-based literature, concussions are considered to be a sub-set of mild traumatic brain injury (mTBI). These cases of mTBI are reported in an aggregate, and it is impossible to distinguish sub-sets of mTBI such as concussion. In some of the literature, mTBI and concussion are considered interchangeable terms. See Paul McCrory et al., *Consensus Statement on Concussion in Sport: The 4th International Conference on Concussion in Sport Held in Zurich, November 2012*, 47 BRIT. J. SPORTS MED. 250, 250 (2013).

49. See NATIONAL ELECTRONIC INJURY SURVEILLANCE SYSTEM (NEISS), U.S. CONSUMER PRODUCTS SAFETY COMMISSION, <https://www.cpsc.gov/Research—Statistics/NEISS-Injury-Data> (last visited Mar. 14, 2018). The NEISS collects consumer product-related data from a probability sample of 100 United States emergency departments. Thus, researchers can limit their

ICD code) with one of the provided NEISS diagnostic codes, one of which is “concussion.”⁵⁰ The NEISS is the sole nationally representative stratified probability sample, and it provides a valuable repository for United States youth concussion data.⁵¹ However, specifying SRCs from NEISS and other medical data can be difficult.⁵² In addition, incidence is often presented as a national estimate based on U.S. Census data (likely not reflective of participation).⁵³

Using emergency room data to assess the incidence rate of youth concussion has several limitations. For one, ICD codes and other administrative database tools cannot always specify whether concussions occurred during an organized sport event or whether they were just the result of playing baseball in the backyard.⁵⁴ In addition, ICD codes captured by these studies are often under or over-inclusive of SRCs as the diagnosis.⁵⁵ In fact, a 2015 report from the CDC claimed that “[u]sing current data systems it is not possible to describe sports- and recreation-related TBIs as a separate category for those who are hospitalized or die as the result of sports- or recreation-related TBI.”⁵⁶ Despite these limitations, emergency room data is useful for identifying concussion incidence trends over time and across age groups.

2. Injury Surveillance Systems

Injury surveillance systems have been a primary source of youth sports-related concussion incidence.⁵⁷ Here, “surveillance” is an epidemiological term

dataset to only injuries involving “baseball bat” or “volleyball net” in order to find sport-specific data. Since 2001, the NEISS has also been augmented with the NEISS-All Injuries Program (AIP); this is a subset of 66 hospitals where all cases, not just ones related to consumer products, are included.

50. See *NEISS Coding Manual*, U.S. CONSUMER PROD. SAFETY COMM’N 10 (Jan. 2017), <https://www.cpsc.gov/s3fs-public/2017NEISSCodingManualCPSCOnlyNontrauma.pdf>.

51. David Buzas et al., *Concussions From 9 Youth Organized Sports: Results from NEISS Hospitals over an 11-Year Time Frame, 2002-2012*, 2 *ORTHOPAEDIC J. SPORTS MED.*, Apr. 2014, at 2, 3, 7.

52. Victor G. Coronado et al., *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*, 30 *J. HEAD TRAUMA REHAB.* 185, 194-195 (2015), *CTRS. FOR DISEASE CONTROL & PREVENTION, U.S. DEPT. HEALTH & HUM. SERVS., REPORT TO CONGRESS: TRAUMATIC BRAIN INJURY IN THE UNITED STATES: EPIDEMIOLOGY AND REHABILITATION 23* (2015) (noting the gaps in the surveillance of TBIs that occur in sports-related activities and that current surveillance systems do not routinely collect a person’s concussion history, use of personal protective equipment, and other circumstances of an injury).

53. See, e.g., Coronado et al., *supra* note 52, at 194.

54. REPORT TO CONGRESS, *supra* note 52, at 23.

55. *Id.*

56. *Id.* at 23.

57. For example, the results of the High School Sports-Related Injury Surveillance Study, Reporting Information Online (HS RIO) has been cited over 700 times according to Google Scholar. The High School RIO has formed the basis for over 100 publications <http://www.ucdenver.edu/academics/colleges/PublicHealth/research/ResearchProjects/piper/projects/RIO/Pages/Publications.aspx>, accessed April 20, 2018.

of art, referring to “the ongoing systematic collection, analysis, and interpretation of outcome-specific data for use in the planning, implementation, and evaluation of public health practice.”⁵⁸ In general, these approaches rely on certified athletic trainers employed at the sampled schools or teams to report injuries and exposure time for athletes via an online interface. For high school athletes, there are two major extant surveillance systems.⁵⁹ Both are national systems: (1) the High School Reporting Information Online (HS RIO), part of the National High School Sports-Related Injury Surveillance System Study;⁶⁰ and (2) the National Athletic Treatment, Injury and Outcomes Network (NATION).⁶¹ There was also one regional system, the Fairfax County Public School System Injury Treatment Tracking System.⁶² By contrast, there is only a single surveillance system for youth athletes – the Youth Football Safety Study (YFSS).⁶³

The National High School Sports-Related Injury Surveillance Reporting Information Online System (RIO) is an internet-based injury reporting system, drawing from all U.S. public high schools with a National Athletic Trainers’ Association (NATA) certified athletic trainer.⁶⁴ Concussions are defined

58. PRINCIPLES AND PRACTICE OF PUBLIC HEALTH SURVEILLANCE 1 (Steven M. Teutsch & R. Elliott Churchill eds., 2000).

59. Beyond these major surveillance systems, additional sport-specific (e.g. for ice hockey, soccer or football) and regional (e.g. in Washington State) surveillance systems exist with variable reporting methods and criteria for concussion.

60. The HS RIO is a stratified national sample of 100 U.S. public high schools with a National Athletic Trainers’ Association (NATA) certified athletic trainer who is willing to report information. It attempts to mirror the NCAA Injury Surveillance System. It has been in effect since the 2005-2006 school year collecting data across 9 high school sports: football, boys’ soccer, girls’ soccer, boys’ basketball, girls’ basketball, wrestling, baseball, volleyball, and softball. During the 2008-2009 academic year an additional convenience sample expanded the study to ensure that rarer sports (girls’ gymnastics and field hockey, boys’ ice hockey and volleyball, and boys’ and girls’ lacrosse, cheerleading, track/field, and swim/dive) were also represented in the study.

61. NATION was initiated in 2011-2012 by the Datalys Center for Sports Injury Research and Prevention and captures 31 sports from a convenience sample of 147 public high schools (47 in 2011-2012, 68 in 2012-2013, and 147 in 2013-2014) with certified athlete trainers willing to report. Thomas P. Dompier et al., *The National Athletic Treatment, Injury and Outcomes Network (NATION): Methods of the Surveillance Program, 2011–2012 through 2013–2014*, 50 J. ATHLETIC TRAINING 862, 863 (2015).

62. The Fairfax County Public School System Injury Treatment Tracking System captured information on 27 sports from all 25 high schools in Fairfax County, Virginia between 1997 and 2008. See Andrew E. Lincoln et al., *Trends in Concussion Incidence in High School Sports: A Prospective 11-Year Study*, 39 Am. J. Sports Med. 958, 960 (2011), at 959.

63. The YFSS is managed by the Datalys Center, which also runs the NCAA ISS and the NATION, with support from USA Football. It captures a convenience sample of non-school football teams for youth 5 to 14 across 6 geographically distinct states. See Youth Football Safety Study, DATALYS CENTER (2014) <http://www.datalyscenter.org/youth-football-safety-study/>, Zachary Y. Kerr et al., *Injury Rates in Age-Only Versus Age-and-Weight Playing Standard Conditions in American Youth Football*, 3 ORTHOPAEDIC J. SPORTS MED., Sept. 23, 2015, at 1.

64. For the most current NATA position statement regarding “concussion,” see Steven P. Broglio et al., *National Athletic Trainers’ Association Position Statement: Management of Sport Concussion*, 49 J. ATHLETIC TRAINING 245 (2014).

according to the participating athletic trainers, and have only included non-time loss injuries (e.g. no participation time lost from games or practice) since the 2007-08 academic year.⁶⁵ By contrast, the National Athletic Treatment, Injury and Outcomes Network captures both time-loss and non-time loss injuries.⁶⁶

In all systems, “concussion” is reported as a specific diagnosis in an injury form, online portal or athletic data management tool particular to each system.⁶⁷ However, there are no specific criteria that a case must meet to be classified as a concussion; it is up to individual athletic trainer’s discretion and the reporting guidelines in individual states or districts.⁶⁸ All four surveillance systems also report injury incidence rate as a function of athlete-exposures (AE), or 1 athlete participating in 1 game or practice.⁶⁹ To illustrate, if a league has 10 teams, each team has 20 players, and all players complete a season with 40 practices and 10 games, this would represent 10,000 AEs. If there is a reported incidence rate of 0.5 concussions per 1,000 AEs, that would indicate an average of 5 concussions occurring during that season across the entire league of 10 teams.⁷⁰

Even within sports-injury surveillance systems, there may be significant differences between reported concussion incidence rates for high school and youth athletes. Epidemiologist Zachary Kerr and colleagues compared a sample of sports-injury surveillance systems that are often used to estimate concussion incidence rates.⁷¹ Different surveillance systems report information from different sports, and the same system may change which sports are reported over time, such as the HS RIO. In particular, sports such as rugby, water polo, equestrian and figure skating may lack representation in surveillance systems due to low participation numbers or low visibility.⁷² Even commonly studied sports such as ice hockey have poor representation in national samples of high school

65. Rosenthal et al., *National High School Athlete Concussion Rates from 2005-2006 to 2011-2012*, 42 AM. J. SPORTS MED. 1710, 1711 (2014).

66. Dompier et al., *supra* note 60, at 583.

67. Zachary Y. Kerr et al., *Estimating Concussion Incidence Using Sports Injury Surveillance Systems: Complexities and Potential Pitfalls*, 35 NEUROLOGIC CLINICS 409, 419 (2017); Richard Y. Hinton, *Sports Injury Surveillance Systems*, SPORTS MED. UPDATE, 2, 4-5 (2012).

68. *Id* at 419; Nicholas J. Lombardi et al., *Accuracy of Athletic Trainer and Physician Diagnoses in Sports Medicine*, 39 ORTHOPEDICS 944, 945 (2016) (There is high concordance between concussion diagnoses from athletic trainers, and concussion diagnoses from a physician (kappa = 0.99). However, it is uncommon for athletic trainer cases to be seen by a physician, and these tend to be the most severe cases, which may inflate concordance.).

69. See Lianne Castile et al., *The Epidemiology of New Versus Recurrent Sports Concussions Among High School Athletes, 2005–2010*, 46 BRIT. J. SPORTS MED. 603, 604 (2011).

70. For further description of athlete exposures, as well as alternative methods of presenting concussion incidence, see Zachary Y. Kerr et al., *Epidemiologic measures for quantifying the incidence of concussion in National Collegiate Athletic Association sports*, 52 J. ATHLETIC TRAINING 167 (2017).

71. See Kerr et al., *supra* note 66.

72. See Kerr et al., *supra* note 66, at 415.

athletes.⁷³

Another major concern is the denominator used by individual surveillance system to determine risk. Determining absolute time of participation of athletes is often unfeasible. It is not possible for a reporter to be present at all practices and games across all sports. Thus, the assumption in calculations based on athlete-exposures is that each AE is equal to another, i.e. that Athlete X is exposed to as many risks as Athlete Y during a practice or game. But this generally assumes that everyone on the roster participates equally at every event, overlooking the reality that some athletes may play a lot while and others may not. Finally, injuries occurring during outside training such as weightlifting are often entirely discounted by sports surveillance systems.⁷⁴

3. Athlete Self-Report

Another group of studies has determined concussion incidence using self-report data from athletes. These types of studies are based on questionnaires, often including symptom and signs lists, either alone or in conjunction with interviews. Self-report data, particularly data collected post-season or anonymously, often results in significantly higher estimations of concussion incidence than demonstrated by either medical record or injury surveillance system data. For instance, in one study of youth amateur ice hockey players, concussion incidence rates were 30 times higher in retrospective self-report than official records.⁷⁵ This gap between official records and self-report data is problematic. Both of the other major methods for determining incidence are dependent on athletes reporting concussions or concussion symptoms to medical professionals; this may contribute to significantly underestimating the true incidence. On the other hand, athlete self-diagnosis may overestimate incidence. Without more objective assessment criteria, it is hard to know.

III. WHAT WE KNOW: DETAILED REVIEW OF RESEARCH ON YOUTH SPORTS CONCUSSION INCIDENCE

Based on the inclusion criteria discussed above, in this Part we review the peer-reviewed studies to date of youth sports concussion incidence. Our review suggests the following conclusions.

73. For example, in the 2016-2017 High School RIO research report, only 22 schools across the nation reported information about boys' ice hockey compared to 145 for football, 133 for boys' soccer, and 141 for boys' basketball. No schools reported information about girls' ice hockey. See National High School Sports-Related Injury Surveillance Study at 22 <http://www.ucdenver.edu/academics/colleges/PublicHealth/research/ResearchProjects/piper/projects/RIO/Documents/2016-17%20Convenience%20Sample.pdf.pdf> (accessed April 20, 2018).

74. None of the four major surveillance systems described above report injuries sustained during outside training.

75. I.J.S. Williamson & D. Goodman, *Converging Evidence for the Under-Reporting of Concussions in Youth Ice Hockey*, 40 BRIT. J. SPORTS MED. 128, 130 (2006).

1. *First*, precisely estimating the actual incidence of youth sports concussions is difficult because different research methodologies lead to markedly different conclusions. For instance, estimating the number of sports-related concussions amongst youth athletes using emergency department data likely underestimates incidence.
2. *Second*, and recognizing many caveats about methodology, it appears that across all high school sports for which data has been collected, the incidence rate of sports concussion is roughly between 0.4 to 0.5 concussions per 1,000 athlete encounters (“AEs”). Athlete encounters include both practices and games.
3. *Third*, there is great variation from sport-to-sport in concussion rates, ranging from 0 to 0.92 concussions per 1,000AEs. Sports with the consistently highest concussion rates are football, wrestling, ice hockey, soccer, and lacrosse. To illustrate, if a youth football league has 10 teams, with 25 athletes per team, playing 4 days a week for 15 weeks, that league will have 15,000 athlete exposures and should, on average, expect about 8-10 concussions for the season. A high school league of 10 teams, with more athletes and more practices per week, will have 45,000 athlete exposures and should expect between 20-40 concussions per season.
4. *Fourth*, in the past 15 years, reported concussion incidence, and associated concussion incidence rates, have approximately doubled in youth sports.
5. *Fifth*, this increase in reported concussions is likely due to improved reporting, rather than an increase in concussions.
6. *Sixth*, although the data is not robust, it is very likely the case that most concussions are not “severe” concussions. That is, post-concussion symptoms resolve on their own, within 2-3 weeks, for roughly 90% of youth athletes.
7. *Seventh*, concussion risk and severity is increased by a history of prior concussion,⁷⁶ and several studies have shown high rates of recurrent concussions in youth populations.⁷⁷
8. *Eighth*, symptom recovery is slower in youth and high school

76. See, e.g., Kevin M. Guskiewicz et al., *Cumulative Effects Associated with Recurrent Concussion in Collegiate Football Players: The NCAA Concussion Study*, 290 J. AM. MED. ASS’N 2549 (2003) (finding that players reporting a history of three or more previous concussions were three times more likely to have an incident concussion than players with no such history); Eric D. Zemper, *Two-Year Prospective Study of Relative Risk of a Second Cerebral Concussion*, 82 AM. J. PHYSICAL MED. & REHABILITATION 653 (2003) (finding the relative risk for individuals with a history of concussion to be 5.8 times greater than for individuals with no history).

77. See, e.g., Castile et al., *supra* note 65; David M. Swenson et al., *Patterns of Recurrent Injuries among US High School Athletes, 2005-2008*, 37 AM. J. SPORTS MED. 1586 (2009).

athletes than collegiate athletes.⁷⁸

9. *Ninth*, female athletes appear to experience as high as double the rate of concussions as their male athlete counterparts in comparable sports. This finding, as well as additional demographic variation in concussion incidence, remains in need of further research.
10. *Tenth*, in the past 15 years, return to play within 24 hours has significantly decreased; today, less than 1% of concussed athletes return to play within a day. This is a marked change from previous decades, when up to 50% of athletes returned to play on the same day.

We now review the evidence for each of these ten conclusions.

A. *Different Methodologies, Different Incidence Rates*

Emergency room data is often used to calculate incidence rates. According to the CDC, youth injuries represent a significant portion of all sports- and recreation-related traumatic brain injuries in the emergency department.⁷⁹ Emergency room data is often cited by legislators and used to shape policy discussions.⁸⁰ For example, a short review essay of CDC emergency room data has been cited over 2,000 times.⁸¹ Yet, emergency room data is limited in what it tells us about youth sports concussion incidence.

Although there have been prior attempts to review and meta-analyze the incidence and incidence rate of sports-related concussions, there have been significant difficulties in synthesizing an accurate picture of SRC in the United States youth athlete population. There are three primary issues: (1) there is significant variation in study methodology, with varying criteria for concussion definition; (2) different study methodologies employ different denominators, and even studies using ostensibly the same denominator may calculate incidence and incidence rate differently;⁸² and (3) incidence and incidence rate vary significantly across age, gender, sport and practice vs. competition.

For example, in one meta-analysis of youth SRC, researchers estimated a

78. Melvin Field et al., *Does Age Play a Role in Recovery from Sports-Related Concussion? A Comparison of High School and Collegiate Athletes*, 142 J. PEDIATRICS 546, 552 (2003).

79. Ctrs. for Disease Control & Prevention, *Nonfatal Traumatic Brain Injuries Related to Sports and Recreation Activities Among Persons Aged ≤ 19 Years—United States, 2001—2009*, 60 MORBIDITY & MORTALITY WKLY. REP. 1337 (2011) (5- to 18-year-olds constituted about 65% of sports and recreation related TBI cases from 2001 to 2009).

80. The CDC's HEADS UP to Youth Sports program relies on emergency room and other medically attended data in its information packets. <https://www.cdc.gov/headsup/youthsports/index.html> (last updated February 1, 2017).

81. Langlois et al., *supra* note 45 (according to Google scholar).

82. Kerr et al., *supra* note 66, at 411-413 tbl 1, 419 (incidence and incidence rate may be calculated per season, per player or per athlete exposure, amongst others).

concussion incidence rate of 0.23 concussions per 1,000 athletic exposures (AEs).⁸³ However, in the 14 sports⁸⁴ included in the studies, rates ranged from less than 0.06 concussions per 1,000 AEs in volleyball and baseball up to 4.18 per 1,000 AEs in rugby, 1.2 per 1,000 AEs in ice hockey, and 0.53 per 1,000 AEs in football.⁸⁵ To translate, a team of 20 volleyball players might expect less than 1 concussion a season, while a team of 20 hockey players would expect about 12 concussions a season. And even within sports, wide variations exist: a study of 11- to 12-year-old football players reported over 2.5 times the incidence rate of concussions as seen in high school players.⁸⁶

Even limiting by sport and age range does not eliminate variation. Another review of the literature reported incidence rates ranging from 0.47⁸⁷ – 1.03⁸⁸ concussions per 1,000 athlete exposures amongst high school football players.⁸⁹ Thus, it is unknown whether this difference is the result of actual differences in underlying concussion incidence, or simply the result of methodological differences.⁹⁰

In addition, the incidence of concussions captured by different databases and surveillance systems can lead to very different conclusions. For example, using emergency room NEISS data from 2005 to 2013, one study estimated that 1,459 concussions occurred amongst soccer players aged 14 to 17 years.⁹¹ By contrast, the same authors estimated that 604,371 concussions occurred amongst high school (aged ~14 to 17 years) soccer players during the same period when using HS RIO data.⁹² In basketball from 2005 to 2010, 68,359 concussions occurred nationally amongst 13- to 19-year-olds according to the NEISS, while 106,942 concussions occurred according to HS RIO.⁹³

83. Ted Pfister et al., *The Incidence of Concussion in Youth Sports: A Systematic Review and Meta-Analysis*, 50 BRIT. J. SPORTS MED. 292, 295 (2016).

84. American football, rugby, hockey, lacrosse, soccer, basketball, baseball, softball, wrestling, field hockey, track, taekwondo, volleyball and cheerleading.

85. Pfister et al., *supra* note 83, at 295.

86. Anthony P. Kontos et al., *Incidence of Sports-Related Concussion Among Youth Football Players Aged 8-12 Years*, 163 J. PEDIATRICS 717, 719 (2013). (the Kontos et al. study reported an incidence rate of 1.76 concussions per 1,000 AEs, contrasted with incidence rates of between 0.47 and 0.64 concussions per 1,000 AEs amongst high school athletes)

87. Luke M. Gessel et al., *Concussions Among United States High School and Collegiate Athletes*, 42 J. ATHLETIC TRAINING 495, 496 (2007).

88. Kevin M. Guskiewicz et al., *Epidemiology of Concussion in Collegiate and High School Football Players*, 28 AM. J. SPORTS MED. 643, 647 (2000).

89. Pfister et al., *supra* note 83, at 295.

90. The three high school studies drew from national or regional surveillance system data reported by athletic trainers. However, the study of 8- to 12-year-olds had members of the research team present at games and regularly contacted coaches to determine more specific athlete exposure. Kontos et al., *supra* note 77, at 718.

91. Zachary Y. Kerr et al., *Epidemiologic Comparisons of Soccer-Related Injuries Presenting to Emergency Departments and Reported within High School and Collegiate Settings*, 4 INJURY EPIDEMIOLOGY 19, July 3, 2017, at 1, 9.

92. *Id.*

93. Erica N. Fletcher et al., *Epidemiologic Comparison of Injured High School Basketball*

Interestingly, there is less discrepancy when comparing collegiate data from the NCAA Injury Surveillance Program (NCAA-ISP) with NEISS data for individuals aged 18 to 22 years.⁹⁴ The NCAA-ISP reported that approximately 8,445 concussions occurred during the time period; the NEISS reported that 5,865 concussions occurred.⁹⁵ In all cases, the national estimate from emergency room data was significantly lower than the national estimate from designated injury surveillance systems despite emergency rooms capturing a greater swath of the population.⁹⁶

B. Average Concussion Incidence Rates

For the many reasons discussed above, it is difficult to ascertain a single, accurate estimate of concussion incidence. Nevertheless, researchers have used a variety of methods to examine the incidence of youth sports concussion. We review that research below.

Incidence rates as measured by all medically attended events and fatalities: Mersine Bryan and colleagues from the Seattle Sports Concussion Research Collaborative identified sports- and recreation-related concussions (SRRCs) in youth ages 18 and younger.⁹⁷ The SRRCs were identified using the data from three national databases (MarketScan,⁹⁸ NEISS,⁹⁹ and HS RIO). From MarketScan data, which captures all SRRCs treated by health care providers, they estimated between 582,228 and 635,728 SRRCs.¹⁰⁰ Using data from the NEISS, the researchers estimated a total of 115,479 SRRCs amongst all children aged 18 and younger visiting an emergency department.¹⁰¹ Finally, from the 2012-13 HS RIO, the authors estimated 335,342 SRRCs occurred annually amongst

Athletes Reporting to Emergency Departments and the Athletic Training Setting, 49 J. ATHLETIC TRAINING 381, 381, 385–86 (2014).

94. Kerr et al., *supra* note 91, at 9.

95. *Id.*

96. *Id.*

97. Bryan et al., *supra* note 46, at 1.

98. *Id.* at 2–3 (noting that MarketScan captures information on emergency department visits, inpatient hospitalizations, and primary and subspecialty office visits and that its sample includes about 15% of the U.S. population).

99. *Id.* (explaining that this is a database operated by the U.S. Consumer Product Safety Commission).

100. *Id.* at 4. SRRCs from MarketScan were identified using ICD-9-CM codes by excluding concussions with codes for motor vehicle collisions (ICD-9-CM codes E810-E819) and falls (ICD-9-CM codes E880.×, E881.×, E882, E883.×, E884.×, E885.9, E888.×). *Id.* at 2. Further limitations included an additional 15% due to previous literature, and all concussions within 1 month of a prior visit for concussion. *Id.* at 3.

101. *Id.* at 5. SRRCs from the NEISS were identified as any visit where any sport, recreation activity or place of recreation, such as a playground, was mentioned, regardless of mechanism of injury, in conjunction with code of concussion. *Id.* at 2. The authors then weighted the absolute number of visits based on the NEISS's sampling probability to estimate a national total. *Id.* at 3.

high school athletes in nine sports.¹⁰²

The authors also attempted to determine the number of SRRCs not seen in health care settings. Using previously reported values of concussion underreporting amongst youth athletes,¹⁰³ the authors estimated a range of 511,590 to 1,240,972 SRRCs untreated by a health care provider amongst those 18 and younger.¹⁰⁴ By using these values in conjunction with database data, the authors estimated a range of 511,590 to 1,240,972 SSRCs in those 18 and younger that went untreated by health care providers.¹⁰⁵ Using their estimated values for both SRRCs that had received healthcare provider treatment and those that had not, the authors reported a total estimated incidence of between 1,093,818 to 1,876,700 SRRCs amongst those 18 and younger.¹⁰⁶ Thus in 2013, the researchers calculated an incidence rate of between 14 and 24 sports- and recreation-related concussions per 1,000 children.¹⁰⁷

National Surveillance Systems. From 1995 to 1997, there were an estimated 62,816 annual mild traumatic brain injuries (mTBI)¹⁰⁸ due to participation in ten high school sports: the nine original HS RIO sports and girls' field hockey.¹⁰⁹ These mTBIs constituted only 5.5% of time-loss injuries, those injuries leading to at least one day of missed participation from either practice or competition.¹¹⁰ By the 2005–06 academic year, an estimated 135,901 concussions occurred nationally during participation in the nine original HS RIO sports, representing 8.9% of the reported time-loss.¹¹¹ As of the 2015–16 academic year, an estimated 342,497 concussions occurred nationally, representing 24.6% of reported time-loss injuries in the nine original HS RIO sports.¹¹² In NATION,

102. *Id.* at 4.

103. Previous literature evaluating incidence of concussion amongst youth athletes has reported percentages between 22.5% and 52.7% reporting rate for high school aged athletes (14- to 18-years-old). *See, e.g.,* Michael McCrea et al., *Unreported Concussion in High School Football Players: Implications for Prevention*, 14 CLINICAL J. SPORT MED. 13, 15 (2004). Meanwhile, another study found that 55.9% of middle school female soccer players who reported concussion symptoms were never evaluated. John W. O'Kane et al., *Concussion Among Female Middle-School Soccer Players*, 168 J. AM. MED. ASS'N PEDIATRICS 258, 261 (2014).

104. Bryan et al., *supra* note 46, at 6.

105. *Id.*

106. *Id.*

107. *Id.*

108. Mild traumatic brain injuries are the wider subset of brain injuries into which concussions fall. John W. Powell & Kim D. Barber-Foss, *Traumatic Brain Injury in High School Athletes*, 10 J. AM. MED. ASS'N 958, 958 (1999).

109. *Id.* (estimating mTBIs in the nine original HS RIO sports—boys' football, boys' and girls' soccer, girls' volleyball, boys' and girls' basketball, boys' wrestling, boys' baseball, and girls' softball—and girls' field hockey).

110. *Id.*

111. Gessel et al., *supra* note 87, at 496.

112. R. DAWN COMSTOCK ET AL., COLO. SCH. PUB. HEALTH, NATIONAL HIGH SCHOOL SPORTS-RELATED INJURY SURVEILLANCE STUDY 2015-2016 SCHOOL YEAR, at 20. http://www.ucdenver.edu/academics/colleges/PublicHealth/research/ResearchProjects/piper/projects/RIO/Documents/Original%20Report_Final%202015%2016%2009%2003%2016.pdf

the other major national surveillance system of high school athletes, concussions constituted a similar proportion, 24%, of time-loss injuries during the 2011-12 through 2013-14 academic years.¹¹³ Despite representing such a high percentage of time-loss injuries, concussions were only 4.3% of total injuries.¹¹⁴ In addition, concussions did not compose a large percentage of severe injuries. For all original HS RIO sports besides boys' soccer, they represented less than 10% of severe injuries in the 2007-08 academic year.¹¹⁵

National surveillance systems also provide sport-specific information regarding concussion incidence. Consistently, football has the greatest incidence, accounting for roughly 50% of all concussions, and highest incidence rate of concussions amongst high school sports.¹¹⁶ Other sports with consistently high incidence and incidence rates include wrestling, girls' and boys' soccer, girls' and boys' lacrosse, and boys' ice hockey.¹¹⁷ Overall, boys' sports have a higher incidence and incidence rate of concussions.¹¹⁸ However, in gender-comparable sports such as soccer, basketball, crew, cross-country, swimming/diving, tennis, and softball/baseball, girls have approximately 1.6¹¹⁹ to 2¹²⁰ times the incidence rate of concussions as their male counterparts. There is no particular association between grade in school and concussion incidence, but varsity athletes sustain about half of all concussions.¹²¹

Regional Surveillance Systems. In addition to the national systems, some states and school districts administer their own injury and concussion surveillance systems. The Fairfax County Injury Database was one such surveillance system. From the 1997-98 academic year through 2007-08, it captured freshman, junior varsity and varsity teams across 12 sports at 25 large

113. Dompier et al., *supra* note 60, at 865; Kathryn L. O'Connor et al., *Epidemiology of Sport-Related Concussions in High School Athletes: National Athletic Treatment, Injury and Outcomes Network (NATION), 2011-2012 Through 2013-2014*, 52 J. ATHLETIC TRAINING 175, 177 (2017).

114. *Id.* at 86; *id.* at 177.

115. Cory J. Darrow et al., *Epidemiology of Severe Injuries Among United States High School Athletes*, 37 AM. J. SPORTS MED. 1798, 1802 (2009). Severe injuries are those leading to more than 21 days lost from sports participation. *Id.* at 1799.

116. See, e.g., Mallika Marar et al., *Epidemiology of Concussions Among United States High School Athletes in 20 Sports*, 40 AM. J. SPORTS MED. 747, 749 (2012) (finding 47.1% of concussions resulted from participation in football); Castile et al., *supra* note 69, at 605 (48.5%); William P. Meehan III et al., *High School Concussions in the 2008-2009 Academic Year: Mechanism, Symptoms, and Management*, 38 AM. J. SPORTS MED. 2405, 2406-07 (2010) (56.8%); O'Connor et al., *supra* note 112, at 177 (53.6%). However, overtime, the proportion of concussions/mild traumatic brain injury due to football have dropped, from about 63% in 1995-1997. See Powell & Barber-Foss, *supra* note 108, at 960.

117. See O'Connor et al., *supra* note 116, at 179, 181.

118. Lincoln et al., *supra* note 61, at 959.

119. O'Connor et al., *supra* note 116, at 175.

120. Marar et al., *supra* note 116, at 747; Lincoln et al., *supra* note 61, at 960.

121. Meehan et al., *supra* note 116, at 2406

Virginia public high schools.¹²² During the 2005-06 academic year, the school system's policy was changed to require one full-time and one part-time athletic trainer at all high schools.¹²³ Concussion rates in the database increased 4.2 fold from the 1997-98 to the 2007-08 academic year, from approximately 0.1 concussions per 1,000 AEs to about 0.5 concussions per 1,000 AEs.¹²⁴ In fact, there was an average increase in concussion incidence rate of 16.5% every year.¹²⁵ The sharpest increase occurred around 2005-06 when the policy change regarding athletic trainers was enacted.¹²⁶

By sport, football was highest in incidence and incidence rate over the study period – about half of all concussions were due to football, and football players sustained 0.6 concussions per 1,000 AEs.¹²⁷ Girls' soccer had the second highest incidence rate (0.35 concussions per 1,000 AEs), followed by boys' lacrosse (0.3 concussions per 1,000 AEs) and girls' lacrosse (0.2 concussions per 1,000 AEs).¹²⁸

In addition, we can use these sub-national systems to examine variation by region. For example, Washington State led the charge in enacting policy change to combat youth sports concussion with the passage of the Lystedt Law in 2009.¹²⁹ In summary, the statute requires concussion education for coaches, players and parents; immediate removal from play following a suspected concussion; and medical clearance prior to returning to play.¹³⁰ Even after the passage of the law, and a subsequent doubled incidence rate, the incidence rate in Seattle public schools was just 0.359 reported concussions per 1,000 AEs in 2010-11.¹³¹ By contrast, Fairfax County reported approximately 0.5 concussions per 1,000 AEs in 2007-08.¹³²

Studies Beyond the National Surveillance System. Currently, there are no national injury surveillance systems of youth (younger than high school) sports similar to the HS RIO or NATION.¹³³ However, there have been several studies that use certified athletic trainers or other medical professionals to determine concussion incidence within specific states, leagues or sports.

122. See, e.g., Lincoln et al., *supra* note 118, at 958, 959.

123. *Id.* at 959.

124. *Id.* at 960.

125. *Id.* at 962.

126. *Id.*

127. *Id.* at 960.

128. *Id.*

129. See WASH. REV. CODE § 28A.600.190 (2009) (“The Lystedt Law”); Kerri McGowan Lowrey & Stephanie R. Morain, *State Experiences Implementing Youth Sports Concussion Laws: Challenges, Successes, and Lessons for Evaluating Impact*, 42 J. L. MED. & ETHICS 290, 290 (2014).

130. § 28A.600.190, (2)–(4).

131. Viviana Bompadre et al., *Washington State's Lystedt Law in Concussion Documentation in Seattle Public High Schools*, 49 J. ATHLETIC TRAINING 486, 490 (2014).

132. Lincoln et al., *supra* note 61118, at 960.

133. There is one national youth football surveillance system (Youth Football Safety Study).

In the United States, the bulk of concussion incidence research has been performed on collision or contact sports. There are mixed results regarding the comparative incidence between youth (i.e. those 14 and younger) and high school athletes. As of 2012-14, there are similar incidence rates of concussion between high school and youth football in both games (2.13 per 1,000 AEs for youth and 1.61 per 1,000 AEs for high school) and practices (0.53 per 1,000 AEs for youth and 0.47 per 1,000 AEs for high school).¹³⁴ However, the risk of a youth football athlete sustaining a concussion is lower per season than a high school football athlete sustaining a concussion – in 2012 and 2013, the risks for youth were 3.53% for games and 3.13% for practices, while the risks for high schoolers were and 9.98% for games and 4.5% for practices.¹³⁵

Sport-Specific Incidence and Incidence Rates

Football. Kerr and colleagues investigated the incidence and outcome of concussions in youth and high school football during the 2012 through 2014 seasons.¹³⁶ The authors used data from the Youth Football Surveillance System (YFSS), a surveillance system for youth football players aged 5 to 14 years.¹³⁷ The YFSS included a total of 118 teams in 6 states (Arizona, Indiana, Massachusetts, Ohio, South Carolina, and West Virginia).¹³⁸ Concussions were defined and reported according to the discretion of individual athletic trainers present at all practices and games.¹³⁹ Over the course of the study's three football seasons, there were 95 youth game concussions, giving an incidence rate of 2.13 per 1,000 AEs, and 87 youth practice concussions, an incidence rate of 0.53 per 1,000 AEs.¹⁴⁰ One key limitation described by the study authors was that athletic trainers lacked familiarity with the youth population, who may have presented different types of symptoms or had poorer understanding of concussions than the athletes' older counterparts.¹⁴¹

From 2012 through 2013, Kerr and colleagues also evaluated how league rules affect injury rates in 5- to 14 year-old recreational football players, comparing leagues with age-only criteria for inclusion and leagues with age and

134. Kerr et al., *supra* note 38, at 649.

135. Thomas P. Dompier et al., *Incidence of Concussion During Practice and Games in Youth, High School, and Collegiate American Football Players*, 169 J. AM. MED. ASS'N PEDIATRICS 659, 662 (2015).

136. Kerr et al., *supra* note 38, at 647.

137. *Id.* at 649.

138. *Id.* at 647.

139. *Id.* at 661. Although no explicit definition was provided, athletic trainers were encouraged to use their state or local guidelines or the definition from the 4th Consensus Statement on Concussion in Sport. See Paul McCrory et al., *Consensus Statement on Concussion in Sport: The 4th International Conference on Concussion in Sport held in Zurich, November 2012*, 47 BRIT. J. SPORTS MED. 250, 250 (2013).

140. Kerr et al., *supra* note 38, at 649.

141. *Id.* at 651.

weight-criteria for inclusion.¹⁴² Using comparable methodology to the YFSS, they collected data from 3,167 (97.9%) players from 210 teams across 13 leagues in 6 states (Arizona, Indiana, Massachusetts, Ohio, South Carolina, and West Virginia).¹⁴³ In total, there were 141 concussions across the study—62 in age-weight leagues and 79 in age-only leagues.¹⁴⁴ Concussions were the third most common injury, representing 9.6% of the 1,475 total injuries.¹⁴⁵ Across both types of leagues, the concussion incidence rate was 1.0 per 1,000 athlete exposures, with 0.8 concussions per 1,000 AEs amongst age-weight and 1.2 concussions per 1,000 AEs amongst age-only leagues.¹⁴⁶ Across both leagues, games had an incidence rate of 2.4 concussions per 1,000 AEs and practices had an incidence rate of 0.6 concussions per 1,000 AEs.¹⁴⁷

During the 2013 recreational football season, researchers at the University of Pittsburgh Medical Center Sports Medicine Concussion Program investigated the incidence of concussions in 8- to 12-year-old football players.¹⁴⁸ They performed a prospective, observational study on 468 of 571 (82%) youth players from 18 tackle football teams in western Pennsylvania.¹⁴⁹ The authors administered concussion education material to coaches, players and parents; trained team reporters track athlete exposure; and required medical diagnosis of included concussions.¹⁵⁰ During the season, they recorded 20 concussions (90% of which were sustained in games), for an overall incidence rate of 1.76 concussions per 1,000 AEs.¹⁵¹ However, this rate varied significantly based on age – older players (11-12 years old) had about 2.5 times the rate of concussions as younger players (8-10 years old).¹⁵²

Prospective or surveillance studies evaluating youth concussion incidence are limited. Michael Stuart and colleagues from the Mayo Clinic examined injury incidence in youth football players over the course of 1 season in fall of 1997.¹⁵³ Over the course of the season, 55 injuries occurred, all diagnosed by an on-field orthopedic surgeon.¹⁵⁴ They included all concussion, dental, eye and nerve

142. Kerr et al., *supra* note 62 at 1.

143. *Id.* at 2.

144. *Id.* at 4.

145. *Id.*

146. *Id.* at 5.

147. *Id.*

148. Kontos et al., *supra* note 77, at 717.

149. *Id.* at 718.

150. *Id.*

151. *Id.* at 718–19.

152. *Id.* at 719 (11- to 12-year-olds had 2.53 concussions per 1,000 AEs while 8- to 10-year-olds reported 0.93 concussions per 1,000 AEs).

153. Michael J. Stuart et al., *Injuries in Youth Football: A Prospective Observational Cohort Analysis Among Players Aged 9 to 13 years*, 77 MAYO CLINIC PROC. 317, 317 (2002).

154. *Id.* at 318. In order for an injury to count for the study, it had to occur during the game, lead to suspension of play, and require physical attention. *Id.* at 317

injuries.¹⁵⁵ Of these, 1 was a concussion (2% of total injuries).¹⁵⁶ These injuries occurred across 915 observed children aged 9 to 13 years competing on 42 teams in the Rochester, Minnesota area.¹⁵⁷ No concussion incidence rate was reported.

Soccer: John O’Kane and colleagues evaluated concussions in girls’ youth soccer in the Puget Sound region of Washington State.¹⁵⁸ The study followed a total of 351 soccer players from 33 teams between the 2008-09 and 2011-12 seasons.¹⁵⁹ To calculate concussion incidence, the study used an online surveillance system that relied on parental reporting. Parents reported blows to their child’s head incurred during soccer, as well as weekly practice exposure.¹⁶⁰ A concussion was defined as any blow to the head leading to symptoms consistent with concussion, and the symptoms were clarified via a phone interview with the athlete within a week of reporting the injury.¹⁶¹ Interviews and case details were reviewed weekly by the research team.¹⁶²

In total there were 59 concussions: 43 players reported one concussion and eight players reported two concussions.¹⁶³ Per season, there was a 13% incidence of concussion, and an incidence rate of 1.3 concussions per 1,000 AEs.¹⁶⁴ There was no statistically significant difference between age groups or by level of play.¹⁶⁵ Rates were significantly higher in competition than practice; the concussion incidence rate in games was 22.9 times greater than in practices.¹⁶⁶

Ice Hockey: Anthony Kontos and colleagues followed a prospective cohort of 401 competition-level youth ice hockey players aged 12 to 18 years during two seasons between September 2012 and April 2014.¹⁶⁷ In total, 37 concussions were reported, with an incidence rate of 1.58 concussions per 1,000 AEs.¹⁶⁸

155. *Id.* at 317.

156. *Id.* at 318.

157. *Id.* at 317.

158. O’Kane et al., *supra* note 103, at 258.

159. *Id.* at 259.

160. *Id.* at 262.

161. *Id.* at 259 (these symptoms included “memory loss, difficulty concentrating, confusion or disorientation, dizziness, drowsiness, headache, more emotional than usual, irritability, losing consciousness, nausea, ringing in the ears, sensitivity to light or blurry vision, and sensitivity to noise”).

162. *Id.*

163. *Id.* at 260–61.

164. *Id.* at 261.

165. *Id.*

166. *Id.*

167. Anthony P. Kontos et al., *Incidence of Concussion in Youth Ice Hockey Players*, 137 PEDIATRICS, Jan. 2016, at 2. Out of the 401 participants, 397 reported demographic information. Participants were mostly boys (83.1%), grouped into 12- to 14-year-olds (40.1%) and 15- to 18-year-olds (59.9%). *Id.* at 3. Amongst these, 26.5% had sustained a prior concussion: 18.6% had 1 prior concussion, 6.3% had 2 prior concussions, 0.8% had 3 prior concussions, and 0.8% had 4 prior concussions. *Id.*

168. *Id.* at 1.

Players were taken from multiple levels and locations, including three states (Pennsylvania, Massachusetts, and Alabama) and 31 teams (11 high school, 10 midget, 7 bantam, 3 peewee).¹⁶⁹ There were four girls' teams included; they and the three peewee teams did not allow checking.¹⁷⁰ Participant exclusion criteria included history of brain surgery, moderate or severe TBI, neurologic/psychiatric disorder, and current or recent (previous 6 months) concussion.¹⁷¹ A medical professional, present at all games and practices, officially diagnosed all included concussions.¹⁷²

During the two seasons of the study, there were 11 practice concussions and 26 game concussions, with no multiple concussions.¹⁷³ The incidence rate was 2.86 times higher for games than practices.¹⁷⁴ In 14 of the concussions, the player already had a prior concussion: nine concussed players had one prior concussion and five concussed players had two or more prior concussions.¹⁷⁵ Younger players (aged 12-14 years) had a 2.4 times higher incidence rate than older players (aged 15-18 years), with 2.84 concussions per 1,000 AEs compared to 1.18 concussions per 1,000 AEs in older players.¹⁷⁶

Incidence rates as measured by non-certified team reporter: Attempts to determine concussion and injury rates in middle-school-aged children and younger have proven difficult, but trend towards lower rates amongst younger individuals. In a sample of 7- to 13-year-olds on community sports teams there was a low incidence of concussion; only 2 officially diagnosed concussions were reported across 1,659 children during a season.¹⁷⁷ In addition, under-9-year-old soccer teams suffered less concussions per season than under-11-year-old soccer teams and under-13-year-old soccer teams.¹⁷⁸

Radelet and colleagues evaluated the baseline injury rate in community-organized sports for male and female youths aged 7 to 13.¹⁷⁹ During the 1999 to 2000 season, they tracked injuries¹⁸⁰ across 1,659 children on 125 community-

169. *Id.* at 2.

170. *Id.*

171. *Id.*

172. *Id.* at 3.

173. *Id.*

174. *Id.* at 4 (2.46 concussions per 1,000 AEs for games and 1.17 concussions per 1,000 for practices).

175. *Id.* at 3-4.

176. *Id.* at 4.

177. Marirose A. Radelet et al., *Survey of the Injury Rate for Children in Community Sports*, 110 PEDIATRICS, Sept. 2002, at 1..

178. Oliver Faude et al., *Head Injuries in Children's Football—Results from Two Prospective Cohort Studies in Four European Countries*, 27 SCANDINAVIAN J. MED. & SCI. SPORTS 1986, 1988 tbl.1 (2017) (analyzing head and neck injuries in organized football in 7- to 12-year-old children in European countries).

179. Radelet et al., *supra* note 177, at 1.

180. *Id.* at 2. An injury was defined as any event that brings a player off the field, brings any staff/coaching member onto the field to check a player during game/practice or requires first aid at any time during game/practice. *Id.* An athletic exposure (AE) was defined as one game or practice,

organized baseball, softball, football, and soccer teams in the Pittsburgh area.¹⁸¹ Across all sports, there were 383 reported injuries¹⁸² during 2,092 combined practices and games.¹⁸³ Only two officially diagnosed concussions were reported—one in baseball and one in football.¹⁸⁴ However, the results of this study are constrained by poor reporting. There was only a 35% return rate of the form specifying injury type; the authors raised doubts about significant underreporting.¹⁸⁵ There were often discrepancies between direct researcher observation and the information on the returned forms.¹⁸⁶

Outside of the United States, there have also been efforts to determine sports-related concussion incidence in youth sports. During the 2012 through 2015 seasons, Oliver Faude and colleagues prospectively investigated the incidence of concussion and other injuries in youth soccer.¹⁸⁷ The sample included primarily male, under-9, under-11, and under-13 soccer teams in the Czech Republic, Germany, Switzerland and the Netherlands.¹⁸⁸ Although the contact person (usually a coach) received detailed instructions regarding reporting and injury information, no explicit definition of a concussion was given.¹⁸⁹ In many cases, only a coach and/or parent diagnosed the concussion.¹⁹⁰ During the study, there were a total of 11 documented concussions: under-9 players suffered zero concussions, under-11 players suffered five concussions, and under-13 players suffered six concussions.¹⁹¹ This included one re-injury.¹⁹² Overall incidence was low, at 0.02 concussions per 1,000 hours of exposure.¹⁹³

In New South Wales, a research team investigated the incidence of injuries in male rugby union football players, including under-13, under-15, under-18 and under-20 teams, over two years.¹⁹⁴ They reported 199 concussions and overall incidence rates of 6.9 game injury concussions per 1,000 player hours and 1.9 missed game injury concussions per 1,000 player hours.¹⁹⁵ Under-13 teams had the lowest rates of both game and missed game injuries, and these

and league guidelines had a policy of “every player plays every event.” *Id.*

181. *Id.* at 2, 5 tbl.1.

182. *Id.* at 6 tbl.2

183. *Id.* at 5 tbl.1.

184. *Id.* at 5–6.

185. *Id.* at 10.

186. *Id.*

187. Faude et al., *supra* note 178, at 1986–87.

188. *Id.* at 1987, 1991.

189. *Id.* at 1988.

190. *Id.* at 1991.

191. *Id.* at 1988 tbl.1.

192. *Id.*

193. *Id.*

194. A.S. McIntosh et al., *Head, Face and Neck Injury in Youth Rugby: Incidence and Risk Factors*, 44 BRIT. J. SPORTS MED. 188, 188–89 (2010).

195. *Id.* at 189.

rates increased through each subsequent age group.¹⁹⁶ However, in terms of concussions, rates actually peaked in the under-18 age group.¹⁹⁷ There did not seem to be a definite trend amongst the other age groups, and the under-13s did not necessarily have the lowest rate of concussions.¹⁹⁸

Athlete Self-Report. Historically, self-report has been the primary method of gauging concussion incidence, primarily in football players. How to interpret this data is unclear; given the poorly defined nature of concussion and the fact that concussion may lead to long-term impaired neurological function, self-report may not always be accurate. A 2016 survey found that 19.5% of all high school students reported sustaining a concussion during their lifetime, and a full one-third of contact sport athletes reported sustaining at least one concussion during their lifetime.¹⁹⁹

In 1977, approximately 19% of high school football players self-reported sustaining concussions during the previous athletic season.²⁰⁰ During the 1995 – 2002 period, between 15.3%²⁰¹ and 47.2%²⁰² of high school football players self-reported concussion. From 2008 through 2010, 26.3% of high school athletes reported sustaining concussions during their high school career.²⁰³ In 2013, 16.6% of respondents reported sustaining a concussion during the previous season.²⁰⁴

In another self-report study, Sarah Strand and colleagues evaluated the risk of concussion in girl soccer players aged 11 to 13 years.²⁰⁵ They compared the number of self-reported probable concussions sustained in the previous season by 195 organized soccer players with those sustained by 147 control group of non-soccer playing female youths, all from major metropolitan areas in the United States.²⁰⁶ The authors asked participants about blows to the head leading to signs or symptoms of concussions, followed up with a phone interview. Amongst the soccer group, 48% reported sustaining a probable concussion.²⁰⁷ By contrast,

196. *Id.* at 190.

197. *Id.* at 191 tbl.2.

198. *Id.*

199. Phil Veliz et al., *Prevalence of Concussion Among US Adolescents and Correlated Factors*, 318 JAMA 1180, 1180-82 (2017).

200. Susan Goodwin Gerberic et al., *Concussion Incidences and Severity in Secondary School Varsity Football Players*, 73 AM. J. PUB. HEALTH 1370, 1370-73 (1983).

201. McCrea et al., *supra* note 103, at 14 (2004).

202. Wayne Langburt et al., *Incidence of Concussion in High School Football Players of Ohio and Pennsylvania*, 16 J. CHILD NEUROLOGY 83, 83-85 (2001).

203. Johna K. Register-Mihalik et al., *Knowledge, Attitude, and Concussion-Reporting Behaviors Among High School Athletes: A Preliminary Study*, 48 J. ATHLETIC TRAINING 645, 645-53 (2013).

204. Ashley A. LaRoche et al., *Sport-Related Concussion Reporting and State Legislative Effects*, 26 CLINICAL J. SPORT MED.: OFFICIAL J. CAN. ACAD. SPORT MED. 33 (2016).

205. Sarah Strand et al., *Relative Risk for Concussions in Young Female Soccer Players*, 4 APPLIED NEUROPSYCHOL.: CHILD 58, 60 (2015).

206. *Id.*

207. *Id.*

only 23% of the control group had sustained a probable concussion, indicating about twice the risk for concussion in the soccer group.²⁰⁸

C. Variation in Incidence Rates Across Sports

Assessing concussion risk involves sport-to-sport comparisons. Across the past decade, a cluster of collision and contact sports have emerged as high risk for incidence of concussion. Football is consistently in the lead in terms of both incidence and incidence rate, across studies and years, with rates nearly doubling from 0.47²⁰⁹ to 0.92²¹⁰ per 1,000 AEs between 2005-06 and 2012-13. During the past decade, girls' soccer, girls' and boys' lacrosse, boys' ice hockey and boys' wrestling have also had high incidence rates.²¹¹ Following football, the three sports with the highest incidence rates amongst the nine original sports captured by the HS RIO (during 2011-12) were girls' soccer, with a rate of 0.73 concussions per 1,000 AEs; boys' soccer, with a rate of 0.41 concussions per 1,000 AEs; and boys' wrestling, with a rate of 0.57 concussions per 1,000 AEs.²¹² Following football, the highest three incidence rates from the expanded HS RIO (in 2008-10) were ice hockey with 0.54 concussions per 1,000 AEs; boys' lacrosse with 0.40 concussions per 1,000 AEs; and girls' lacrosse with 0.35 concussion per 1,000 AEs.²¹³ Girls' soccer followed just behind girls' lacrosse with 0.34 concussions per 1,000 AEs.²¹⁴ Finally, the three sports following football in incidence rate from 2011-12 through 2013-14 were boys' lacrosse with 0.67 per 1,000 AEs, girls' soccer with 0.61 concussions per 1,000 AEs, and wrestling with 0.58 per 1,000 AEs.²¹⁵

A study in the emergency room investigating organized team sports for 8 to 13-year-olds found that football had the highest risk of ED visit for concussion, followed by basketball, baseball, soccer and ice hockey.²¹⁶ Amongst 7 to 11-year-olds and 12 to 17-year-olds, the highest incidence rates were for ice hockey (0.10 per 1,000 participants and 0.29 per 1,000 participants respectively), football (0.08 per 1,000 participants and 0.27 per 1,000 participants), and soccer (0.01 per 1,000 participants and 0.03 per 1,000

208. *Id.*

209. Gessel et al., *supra* note 87, at 497 tbl. 1.

210. Christy L. Collins et al., *Concussion Characteristics in High School Football by Helmet Age/Recondition Status, Manufacturer, and Model: 2008-2009 through 2012-2013 Academic Years in the United States*, 44 AM. J. SPORTS MED. 1382, 1382-90 (2016).

211. Joseph A. Rosenthal et al., *National High School Athlete Concussion Rates from 2005-2006 to 2011-2012*, 42 AM. J. SPORTS MED. 1710, at 1711 tbl. 1 (2014); *see also* Marar et al., *supra* note 116, at 750 tbl.1; O'Connor et al., *supra* note 116, at 178 tbl.1.

212. Rosenthal et al., *supra* note 211, at 1711 tbl. 1.

213. Marar et al., *supra* note 116, at 750 tbl. 1 (2012).

214. *Id.*

215. O'Connor et al., *supra* note 116, at 178 tbl. 1 (2017).

216. Lisa L. Bakhos et al., *Emergency Department Visits for Concussion in Young Child Athletes*, 126 PEDIATRICS e550, e553 tbl. 2 (2010).

participants).²¹⁷ According to the CDC, amongst 5 to 18- year-olds in team sports, football contributes the most sports-related TBI²¹⁸, followed by basketball, soccer, baseball, and hockey.²¹⁹ Similar findings were reported in a study of emergency room visits due to pediatric sports-related concussion in pre-high school and high school aged athletes.²²⁰

From 2001 to 2005, within sports-related concussions in the emergency department, 38% were sustained due to organized team sports.²²¹ Although organized team sports were responsible for only a quarter of pre-high school SRC, they constituted nearly half of high school-aged SRC.²²² Breaking this down by sport, 8 to 13-year-olds had the highest risk of ED visit for concussion in football, followed by basketball, baseball, soccer and ice hockey²²³. In 14 to 19-year-olds, football exhibited the highest incidence of concussion, followed by soccer, basketball, ice hockey, and baseball.²²⁴

D. Concussion Incidence Has Risen Over Past 15 Years

Across studies and methodologies, researchers have found increases in traumatic brain injury incidence over time, including sports-related concussion. The High School RIO data found that between 2005-06 and 2011-12, the concussion incidence rate approximately doubled.²²⁵ Over the past 15 years, it appears that concussions have also increased in prevalence amongst younger athletes, although the lack of a long-running, national surveillance system makes it difficult to fully support conclusions for these cohorts.

One study using NEISS data reported a 1,595% increase in the incidence rate of concussions and other head injuries from 1990 to 2014.²²⁶ In another study drawing from the same databank, researchers calculated incidence rates for 4 to 13-year-old athletes from 2002 through 2012 in nine sports (basketball, baseball, football, gymnastics, hockey, lacrosse, soccer, softball, and wrestling).²²⁷ Concussion cases in football and gymnastics increased by approximately six-

217. *Id.*

218. For further discussion of the use of sports-related TBI versus sports-related concussion, see *supra* Section II.C.

219. *Concussion in Youth Sports*, CTRS. FOR DISEASE CONTROL & PREVENTION 1 (2011).

220. Bakhos et al., *supra* note 216, at e553 tbl. 2.

221. *Id.* (organized team sports include the five primary concussion-generating sports of football, ice hockey, soccer, basketball and baseball).

222. *Id.* at e552, fig 1.

223. *Id.* at e553, tbl 2.

224. *Id.*

225. Rosenthal et al., *supra* note 211, at 1710-15.

226. Nicholas A. Smith et al., *Soccer-Related Injuries Treated in Emergency Departments: 1990–2014*, 138 PEDIATRICS 346, 349 (2016).

227. Buzas et al., *supra* note 51, at 1-2. Football contributed the largest percentage (41%), followed by basketball (20%) and soccer (17%). Overall, concussions were primarily due to older athletes (mean age 11.1 years, median age 12 years), with the 4 to 7 age group contributing only 6% of total cases.

fold; baseball and softball by approximately three-fold; wrestling by approximately four-fold; soccer and hockey by approximately five and a half-fold; basketball by two-thirds-fold; and lacrosse by thirty-fold.²²⁸ By 2012, about 11,000 football concussions occurred in athletes aged 5 to 13- years-old.²²⁹

Scholars have observed similar trends in emergency room concussion incidence amongst pre-high school and high school individuals.²³⁰ From 2001 to 2005, approximately 253,000 sports-related concussions (~50% of total concussions) occurred in children aged 8 to 19 year old, of which 40% were sustained by 8 to 13-year-olds.²³¹ Despite decreases in participation rates during the study period, 8 to 13-year-olds experienced increased concussion incidence.²³²

Other research has reported similar increases in sports-related TBI emergency department visits between 2006 and 2011.²³³ The greatest increases in incidence occurred in middle school aged children (94.9%) and children under 12-years-old (71.7%).²³⁴ Another found that the rate of concussions in organized team sports has increased over time in both 8 to 13-year-olds and 14 to 19-year-olds; however, 14 to 19-year-olds have experienced a much more drastic increase in organized team sports related concussions.²³⁵

E. Increase in Reported Concussions Most Likely Due to Changes in Reporting Practice

Does the increase in the number of reported youth sports concussions mean that these sports are getting more dangerous, or simply that we are simply better at identifying injuries that previously would have been unreported? There is good reason to think that the uptick in incidence is the result of better monitoring and reporting.

Two self-report studies, published about a decade apart, provide a clear demonstration of how changes in concussion reporting may drive the rising

228. *Id.* at 6, tbl. 10

229. Nathan A. Jacobson et al., *Concussions from Youth Football: Results from NEISS Hospitals over an 11-year Time Frame, 2002-2012*, 1 ORTHOPAEDIC J. SPORTS MED 7, 3 Fig. 1 (2013).

230. Lisa L. Bakhos et al. *Emergency Department Visits for Concussion in Young Child Athletes*, 126 PEDIATRICS 550 (2010) (augmenting NEISS from 1997 to 2007 with data from the NEISS All Injury Program from 2001 to 2005).

231. *Id.* at 552, fig. 1.

232. *Id.* at 554. Within these sports-related concussions, a quarter of pre-high school SRC were due to organized team sports (e.g. football, basketball, baseball, ice hockey and soccer). Thus, nationally between 2001 and 2005, an estimated 4 in 1,000 8 to 13-year-olds sustained an ED-treated sports-related concussion (denominator from U.S. Census population estimate).

233. *Id.* at 551 (cases with a primary diagnosis of TBI were included, identified using the CDC recommended International Classification of Diseases, 9th Edition (ICD-9) codes of 800.0-801.9, 803.0-804.9, 850.0-854.18; specified sports-related with E-codes of 917.0 and 917.5).

234. *Id.*

235. Bakhos et al., *supra* note 230 at 554.

incidence rates. From 1997 to 2002, neuropsychologist and current head of the American Academy of Clinical Neuropsychology Michael McCrea and a research team investigated the frequency of unreported concussions in high school football players.²³⁶ They used a survey that included a specific description of a concussion.²³⁷ Using self-report data from Milwaukee, Wisconsin area high schools, the study found that only 47.3% of male varsity football players who sustained a concussion actually reported it.²³⁸

A 2016 modified replication of the McCrea et al. study evaluated how the Wisconsin high school sports-related concussion law affected concussion incidence rates.²³⁹ Although distributed to athletes from six sports across high school and college in Wisconsin, most respondents were football players, so the authors specifically compared the 2013 high school football players with the original sample. Similar proportions of high school football players in 2013 and 1997-2002 reported a prior concussion (31.1% versus 29.9% respectively) and a concussion in the previous season (16.6% versus 15.3% respectively).²⁴⁰ However, during 2013, there was significantly better reporting than in 1999-2002 – 70.6% of high school football players self-reporting a concussion in 2013 also reported that concussion to another individual, versus only 47.3% in 1999-2002.²⁴¹ A study of collegiate athletes also supported this trend: 54% of those who began college prior to 2001 reported failing to disclose a concussion, while only 17% of those beginning college in 2001 and after reported failing to disclose a concussion.²⁴²

Of course, reporting practices may not be improved across all sports or regions in the United States. To illustrate, consider a study of concussion knowledge and reporting behavior in high school athletes.²⁴³ From 2008 to 2010, the researchers administered a self-report survey to 1,669 varsity athletes at 28 high schools in nine states, and received 167 fully complete surveys. They were specifically probed about concussion and “bell ringer” events they recalled during high school competitions and practices, whether or not they reported those events, and knowledge of symptoms of concussion.²⁴⁴ In total, 44 athletes

236. McCrea et al., *supra* note 103.

237. *Id.* at 14 (“A concussion is a blow to the head followed by a variety of symptoms that may include any of the following: headache, dizziness, loss of balance, blurred vision, ‘seeing stars,’ feeling in a fog or slowed down, memory problems, poor concentration, nausea, or throwing up. Getting ‘knocked out’ or being unconscious does *not* always occur with a concussion.”).

238. *Id.* at 14-15.

239. LaRoche et al., *supra* note 204.

240. *Id.* at 37.

241. *Id.*

242. Zachary Y. Kerr et al., *Motivations Associated with Nondisclosure of Self-Reported Concussions in Former Collegiate Athletes*, 44 AM. J. SPORTS MED. 220, 223 (2015).

243. Register-Mihalik et al., *supra* note 203.

244. University of Pittsburgh Medical Center, ‘Bell Ringers’ Or ‘Dings’ in Young Athletes Are Serious Events That Require Removal From the Game, SCIENCE NEWS (Jan. 21, 2004), <https://www.sciencedaily.com/releases/2004/01/040121082919.htm>. A bell ringer event is a Grade

(26.3%) reported at least one previous concussion event during their high school career and 81 athletes (48.5%) reported a history of at least one previous bell ringer/ding event during their high school career.²⁴⁵ There were 84 self-reported concussions, of which 48.8% were reported to a trainer or coach; by contrast, only 12.3% of bell-ringer events were reported.²⁴⁶ In addition, almost 40% of athletes reported continuing participation while symptomatic.²⁴⁷ These numbers for failure to report are more similar to 1997-2002 than to 2013.²⁴⁸

F. Most Concussion Symptoms Resolve Within Three Weeks

Concussions are scary. But as UCLA neurologist and concussion specialist Chris Giza reminds us, although brain injury may be common, “Mother Nature designed us, for the most part, to recover from these kinds of injuries.”²⁴⁹

Data from a number of studies confirms this observation. Studies using emergency department data found that 96.5% cases were mild, and only 3.7% of all sports-related TBI cases led to hospital admission.²⁵⁰ In addition, although concussions represent more than 20% of specific injuries reported to public high school athletic trainers, the rate of concussions with long-lasting symptoms remains low.²⁵¹ From the NCAA ISS, there is an incidence rate of about 0.058 severe concussions per 1,000 athlete encounters.²⁵² In addition, mild traumatic brain injury due to sports or recreation is rarely fatal.²⁵³

Symptoms such as headache, dizziness and nausea are common.²⁵⁴ Amongst both male and female athletes in high school athletes the most common symptoms are headache (94.2²⁵⁵ – 94.7%²⁵⁶), followed by dizziness (74.8²⁵⁷ –

1 event on the American Academy of Neurology scale, indicating transient confusion that resolves within 15 minutes.

245. Register-Mihalik et al., *supra* note 203, at 647.

246. *Id.* at 649.

247. *Id.*

248. It is worth noting that here that the response rate was much poorer (10%) than both the McCrea (2004) study (92.3%) and the LaRoche (2016) study (60.4%).

249. Scott Hensley, *Poll: Nearly 1 in 4 Americans Reports Having Had a Concussion*, NPR (May 31, 2016), <http://www.npr.org/sections/health-shots/2016/05/31/479750268/poll-nearly-1-in-4-americans-report-having-had-a-concussion/>.

250. Haring et al., *Trends in Incidence and Severity of Sports-Related Traumatic Brain Injury (TBI) in the Emergency Department, 2006-2011*, 29 BRAIN INJURY 989, 990 (2015).

251. Rosenthal et al., *supra* note 211, at 1712.

252. Melissa C. Kay et al., *The Epidemiology of Severe Injuries Sustained by National Collegiate Athletic Association Student-Athletes, 2009–2010 Through 2014–2015*, 52 J. ATHLETIC TRAINING 117, 117-28 (2017).

253. David J. Thurman, *The Epidemiology of Traumatic Brain injury in Children and Youths: A Review of Research Since 1990*, 31 J. CHILD NEUROLOGY 320, 20-27 (2016).

254. Marar et al., *supra* note 116, at 3; Gessel et al., *supra* note 87, at 497.

255. Marar et al., *supra* note 116, at 3.

256. O’Connor et al., *supra* note 116, at 179.

257. *Id.*

75.6%²⁵⁸), difficulty concentrating (54.8²⁵⁹ – 61%²⁶⁰), and light sensitivity (36%²⁶¹ – 46.6%²⁶²). However, more severe symptoms of concussion, such as amnesia and loss of consciousness, are rare; amnesia (either post-traumatic or retrograde) occurs in 24.3% of cases²⁶³ and loss of consciousness occurs in less than 5% of cases (4.6%).²⁶⁴ In addition, symptoms dissipate within seven days in most (90%) of cases.²⁶⁵

Of course, just as there are differences in incidence across methods, there are also differences in symptom resolution time. From NATION, symptom resolution was usually reported within 7 days (40.5%) or between 8 and 14 days (21.7%).²⁶⁶ From the HS RIO, 27% resolved within 24 hours and 20.2% of cases resolved within one week.²⁶⁷ In addition, about 13% of concussed athletes from NATION took more than 28 days for full symptom resolution,²⁶⁸ while only about 1.5% of concussed athletes from HS RIO took more than a month to resolve.²⁶⁹

G. Previous Concussions Increase Risk

In schools sampled by the HS RIO, 13.2% of recorded concussions were recurrent (i.e. the athlete had already sustained at least one concussion).²⁷⁰ Recurrent and new concussions follow similar trends; football had the highest rates of both types, along with by girls' field hockey, boys' and girls' lacrosse, and boys' and girls' soccer.²⁷¹ Having a prior concussion is a strong risk factor for future concussions. According to a nationally representative study of high school football players in 1997-99, those with prior concussions had 6.6 times the risk for sustaining a concussion during the study period.²⁷²

Elizabeth Teel of the Matthew Gfeller Sport-Related Traumatic Brain Injury Research Center and her colleagues also found elevated risk of concussion amongst athlete with prior concussions, particularly a history of multiple concussions.²⁷³ Athletes with one

258. Marar et al., *supra* note 116, at 3.

259. *Id.*

260. O'Connor et al., *supra* note 116, at 179.

261. Marar et al., *supra* note 116, at 3.

262. O'Connor et al., *supra* note 116, at 179.

263. Meehan III et al., *supra* note 116, at 2406.

264. *Id.*

265. McCrea et al., *Incidence, Clinical Course, and Predictors of Prolonged Recovery Time Following Sport-Related Concussion in High School and College Athletes*, 19 J. INT'L NEUROPSYCHOLOGICAL SOC'Y 22, 23 (2013)

266. O'Connor et al., *supra* note 116, at 180.

267. Meehan III et al., *supra* note 116 at 2406.

268. O'Connor et al., *supra* note 116 at 180.

269. Meehan III et al., *supra* note 116, at 2406.

270. Castile et al., *supra* note 69, at 603. A different study listed the number of recurrent concussions at 2.9%. O'Connor et al., *supra* note 116, at 179.

271. *Id.*

272. Zemper, *supra* note 76, at 657.

273. Elizabeth F. Teel et al., *Predicting Recovery Patterns After Sport-Related Concussion*

previous concussion were 2.2 times as likely, and those with two or more previous concussions were 4.2 times as likely, to sustain a subsequent concussion.²⁷⁴

Across all 20 sports captured in the expanded HS RIO, 11.5% of high school athletes who sustained a concussion had already sustained a sports-related concussion.²⁷⁵ In addition, in Fairfax County, almost 20% of recurrent concussions occurred within 31 days of a previous concussion.²⁷⁶ However, in contrast to the results of the HS RIO, NATION reported recurrent concussions as representing only 2.9% of total concussions.²⁷⁷

More severe symptoms and extended resolution time appear slightly more common in recurrent concussion. Recurrent concussions also led to longer symptom resolution time; while less than 0.6% of new concussions took more than a month to resolve, 6.5% of recurrent concussion symptoms took more than a month to resolve.²⁷⁸ In addition, 13% of recurrent injuries leading to discontinuation were concussions,²⁷⁹ and 16.2% of recurrent concussions lead to medical disqualification.²⁸⁰

For example, loss of consciousness occurred in 7.7% of recurrent cases versus 4.4% of new cases in high school athletes.²⁸¹ Eleven percent of high school and collegiate football players with a history of concussion in the past year experienced loss of consciousness with a new concussion, versus 8% of those without prior concussions.²⁸² From the same study, 31% with concussions during the previous year experienced amnesia following a new concussion, versus 26% of players without that history.²⁸³ Amongst another sample of high school athletes, 25.9% of athletes with three or more previous concussions lost consciousness following a new concussion compared with 5% of athletes without prior concussions.²⁸⁴ Athletes with a history of concussion were also more likely to experience retrograde or anterograde amnesia.²⁸⁵ In addition, 7.5% of players with a recurrent concussion took more than three weeks to return to play versus 3.8% of athletes with no prior concussions.²⁸⁶

52 J. OF ATHLETIC TRAINING 288, 288-98 (2017). For full procedure and design, see Stephen W. Marshall et al., *Epidemiology of Sports-Related Concussion in Seven US High School and Collegiate Sports*, 2 INJURY EPIDEMIOLOGY 13 (2015).

274. Teel et al., *supra* note 273, at 292.

275. Marar et al., *supra* note 116, at 749.

276. Lincoln et al., *supra* note 118, at 961.

277. O'Connor et al., *supra* note 116, at 179.

278. *Id.*

279. *Id.*

280. Castile et al., *supra* note 69, at 603.

281. *Id.*

282. Guskiewicz et al., *supra* note 88, at 647.

283. *Id.*

284. Michael W. Collins et al., *Cumulative Effects of Concussion in High School Athletes*, 51 NEUROSURGERY 1175, 1178 (2002).

285. *Id.* at 1178.

286. Castile et al., *supra* note 65, at 607.

H. Symptom Recovery and Concussion Risk – An Increased Problem in Youth Athletes?

Commentators on concussions sometimes suggest that younger athletes take longer to recover than older athletes.²⁸⁷ But it remains unclear whether the neurobiology of concussion is such that younger ages are more vulnerable.²⁸⁸ Our review indicates that the reported symptoms are highly similar between younger and older adolescent athletes, with the majority reporting headaches and few reporting loss of consciousness.²⁸⁹

A recent review reported “that age may play a role in concussion risk; however, contrasting findings confer a low level of certainty for concussion risk.”²⁹⁰ For instance, from the NEISS data, players aged 12 to 17-years-old had a higher proportion of concussion or head injury than the younger age group (7.9% of total injuries versus 5.5%).²⁹¹ In addition, emergency room data shows a lower population-based TBI incidence rate amongst those under 12-years-old, in contrast to 12 to 18-year-olds.²⁹² However, from observational studies, 11 to 12-year-old youth hockey players suffered concussions at a higher rate than both high school and older club players.²⁹³ By contrast, in football, one study reported similar incidence rates across 5 to 14-year-olds, high school and even collegiate players.²⁹⁴ It seems likely that differences in rules between ages, such as allowing body-checking in older hockey age groups might account for some of these differences.²⁹⁵

I. Female Athletes Experience Higher Concussion Incidence Rate

A consistent finding across time and surveillance systems is the existence of gender differences in concussion incidence rates in gender-comparable

287. Anahad O’Connor, *Concussions May Be More Severe in Girls and Young Athletes*, N.Y. TIMES (May 10, 2012), <https://well.blogs.nytimes.com/2012/05/10/concussions-may-be-more-severe-in-girls-and-young-athletes/?ref=health&mcubz=0>.

288. Daniel W. Shrey et al., *The Pathophysiology of Concussions in Youth*, 22 PHYS. MED. REHAB. CLINICS N. AM. 577 (2011); Meeryo C. Choe et al., *A Pediatric Perspective on Concussion Pathophysiology*, 24 CURRENT OP. PEDIATRICS. 689, 690 (2012) (“The developing brain responds differently to concussion than the mature brain, and should be managed more conservatively.”). Roger Zemek et al., *Clinical Risk Score for Persistent Postconcussion Symptoms Among Children with Acute Concussion in the ED*, 315 JAMA 1014 (2016) (finding that older youth may have longer-lasting symptoms).

289. Strand et al., *supra* note 205, at 61.

290. Shameemah Abrahams et al., *Risk Factors for Sports Concussion: An Evidence-Based Systematic Review*, 48 BR J. SPORTS MED. 91, 94 (2014).

291. Smith et al., *supra* note 226, at 4.

292. Haring et al., *supra* note 247, at 992 (While under-12-year-olds suffer 0.346 TBI per 1,000 population, 12 to 18-year-olds suffer ~2.37 per 1,000 population).

293. Carolyn A. Emery et al., *Risk of Injury Associated with Body Checking Among Youth Ice Hockey Players*, 303 JAMA 2265, 2265-72 (2010).

294. Kerr et al., *supra* note 38, at 649.

295. *See, e.g.*, Emery et al, *supra* note 293.

sports.²⁹⁶ In gender-comparable high school sports (i.e. soccer, basketball, softball/baseball, track and field, and swim and dive), the reported incidence and incidence rate was higher for girls than for boys.²⁹⁷ Across these sports, they sustained concussions at between 1.56²⁹⁸ and two-times the incidence rate of their male counterparts.²⁹⁹ This may be age-linked; from the NEISS emergency room data, boys aged 7 to 11 years old had a slightly higher of concussions and head injuries than girls (6.2% versus 4.5%).³⁰⁰ However, concussions represented comparable proportions of injuries amongst girls aged 12 to 17-years-old than boys (7.3% vs 8.7% respectively).³⁰¹ There are several possible reasons for this difference, including cultural (such as differences in coach-athlete relationship and differences in reporting) and biological (such as neuroanatomical differences and poorer neck strength in female athletes).³⁰²

Studies indicate that female and male athletes both underreport concussions.³⁰³ However, male athletes may be twice as likely to not report a concussion compared to female athletes.³⁰⁴ In addition, non-concussed female athletes reported more symptoms than non-concussed males.³⁰⁵ The current state of the literature indicates there are sex differences in sports-related concussion outcomes, possibly due to biological differences. A 2017 review demonstrated that a greater proportion of female athletes remain symptomatic at 28 days and 60 days post-concussion compared to male athletes, with average recovery times

296. *Concussions and Female Athletes: The Untold Story*, THE UNIVERSITY OF MINNESOTA TUCKER CENTER FOR RESEARCH ON GIRLS & WOMEN IN SPORT (Oct. 2011), <http://www.cehd.umn.edu/tuckercenter/multimedia/concussions.html>; Tracey Covassin et al., *Sex Differences in Reported Concussion Injury Rates and Time Loss from Participation: An Update of the National Collegiate Athletic Association Injury Surveillance Program from 2004–2005 through 2008–2009*, 51 J. ATHLETIC TRAINING 189 (2016); Emily M. Brook et al., *A Heads Up on Concussions: Are There Sex-Related Differences?*, 44 THE PHYSICIAN AND SPORTS MEDICINE 20 (2016).

297. Castile et al., *supra* note 69, at 609; O'Connor et al., *supra* note 115, at 178, 181-82. For example, although boys' lacrosse and girls' lacrosse are called the same name, boys' lacrosse allows the use of checking (intentional physical contact) while girls' lacrosse does not. By contrast, gender-comparable sports like soccer, swimming/diving and softball/baseball have similar rules governing the amount of allowed physical contact, which is likely to impact concussion risk..

298. O'Connor et al., *supra* note 116, at 175-78.

299. Castile et al., *supra* note 69; Marar et al., *supra* note 116; Lincoln et al., *supra* note 118.

300. *Id.*

301. *Id.*

302. Covassin et al., *supra* note 295, at 3-4.

303. Register-Mihalik et al., *supra* note 203, at 646.

304. Covassin et al., *supra* note 295, at 3 (2017). For further discussion, see Theresa L. Miyashita et al., *Gender Differences in Concussion Reporting Among High School Athletes*, 8 SPORTS HEALTH 359, 359-63 (2016); Dana A. Brown et al., *Differences in Symptom Reporting Between Males and Females at Baseline and After a Sports-Related Concussion: A Systematic Review and Meta-analysis*, 45 SPORTS MED. 1027, 1027-40 (2015).

305. Brian L. Brooks, et al., *Absence of differences between male and female adolescents with prior sport concussion*, 29 J. HEAD TRAUMA REHABILITATION 257 (2014).

of 75 days for female athletes and 49 days for male athletes.³⁰⁶ They also reported that male and female athletes did differ in reported symptoms.³⁰⁷ In addition, female athletes may experience greater rates of cognitive impairment compared to male athletes, although findings across studies have been mixed.³⁰⁸

J. Return to Play on Same Day Has Fallen Dramatically Over Past 15 Years

There have been significant changes in return to play protocols since 1995-97, when the median return to play time from mTBI was three days and more than 80% of cases returned to play within a week.³⁰⁹ In the mid-1990's, 68% of football players reported they did not even stop play following a concussive incident.³¹⁰ By contrast, although there were differences in patterns of return to play between NATION and HS RIO, both have significantly longer return-to-play periods. Since 2008-09, return to play within 24 hours of a concussion event has been uncommon, occurring in less than 2% of athletes.³¹¹ In addition, only 10.5% of concussed athletes in the 2011-14 NATION sample returned to play in less than seven days,³¹² while about 21% of the HS RIO sample did.³¹³ Both results are also markedly different from 2005-06; from the HS RIO, about half of athletes returned to play within nine days.³¹⁴

However, this increase in return-to-play time may not hold true for all age groups. Although less than 1% of concussed high school football players returned to play within 24 hours between 2012 and 2014, 10% of youth football players (aged 5 to 14-years-old) suffering concussions returned to play within 24 hours.³¹⁵ Thus, it seems that the youngest (and potentially most vulnerable³¹⁶) athletes may be more likely to return to play the same day.

IV. DISCUSSION

In this Part we discuss the implications of the research just reviewed. We begin with suggestions for more research on: concussion measurement tools; the

306. Tracey Covassin et al., *Sex Differences in Sport-Related Concussion Long-Term Outcomes*, INT. J. PSYCHOPHYSIOLOGY, 1-2 (2017).

307. *Id.* at 2 (males are more likely to report amnesia and confusion/disorientation, while females are more likely to report drowsiness, sensitivity to light and symptoms from the somatic, migraine-cognitive fatigue and emotional clusters).

308. *Id.*

309. Powell & Barber-Foss, *supra* note 108, at 958-61.

310. Langburt et al., *supra* note 202, at 83-85.

311. O'Connor et al., *supra* note 112, at 178.

312. *Id.*

313. William P. Meehan III et al., *Assessment and Management of Sport-Related Concussions in United States High Schools*, 39 AM. J. SPORTS MED., 2304, 2304-2310 (2011) at 2308

314. Gessel et al., *supra* note 87, at 497.

³¹⁵ Kerr et. al, *supra* note 38, at 648.

315. *Id.* at 650.

316. For further discussion see *supra*, Section III.H.

health outcomes of repeated sub- concussive impact; and the relationship between concussion incidence and socioeconomic inequality. We conclude with an argument that despite the need for this (and much more) additional research, we are already at a point where we can communicate concussion risk to athletes and parents more effectively than we currently do.

A. *We Need Better Concussion Measurement Tools*

Based on our review in Part III, a primary limitation in assessing concussion incidence is a lack of consistency in defining and identifying what a concussion is. In response, a number of research teams across the world are exploring how biomarkers might be used to improve concussion definition, measurement, and care.³¹⁷ These biomarkers may be based on blood tests,³¹⁸ visual tracking,³¹⁹ auditory response,³²⁰ or various brain imaging modalities.³²¹ It is beyond the scope of this article to review that literature in detail, but we offer one illustrative example of how the integration of new technology might affect the assessment of concussion incidence.

At Mayo Clinic in Rochester, Minnesota, researchers are working with local hockey teams to change the way concussions are measured.³²² Rather than rely solely on the diagnosis of an athletic trainer, Drs. Aynsley Smith and Michael Stuart, along with many colleagues, are exploring the use of new tools such as “standardized concussion surveys, the King-Devick test, quantified electroencephalogram, and blood analysis for brain cell- specific biomarkers.”³²³ Post-concussion electroencephalogram results may show disruptions in neurofunction that last longer than behavioral symptoms and cognitive

317. Jonathan T. Finnoff et al., *Biomarkers, Genetics, and Risk Factors for Concussion*, 3 PM&R S452, S452-59 (2011).

318. Rebekah Mannix et al., *Serum biomarkers predict acute symptom burden in children after concussion: a preliminary study*, 31 J. NEUROTRAUMA 1072, 1072-75 (2014); Frederick G. Strathmann et al., *Blood-based Biomarkers for Traumatic Brain Injury: Evaluation Of Research Approaches, Available Methods and Potential Utility from the Clinician and Clinical Laboratory Perspectives*, 47 CLIN. BIOCHEM. 876, 876-88 (2014).

319. Uzma Samadani et al., *Sensitivity and specificity of an eye movement tracking-based biomarker for concussion*, 1 FUTURE MED. (2016); Jun Maruta, et al., *Visual Tracking Synchronization as a Metric for Concussion Screening*, 25 J. HEAD TRAUMA REHABIL. 293, 293-305 (2010): 293-305.

320. Nina Kraus et al., *Auditory Biological Marker of Concussion in Children*, 6 SCIENTIFIC REPORTS 1, 1-6 (2016).

321. Dave Elleberg et al., *Advances in Sport Concussion Assessment: From Behavioral to Brain Imaging Measures*, 26 J. NEUROTRAUMA 2365, 2365-82, (2009); Martha Elizabeth Shenton et al., *A review of magnetic resonance imaging and diffusion tensor imaging findings in mild traumatic brain injury*, 6 BRAIN IMAGING BEHAV. 137, 137-92 (2012).

322. Aynsley M. Smith et al., *Concussion in Ice Hockey: Current Gaps and Future Directions in an Objective Diagnosis*, 27 CLINICAL J. SPORT MED. 503 (2017).

323. *Id.* at 503.

dysfunction, which tend to dissipate within seven days post-concussion.³²⁴ Researchers also cite the utility of new biomarkers such as metabolomics (shown to differentiate concussed and non-concussed adolescent male hockey players)³²⁵ and α II-spectrin N-terminal fragment (SNTF) (detectable post-brain trauma, useful for determining return to play).³²⁶ Whether it is these technologies, or other new biomarkers, the field needs better tools to measure concussion incidence. This is all the more pressing given new concerns about sub-concussive impacts.

B. We Need to Know More About Sub-Concussive Impact

Our review in Part III focused on reported incidence of “concussion.” Yet it may also be the case that negative health outcomes result from a series of repeated sub-concussive impacts.³²⁷ Such impacts may not give rise to symptoms at the time of impact (or even for some considerable time later), but may manifest in poorer future health outcomes.³²⁸ Present surveillance methods are, by definition, incapable of ever capturing such impacts. This is because concussion, for the present, is clinically defined and assessed based on self-reported symptoms and cognitive-behavioral testing. But this may change in the future.

One researcher investigating sub-concussive impact is Dr. Thayne Munce and the Sanford Sports Science Institute. Munce led the longest-running study of youth football players using accelerometers and other measures to determine football’s impact on the brain.³²⁹ Dr. Munce measured Head Impact Exposure (HIE) using the accelerometry-based head impact telemetry (HIT) system and Sideline Response System at all practices and games.

During the study, 6,183 head impacts were measured across all participants; on average, each child had approximately 250 impacts over the season.³³⁰ In general, impacts per child per session varied greatly, with medians ranging from

324. *Id.*

325. Mark Daley et al., *Metabolomics Profiling of Concussion in Adolescent Male Hockey Players: A Novel Diagnostic Method*, 12 METABOLOMICS 185, 185-94 (2016).

326. Smith et al., *supra* note 3322, at 507 (In addition, they urge clinicians to identify these risk factors in possible concussed athletes: “(1) a history of previous concussions, (2) head contact exposures along with the frequency to known accelerations at over 80% probability, and (3) the on-ice position of forward in ice hockey.”).

327. Kausar Abbas et al., *Effects of Repetitive Sub-Concussive Brain Injury on the Functional Connectivity of Default Mode Network in High School Football Athletes*, 40 DEVELOPMENTAL NEUROPSYCHOLOGY 51, 51-56 (2015); Meghan E. Robinson et al., *The Role of Location of Subconcussive Head Impacts in fMRI Brain Activation Change*, 40 DEV. NEUROPSYCHOL. 74, 74-79 (2015).

328. Julian E. Bailes et al., *Role of Subconcussion in Repetitive Mild Traumatic Brain Injury: A Review*, 119 J. NEUROSURGERY 1235, 1235-1245 (2013).

329. Thayne A. Munce et al., *Head Impact Exposure and Neurologic Function of Youth Football Players*, 47 MED. SCI. SPORTS EXERCISE 1567 (2015).

330. *Id.* (Most occurred during practice (3,787 [61%]; n = 27), followed by games (2,037 [33%]; n = 9), and pre-game warm-ups (359 [9%]; n = 9)).

3 to 22 practice impacts and 6 to 18 game impacts.³³¹ Both linear acceleration and rotational acceleration for measured head impacts were higher in games than in than in practices.³³² In relation to the broader literature, the study's data on football players aged 11 to 13 showed lower HIE than college and high school players due to both fewer sessions and fewer hits per session.³³³ However, head impact forces, "on a hit-by-hit basis, were nearly identical to those of high school players."³³⁴

Thus far in Munce's research, football head impacts have not been associated with decreased neurological function on any measured outcomes, including ImPACT performance, oculomotor performance, and postural stability.³³⁵ In addition, there was no association between an individual athlete's HIE and any neurological deficits on the measures used.³³⁶

While the data from Munce's studies is reassuring, data from a series of larger-scale studies at Purdue University raises concerns. The Purdue team, led by Thomas Talavage, a professor of electrical and computer engineering and biomedical engineering, and Eric Nauman, a professor of mechanical engineering, has consistently found potentially harmful brain change in all athletes playing football—even when those athletes do not report a concussion.³³⁷

In a review essay synthesizing the Purdue team's work and reviewing the field, the authors argue that the "evidence now suggests that head impacts commonly occur during contact or collision sports in which symptoms may not develop and there are no outward or visible signs of neurological dysfunction."³³⁸ They argue that it is "the accumulation of multiple blows to the head, rather than a single event, that can produce neurological impairments."³³⁹ To the extent that

331. *Id.*

332. *Id.* at 1571 (Linear acceleration during practice had a mean of 25.0g and a median of 19.9g, contrasted with a mean of 26.8g and a median of 20.9g for games. For rotational acceleration, practices had a respective mean and median of 1628.6 and 1383.0 rad•s², while games had a respective mean and median of 1832.8 and 1448.5 rad•s²).

333. *Id.*

334. *Id.* at 1574.

335. Munce et al., *supra* note 330, at 1567-68; see also Thayne A. Munce et al., *Effects of Youth Football on Selected Clinical Measures of Neurologic Function: A Pilot Study*, 29 J. CHILD NEUROLOGY 1601 (2014) (It should be noted, however, that these studies were small (n < 25) and limited to a single football team each. Due to the small sample size, it is not possible to generalize incidence or incidence rates.).

336. Munce et al., *supra* note 330, at 1572.

337. Victoria N. Poole et al., *Sub-concussive Hit Characteristics Predict Deviant Brain Metabolism in Football Athletes*, 40 DEV. NEUROPSYCHOL. 12, 12-17 (2015); Meghan Robinson et al., *Proximal and Distal Effects of Subconcussive Head Impacts on fMRI Activity in Asymptomatic High School Football Players*, PROC. INTL. SOC. MAG. RESON. MED. 21 (2013),.

338. Julian E. Bailes et al., *Role of Subconcussion in Repetitive Mild Traumatic Brain Injury: A Review*, 119 J. NEUROSURGERY 1235, 1235-45 (2013).

339. *Id.* at 1242.

accumulated sub-concussive impacts are a significant, or perhaps the most important, contributor to impaired mental functioning, the focus placed on “concussion incidence” itself may be misplaced.³⁴⁰

C. We Need to Know More about the Long-Term Effects of Sports Concussions

At present, we do not have robust data on the long-term effects of sustaining a sports concussion. One foundational challenge is modeling the conceptualization of concussion. Diane Wiese-Bjornstal and colleagues have modeled the psychological response to sports concussion based on previous evidence from the sports-concussion literature.³⁴¹ In summary, the model includes pre-injury risk factors that increase vulnerability to injury, post-injury personal and situational factors that may ameliorate or heighten negative psychological outcomes, and post-injury psychological care that can improve those outcomes.³⁴² The psychological effects play an important role post-concussion, along with the biological/physiological effects. These deleterious psychological effects may be challenging to identify.³⁴³

Even if we narrow our focus to on biomedical effects, a review of the literature by McAllister and McCrea found that an impact threshold or lower boundary for “concussion” is not yet known.³⁴⁴ However, animal models have shown that “mild head impacts not typically associated with cellular injury can nonetheless cause damage when repeated several times within a short time period.”³⁴⁵ Studies investigating head-impact frequency have shown variable results across teams, sports, age groups, type of activity (e.g. practice versus game) and position. For example, although on average there were between 520 and 652 impacts per high school football player, one player sustained 2,235 impacts in a single season.³⁴⁶

Research into the short term effects of these types of head impacts have been mixed. Although concussed players showed deficiencies on cognitive tests, impact characteristics and frequency were not associated with self-reported

340. Additional research published in 2017 suggests that the brain’s default mode network may be affected by even just one year of playing youth football. *See New Studies Show Brain Impact of Youth Football*, RADIOLOGICAL ASSOCIATION OF NORTH AMERICA (Nov. 27, 2017), https://press.rsna.org/timssnet/Media/pressreleases/14_pr_target.cfm?id=1975; *see also* Heather G. Belanger et al., *Subconcussive blows to the head: a formative review of short-term clinical outcomes*, 31 J. HEAD TRAUMA REHABILITATION 159 (2016).

341. Diane M. Wiese-Bjornstal et al., *Psychology of Sport Concussions*, 4 KINESIOLOGY REVIEW 169 (2015).

342. *Id.* at 171.

343. *Id.* at 173-74

344. Thomas McAllister & Michael McCrea, *Long-Term Cognitive and Neuropsychiatric Consequences of Repetitive Concussion and Head-Impact Exposure*, 52 J. ATHLETIC TRAINING 309, 314 (2017).

345. *Id.* at 310.

346. *Id.*

symptoms, balance issues or declining performance on cognitive tests.³⁴⁷ In addition, across several publications, even the history of multiple concussions is not associated with diminished neuropsychological performance.³⁴⁸ Using imaging techniques (e.g. fMRI and DTI) in small samples, head impact exposure and sub-concussive hits are associated with lower white-matter diffusion measures.³⁴⁹

In the short term following a concussion, some individuals may show heightened symptoms of depression and anxiety, though not to clinically diagnosable levels.³⁵⁰ Links between increased risk of depression and concussion have also been seen as a long-term neuropsychiatric issue following a sports-related concussion.³⁵¹ Higher rates of suicide amongst individuals with mTBI have also been seen, although repetitive concussion in athletes as “a risk factor for suicidality . . . has been refuted.”³⁵²

Long-term effects of concussion remain unclear. While TBI has been supported as a risk factor for Alzheimer’s disease, the link is unclear and possibly non-existent amongst those who have suffered sports concussions.³⁵³ However, ex-professional football players did show an association between self-reported concussion history and diagnosed mild cognitive impairment late in life.³⁵⁴ In addition, athletes who began playing football before 12-years-old performed worse on cognitive tests, and had more symptoms of depression and apathy, independent of age, education and duration of play.³⁵⁵ Beginning football before 12-years-old more than doubled the risk of “clinically meaningful impairments in reported behavioral regulation, apathy and executive function”³⁵⁶ and more than tripled the risk of “clinically elevated depression scores.”³⁵⁷ On the other hand, a cohort study of Wisconsin men who played football in the late 1950s found no relationship between football participation and the onset of cognitive impairment or depression in later life.³⁵⁸

Taken as a whole, these studies on the effects of concussion still leave open many questions about whether a sports concussion in youth affect life outcomes in meaningful ways. More research is needed.

347. *Id.* at 311.

348. *Id.* at 312.

349. *Id.*

350. *Id.*

351. *Id.*

352. *Id.* at 310.

353. *Id.* at 313.

354. *Id.*

355. Michael L. Alosco et al., *Age of First Exposure to American Football and Long-Term Neuropsychiatric and Cognitive Outcomes*, 7 *TRANSL. PSYCHIATRY* 1, 1-3 (2017).

356. *Id.* at 3.

357. *Id.*

358. Sameer K. Deshpande, et al, *Cognition and Mental Health Later in Life*, 74 *JAMA NEUROLOGY* 909, 916-17 (2017).

D. We Need to Know More about Racial and Socioeconomic Inequality and Sports Concussion

In many social policy domains, scholars recognize the need to consider inequality along a variety of socioeconomic and cultural dimensions. Research on youth sports concussions has, with a few exceptions, failed to engage in the same critical dialogue.³⁵⁹ For instance, in 2014 the National Academy of Sciences published a 350-page report, *Sports-Related Concussions in Youth: Improving the Science, Changing the Culture*.³⁶⁰ The report was produced by the Institute of Medicine-National Research Council (IOM-NRC) Committee on Sports-Related Concussions in Youth, an esteemed group of researchers in medicine, neuroscience, public health, and other disciplines. Strikingly, the report contains no discussion of inequality (the word does not even appear in the document), and no discussion of race. This is, in part, due to the lack of data. As the NRC report recognizes, “studies of sports-related concussions in youth do not routinely include information on the race, ethnicity, or socioeconomic status of the participants.”³⁶¹

But the excuse that we do not discuss race or class in concussion policy because the data is unavailable rings hollow. It simply begs the question: why are we not actively collecting such data? Consider the state of Massachusetts, which leads the nation in terms of its legislatively mandated concussion reporting requirements for high schools.³⁶² In a well-designed publication, schools are given explicit guidance on what data to collect from each student pre-participation (Figure 3). Noticeably absent is the student’s race. On-going research might better incorporate these racial and inequality dimensions.

Imagine tackling other public policy issues for youth—such as math performance or drug abuse—without consideration of such demographic and cultural intermediaries. In those other areas, the research community would find such omissions problematic because those socioeconomic factors likely play a role in outcome determination. Do we not think it would be the same with youth sports concussions?

359. See Anthony P. Kontos et al., *Exploring Differences in Computerized Neurocognitive Concussion Testing Between African American and White Athletes*, 25 ARCHIVES CLINICAL NEUROPSYCHOL. 734 (2010); Zac Houck et al., *Socioeconomic Status and Race Outperform Concussion History and Sport Participation in Predicting Collegiate Athlete Baseline Neurocognitive Scores*, J. INT’L NEUROPSYCHOL. SOC’Y (2017).

360. Robert Graham et al., *SPORTS-RELATED CONCUSSIONS IN YOUTH: IMPROVING THE SCIENCE, CHANGING THE CULTURE* (2014).

361. *Id.* at 7-8.

362. *Head Strong: Guidance for Implementing the Massachusetts Regulations on Head Injuries and Concussions in School Athletics*, Massachusetts Dept. of Public Health (Jan. 2012), <http://www.mass.gov/eohhs/docs/dph/com-health/injury/head-injury-reg-guide-acc.pdf>.

Figure 3. Guidance from the state of Massachusetts to schools about what data to collect in the pre-participation reporting form ³⁶³

Overview:

Both the law and regulations require student athletes and their parents to provide an accurate history of head injury to the school prior to each athletic season. The Department has developed a pre-participation reporting form that may be found in the **Additional Resources** section, as well as on the Department's website. Schools may utilize this form or a "school-based equivalent" form which contains all of the same information as the Department's form, but could be part of another form or contain additional information the school wishes to collect. The following elements should be included in the school-based equivalent of the Pre-participation form:

- Instructions stating this form should be completed by student's parent(s) or legal guardian and submitted to the Athletic Director or official designated by the school, prior to the start of each season a student plans to participate in an extracurricular athletic activity.
- Student's Name, Sex, Date of Birth, Grade
- School Name and Sport(s)
- Home Address and Telephone #
- Has student ever experienced a traumatic head injury (a blow to the head)? (If yes, when?)
- Has student ever received medical attention for a head injury? (If yes, when?)
- Was student diagnosed with a concussion? (If yes, when?)
- Durations of symptoms for most recent concussion
- Parent or guardian's printed name, signature and date
- Student athlete's printed name, signature and date

What to notice in Figure 3: The state of Massachusetts requires high schools to collect a significant amount of data on each athlete treated for a sports concussion. Data on student race is not collected.

363. Id. at 20.

E. Improving Concussion Risk Communication

Over the past fifteen years, every state has passed a youth sports concussion law.³⁶⁴ While each state law looks somewhat different, a core component of virtually every law is a legislative mandate that schools and youth sports organizations provide concussion training for coaches and concussion education to athletes and parents.³⁶⁵

For example, in the state of Minnesota, these organizations are required to “make information accessible to all participating coaches, officials, and youth athletes and their parents or guardians about the nature and risks of concussions, including the effects and risks of continuing to play after receiving a concussion, and the protocols and content, consistent with current medical knowledge from the Centers for Disease Control and Prevention”³⁶⁶ All coaches and officials are required “to receive initial online training and online training at least once every three calendar years . . . consistent with the . . . Concussion in Youth Sports online training program available on the Centers for Disease Control and Prevention Web site.”³⁶⁷ Similar provisions can be found in other states.

The animating theory behind such provisions is that more and better education will lead to improved health outcomes for youth athletes. But as we argue elsewhere, the evidence may not necessarily warrant such an assumption.³⁶⁸

Here, our concern with educational materials is that they omit any direct discussion of the magnitude of concussion risks. That is, athletes and parents are told there is “a risk” and they learn about concussions, but they are not informed about the likelihood of sustaining a concussion.

To be sure, our review above suggests that making generalizable statements about concussion incidence in youth sports is very difficult. Almost all studies specifically of youth athletes rely on the discretion of individual athletic trainers or even the individuals themselves to diagnose and report concussions. Thus, there may be differences between districts and across states due to variations in concussion policy and law. Estimations in youth younger than high school age fare even worse; the one extant surveillance system for athletes younger than high school relies on athletic trainers unfamiliar with youth populations.³⁶⁹ In addition, estimations using medical records and physician diagnosed concussions may underreport concussions – the CDC estimated that 248,418 sports and recreation related TBI occurred in all individuals aged 19 and younger,³⁷⁰ while the High

364. Shen, *supra* note 34, at 8, 10-13.

365. *Id.* at 10-13.

366. MINN. STAT. § 121A.37 (2017).

367. *Id.*

368. Francis X. Shen et al., *The Unknown Public Health Outcomes of Legislatively Mandated Concussion Education* (draft) (on file with author).

369. Kerr et al., *supra* note 38, at 648-49 (2016).

370. Ctrs. for Disease Control & Prevention, *supra* note 79, at 1138.

School RIO that 187,427 concussions occurred in solely high school athletes in just nine sports.³⁷¹ In addition, providing overall incidence rates fails to account for the wide variety in actual risk: over the course of a season, a football team is likely to report far more than 10 times as many concussions as most other sports.³⁷²

On the basis of these limitations, some might argue that we need more data before we can give athletes and parents a reliable estimate. But this position overlooks the many strengths of the scientific literature. There are, as we have discussed, consistent ranges of concussion per athletic exposure; fairly consistent trends in which sports are more dangerous for the brain than others; and consistent data about the average severity of brain injury in sports. Yet none of this data is communicated to parents and athletes.

We think that should change. It is beyond the scope of this article to provide a detailed design for exactly how to communicate concussion risk. But such design is possible, and can make use of extensive literatures in fields such as medicine and public health on the effective communication of medical risk and uncertainty. Entire edited volumes and academic journals are devoted to the topic.³⁷³

Recognizing that these are simply broad guidelines, and that specific policy would need to be worked out at greater length, the following principles could guide risk communication efforts:

- Provide accurate information on health risks and health benefits of particular sports, including where appropriate available estimates of the probability of risk.
- Use information communication techniques that are informed by best practices, such as using easy to understand language and appropriate presentation of statistics.

There are also potential liability implications of the current state of risk communication. To be sure, youth athletes are told (via boilerplate legal consent forms) that there are risks involved in their athletic participation. Here, for instance, is the Pop Warner youth football consent language for parents:

“I acknowledge that I am fully aware of the potential dangers of participation in any sport and I fully understand that participation in

371. *High School RIO™: Reporting Information Online*, NATIONAL HIGH SCHOOL SPORTS-RELATED INJURY SURVEILLANCE STUDY 22 (2010), <http://www.ucdenver.edu/academics/colleges/PublicHealth/research/ResearchProjects/piper/projects/RIO/Documents/2009-10.pdf>.

372. O'Connor et al., *supra* note 116, at 177.

373. See e.g. Jonathan Crichton et al., *COMMUNICATING RISK* (2016); Regina E. Lundgren & Andrea H. McMakin, *RISK COMMUNICATION: A HANDBOOK FOR COMMUNICATING ENVIRONMENTAL, SAFETY, AND HEALTH RISKS* (2013); Baruch Fischhoff, *COMMUNICATING RISKS AND BENEFITS* (2012).

football, cheerleading and/or dance may result in SERIOUS INJURIES, PARALYSIS, PERMANENT DISABILITY AND/OR DEATH.

Furthermore, I fully acknowledge and understand that protective equipment does not prevent all participant injuries, and therefore I do hereby waive, release, absolve, indemnify, and agree to hold harmless the coaches, local, league and regional Pop Warner organization(s) . . .”³⁷⁴

If the educational materials provided to parents does not include information on the probability of the injury—and if that data exists and can be communicated—have parents really been made “fully aware of the potential dangers of participation”?

At the policy level, using evidence-based probabilistic estimates of concussion would also help to clarify our tolerance for risk. For instance, we recall here the example mentioned earlier, in Part III: assume that a youth league has 10 teams, each team has 20 players, and all players complete a season with 40 practices and 10 games. This would produce 10,000 AEs. If there is a reported incidence rate of 0.5 concussions per 1,000 AEs, that would indicate an average of 5 concussions occurring during that season across the entire league of 10 teams.

Going into the season, such a league could be given a general sense of what its concussion incidence will be. Indeed, it would not be hard to develop a simple plug-and-play formula for all stakeholders to determine (based on inputting a few parameters) what the estimated number of concussions will be for a particular sport season. The estimates would not be perfect, but they would be informative.

The extensive research literature we have reviewed has the potential to help athletes and parents become informed consumers. But to date, that potential has not been realized. Because official information sheets do not contain such information, the gaps are filled by anecdotes and media coverage. The scholarly research is left on the sidelines. Going forward, we hope that this research plays a more direct role in informing concussion education efforts.

V. CONCLUSION

This Article has examined the peer-reviewed research literature on concussion incidence rates in youth sports. Our review of over 100 studies reveals a complex, yet still informative empirical reality. On one hand, the data suggests that the vast majority of youth athletes will not sustain a concussion. Moreover, a majority of those who do experience a concussion will see their post-concussion symptoms dissipate within three weeks. At the same time, the data

374. 2018 Participant Contract and Parental Consent Form, POP WARNER LITTLE SCHOLARS, INC. (2018), <https://bsbproduction.s3.amazonaws.com/portals/21799/docs/forms/2017%20forms/2017%20standard%20player%20contract%20pwl%20inc.pdf>.

clearly shows that there are serious, non-zero risks of brain injury from playing contact sports before and during high school. These risks are elevated in collision sports, and current data collection methods likely underestimate actual incidence rates. We argue that concussion education materials should be modified to include information about these known incidence rates of injury from concussion and sub-concussive hits. The data on incidence rates remains incomplete, but it is still informative. We should not hide it from youth athletes.

APPENDIX, LITERATURE REVIEW TABLE: INCIDENCE OF YOUTH HEAD INJURIES

Study	Sport(s) & Year(s)	Head Injury Definition	Denominator	Sample population	Incidence/ Incidence Rate	Incidence (Rate) Calculation	Methodology/ Data collection	Notes
Faul et al. (2010) ³⁷⁵	Sports and recreation related activities / 2002-2006	<i>Traumatic Brain Injury (TBI)</i> : defined using ICD-9-CM E-codes Mortalities determined by ICD-10 codes	Emergency department (ED) visits, hospitalizations and fatalities; Based on U.S. census data for population	U.S. medically attended TBI cases and fatalities (all ages)	2,198 TBI ED visits; 11,880 TBI hospital discharges / 1.7 million annual TBI / 300,000 annual sports and recreation-related TBI	Incidence rate was age adjusted based on U.S. population. Reported national figures were calculated using probability weighting based on demographics and accounting for non-response.	National Hospital Discharge Survey (NHDS), the National Hospital Ambulatory Medical Care Study (NHAMCS), and the National Vital Statistics System (NVSS)	An mTBI is associated with increased risk of binge drinking (1.8×), epilepsy (11×), mortality (7, depression, Alzheimer's disease. ³⁷⁶
Bazarian et al. (2005) ³⁷⁷	Sports and recreation related activities / 1998-2000	<i>Mild Traumatic Brain Injury (mTBI)</i> : defined with mechanisms using the	Emergency department visits (n = 70,900)	U.S. ED attended cases across all ages	878 mTBI cases (estimated 1,367,101 ED visits for mTBI per year) /	Incidence per year is calculated based on the raw count of data and the assumption of 4.1 million ED	Conducted secondary analysis of ED visits in the National Hospital Ambulatory Medical Care	mTBI are primarily due to the 5 to 14 age group, (26.4% of ED-attended mTBIs in the 5 to 14 age group are due to

375. MARK FAUL, LIKANG XU, MARLENA M. WALD & V. G. CORONADO, TRAUMATIC BRAIN INJURY IN THE UNITED STATES, IN EMERGENCY DEPARTMENT VISITS, HOSPITALIZATIONS AND DEATHS 2002-2006 (2010). CITED BY 2407.

376. Jean A. Langlois, Wesley Rutland-Brown & Marlena M. Wald, *The Epidemiology and Impact of Traumatic Brain Injury: A Brief Overview*, 21 J. HEAD TRAUMA REHAB. 375, 375-78 (2006). Cited by 2063.

377. Jeffrey J. Bazarian, Jason Mcclung, Manish N. Shah, Yen Ting Cheng, William Flesher & Jess Kraus, *Mild Traumatic Brain Injury in the United States, 1998-2000*, 19 BRAIN INJURY 85, 85-91 (2005). Cited by 385.

		International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) ³⁷⁸ diagnosis and external codes			503.1 mTBI per 100,000 ED visits 32.3 sports-related mTBI in the ED per 100,000 population	visits annually. They then used the estimations to determine rates for mechanisms and specific age groups.	Survey (NHAMCS)	bicycles or sport), which has the highest percentage of mTBI resulting from sports and recreation, followed by the 15 to 24 age group
Guerrero, Thurman & Sniezek (1999) ³⁷⁹	1995-1996	TBI: ICD-9-CM diagnostic codes 800.0-801.9, 803.0-804.9, or 850.0-854.1 without admittance into the hospital or fatality in the ED; mechanism was based off E-code	Average of the 1995 and 1996 mid-year U.S. Census estimates for non-institutionalized civilians	U.S. non-institutionalized civilians presenting at select ED with TBI diagnosis between 1995 and 1996	449 counts (estimated 1,027,000 per year) / Estimated by age range- 0-14 years: 411,000 per year 15-24: 206 per year / 392 per 100,000 population per year,	Incidence was calculated based on weight of the individual cases and total amounts of ED visits in the United States (derived from the NCHS). Incidence rates were calculated using the denominator described, with further rates	Conducted secondary analysis of ED visits in the National Hospital Ambulatory Medical Care Survey (NHAMCS) by averaging the data from the from 1995 and 1996 (standard error was very high from individual year data)	The study could not provide an accurate estimate of sports and recreation-related TBI due to the lack of definitive e-codes.

378. <https://www.cdc.gov/nchs/icd/icd9.htm>; 800.0, 800.5, 801.0, 801.5, 803.0, 803.5, 804.0, 804.5 - 'skull fracture'; 850.0, 850.1, 850.5, 850.9 - 'concussion'; 854.0 - 'intracranial injury of unspecified nature'; and 959.0 - 'head injury, unspecified'

379. Janet L. Guerrero, David J. Thurman, and Joseph E. Sniezek, *Emergency Department Visits Associated with Traumatic Brain Injury: United States*, 14 BRAIN INJURY, 181, 181-186 (2000). Cited by 242.

					0-14 year: 692 per 100,000 per year 15-24: 411 per 100,000 per year	adjusted by age and gender.		
Jager et al. (2000) ³⁸⁰	1992 – 1994	<i>TBI</i> : ICD-9 E-codes diagnosed in ED; excludes out of hospital, death and out-patients <i>Concussion</i> : subset of TBI, coded by ICD-9 code 850	Mid-year 1993 population estimates from the U.S. Census Bureau	91,935 patient forms processed by the National Center for Health Care Statistics	1,141 patient forms fitting TBI definition / Estimated 1,144,807 ED visits annually for TBI 155,642 ED visits annually for concussion / Estimated annual incidence rate of 4.44 ED attended TBI per 1,000 persons and 0.6 ED attended	Incidence rate and incidence was calculated based on the mid-year 1993 U.S. population estimate, along with data from the NCHS on the mean number of annual ED visits (combined data from 3 years of study to get average).	Conducted secondary analysis of ED visits in the National Hospital Ambulatory Medical Care Survey (NHAMCS)	In the 5 to 14 age group, males suffer TBI at 2.5 times the incidence rate of females. There is a trimodal risk model – highest in children younger than 5, the very elderly, and those 15 to 24.

380. Thomas E. Jager, Harold B. Weiss, Jeffrey H. Coben, and Paul E. Pepe, *Traumatic Brain Injuries Evaluated in US Emergency Departments, 1992-1994*, 7 ACADEMIC EMERGENCY MEDICINE, 131, 131-140 (2000). Cited by 300.

					concussions per 1,000 persons			
Smith, Chounthirath & Xiang (2016) ³⁸¹	Soccer / 1990-2014	<i>Concussion:</i> using NEISS code 1267 with diagnosis of concussion or closed head injury (as coded by database)	Self-report data from the National Sporting Goods sports participation data; includes those aged 7 – 17 who had participated in soccer at least once during the study period (1990 – 2014) ³⁸²	Emergency department visits of children aged 7 – 17 in the U.S. presenting with soccer-related injuries (n = 2,995,765)	217,362 concussions and closed head injuries (7.3% of total injuries) / 1990-2008: 48.91 per 1,000 participants 2008-2014: 234.13 per 1,000 participants	Incidence rate was calculated based on the number of reported concussions during two periods (1990-2008, 2008-2014), using the denominator of sports participation data.	The study used data from the National Electronic Injury Prevention Surveillance System – All Injuries Program (NEISS-AIP) ³⁸³ to find soccer related injuries, with breakdown by specific injury type by the diagnosis codes in the NEISS-AIP.	In the 7 to 11 age range, boys had a higher proportion of concussions and head injuries than girls (6.2% versus 4.5%), while in the 12 to 17 age range girls had a higher proportion (8.7% versus 7.3%). Concussions and closed head injuries were more common in the 12-17 age group (7.9% vs. 5.5%)

381. Nicholas A. Smith, Thiphalak Chounthirath & Huiyun Xiang, *Soccer-Related Injuries Treated in Emergency Departments: 1990–2014*, PEDIATRICS (2016). Cited by 1.

382. NSGA collects self-report sports participation data from annual mail-based surveys of 30,000 preselected US households; it includes those 7 years old and older who have participated in a sport at least once during the 12-month period.

383. The United States Consumer Product Safety Commission also collects emergency department (ED) hospital records in both the U.S. and its territories via its National Electronic Injury Prevention Surveillance System (NEISS). Specifically, the NEISS collects consumer product related injury records from a national probability sample of 100 hospital ED from the U.S. ED open 24 hours with 6 or more beds. Thus, researchers have used the data from this system to collect sports-specific information, based on the product or products associated with an injury (e.g. a soccer ball, basketball hoop). Reporters at the hospital EDs are instructed to match the attending physician’s diagnosis with one of the provided NEISS diagnostic codes, one of which is “concussion”. The NEISS is augmented with the NEISS – All Injury Program that samples a subgroup of 66 of these 100 hospitals for more in-depth data collection.

Coronado et al. (2015) ³⁸⁴	Sports and recreation-related TBI ³⁸⁵ / January 1, 2001 to December 31, 2012	TBI: coded according to NEISS-AIP record with principal head injury diagnosis of either concussion or internal organ injury	U.S. census population data	Emergency department visits for sports-related injuries; all ages (n = 869,472 unweighted)	71,982 (8.3%) unweighted ED TBI cases; 3,417,370 weighted and age-adjusted ED TBI (7% of total sports and recreation-related injury ED visits) / 2001: 0.731 per 1,000 population 2012: 1.52 per 1,000 population	Incidence and incidence rate were weighted based on the inverse probability of their sampling, and age-adjusted according to the U.S. census population data. Specific incidence rates are weighted and given for 2001 and 2012.	NEISS-AIP	Majority (70%) of sports-related TBI occur in those 19 and younger
Haring et al. (2015) ³⁸⁶	Sports-related /	TBI: ICD-9 codes of 800.0-801.9, 803.0-	Population estimates were based on U.S.	Emergency department visits for 65	Total (all years)	Incidence rate was calculated based on U.S.	Nationwide Emergency Department	96.5% cases were mild, with AIS scores of 1 or 2; a

384. Victor G. Coronado, Tadesse Haileyesus, Tabitha A. Cheng, Jeneita M. Bell, Juliet Haarbauer-Krupa, Michael R. Lionbarger, Javier Flores-Herrera, Lisa C. McGuire & Julie Gilchrist, *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*, 30 J. HEAD TRAUMA REHAB. 185, 185-197 (2015). Cited by 35.

385. Collected data on 39 specific sports and recreation related activities: 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/offroad 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

386. R. Sterling Haring, Joseph K. Canner, Anthony O. Asemota, Benjamin P. George, Shalini Selvarajah, Adil H. Haider & Eric B. Schneider, *Trends in Incidence and Severity of Sports-Related Traumatic Brain Injury (TBI) in the Emergency Department, 2006–2011*, 29 BRAIN INJURY 989, 989-92 (2015). Cited by 7.

	2006-2011	804.9, 850.0-854.18; specified sports-related using mechanism E-codes of 917.0 and 917.5	Census data, which is based on 5-year age groups (e.g. 10-14, 15-19),	and under presenting with sports-related TBI cases (n = 487,221)	12-14 years: 123,124 sports-related TBI 15-18 years: 195,947 sports-related TBI / In 2011 – Under 12: 0.346 sports-related TBI per 1,000 population 12-15: 2.37 per 1,000 population 15-18: 2.372 per 1,000 population 18-24: 0.366 per 1,000	Census data which divides population counts into 5-year groups, so their reported figures do not perfectly reflect actual population counts; the authors divided counts into age ranges based on school years (e.g. middle school and high school).	Sample (NEDS) of the Healthcare Cost and Utilization Project (HCUP) of the Agency for Healthcare Research and Quality (AHRQ). Data from those over 65 were excluded because they represented less than 0.1% of cases.	higher proportion (9.5%) of severe TBI occurred in those 24 and older. For age ranges of 12 to 15 and 15 to 18, rates increased from 1.197 to 2.37 per 1,000 and 1.522 to 2.372 per 1,000 respectively from 2006 to 2011.
Buzas, Jacobsen & Morawa (2014) ³⁸⁷	Youth basketball, baseball, football, gymnastics, hockey, lacrosse, soccer,	<i>Concussion:</i> defined using search query of the specific code for sport in conjunction with head body part (location code	All NEISS eligible emergency departments (sampled: n = 100)	4,864 youth (aged 4 – 13) concussion cases [mean age: 11.1; median age: 12.0](excluded	4,864 cases with concussion diagnosis / National estimate: 117,845	National estimates determined from the count of cases, then inversely weighted based on the NEISS	NEISS	All sports increased in number of concussion cases from 2002 through 2012; football and gymnastics (~6x); baseball and softball (~3x); wrestling

387. David Buzas, Nathan A. Jacobson & Lawrence G. Morawa, *Concussions From 9 Youth Organized Sports: Results from NEISS Hospitals over an 11-Year Time Frame, 2002-2012*, ORTHOPAEDIC J. SPORTS MED. (Apr. 2014) <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC26535315/>. Cited by 6.

	softball and wrestling / January 1 st , 2002 – December 31 st , 2012	75), with a diagnosis of concussion ³⁸⁸		748 cases [13%]	[~26,000 in 2012]	probability samples. This is based on the size of the hospital and the number of hospitals of that size across the country.		(~4x); soccer and hockey (~5.5x); 2.6x for basketball, 30x for lacrosse
Jacobson, Buzas & Morawa (2013) ³⁸⁹	Youth football / January 1 st , 2002 – December 31 st , 2012	<i>Concussion</i> : defined using search query of all football-related head injuries (football product code 1211) with head body part (location code 75), with a diagnosis of concussion ³⁹⁰	All NEISS eligible emergency departments (sampled: n = 100)	2,208 football players with concussion diagnosis (aged 5 – 13 years, mean age = 11.2 years) [excluded 374 cases]	Estimated 49,185 national concussions over the 11 year time frame (1,784 in 2002; 10,797 in 2012)	National estimates determined from the count of cases, then inversely weighted based on the NEISS probability samples. This is based on the size of the hospital and the number	NEISS	Greater increase in incidence in the year 2008 to 2009 than in the other years of the study. Most (91.7%) were examined then released.

388. Excluded on the basis of narratives for each case: “those that mentioned ‘play with [a sibling/family member],’ ‘play at home,’ ‘gym class,’ ‘PE [physical education]’ or ‘pick-up game’”; described “bystanders who were injured in the stands or individuals who were injured while helping at practice”; “where the injury occurred from another event and the individual was only identified as a football player”; and “all cases that had a location other than school, place of recreation or sports, or was not recorded” from id. At 2.

389. Nathan A. Jacobson, David Buzas & Lawrence G. Morawa, *Concussions from Youth Football: Results from NEISS Hospitals over an 11-year Time Frame, 2002-2012*, 1 ORTHOPAEDIC J. SPORTS MED. (Dec. 2013) <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC455515/>.

390. Excluded on the basis of narratives for each case: “those that mentioned ‘play with [a sibling/family member],’ ‘play at home,’ ‘gym class,’ ‘PE [physical education]’ or ‘pick-up game’”; described “bystanders who were injured in the stands or individuals who were injured while helping at practice”; “where the injury occurred from another event and the individual was only identified as a football player”; and “all cases that had a location other than school, place

						of hospitals of that size across the country.		
CDC (2011) ³⁹¹	Organized and unorganized sports and recreation activities ³⁹² / 2001-2009	TBI: coded according to NEISS-AIP record with principal head injury diagnosis of either concussion or internal organ injury	U.S Census data from 2001 to 2009, age 19 and younger	453,655 ED sports and recreation-related cases of patients age 19 and younger	36,320 ED visits for sports and recreation-related TBIs over study period / Estimated annual incidence 2001: 153,375 2009: 248,418 / Estimated annual incidence rate	Incidence rates were calculated based on the U.S. Census data during the study period from 2001 to 2009, using the weighted incidence from author's calculations based on weighting samples based on inverse probability of selecting the case.	NEISS-AIP	There was a 62% increase in annual estimated sports/recreation-related TBI incidence from 2001 to 2009

of recreation or sports, or was not recorded” from id. At 2.

391. Ctrs. for Disease Control & Prevention, *Nonfatal Traumatic Brain Injuries Related to Sports and Recreation Activities Among Persons Aged ≤ 19 Years—United States, 2001—2009*, 60 MMWR: MORBIDITY & MORTALITY WKLY. REP. 1337, 1337-42 (2011). Cited by 210.

392. Bicycling, football, playground, basketball, soccer, baseball, all-terrain vehicle riding, skateboarding, swimming, hockey (ice, field, roller, street), miscellaneous ball games (lacrosse, rugby, handball, tetherball), horseback riding, moped/dirt bike riding (two-wheeled, powered, off-road vehicles, dune buggies), scooter riding, gymnastics (cheerleading, gymnastics), combative sports (boxing, wrestling, martial arts, fencing), golf (including relating to golf carts), softball, exercising, tobogganing/sledding, trampolining, ice skating, volleyball, amusement attractions (rides, water slides but not swimming pool slides), roller skating/unspecified skating, go-cart riding, in-line skating, track and field, racquet sports (tennis, badminton, squash), bowling, other specified (water skiing, surfing, personal watercraft, snow skiing, snowmobiling, snowboarding, camping, fishing, archery, darts, table tennis, nonpowder/BB gun, billiards).

					2001: 0.19 per 1,000 population 2009: 2.98 per 1,000 population			
CDC (2007) ³⁹³	Organized and unorganized sports and recreation activities ³⁹⁴ / 2001-2005	TBI: coded according to NEISS-AIP record with principal head injury diagnosis of either concussion or internal organ injury	U.S. Census bridged-race population estimates from 2001 to 2005, 19 and younger	347,597 sports-related ED visits for those age 19 and younger	Unweighted 21,876 sports and recreation-related TBI (19 and younger) / Youth and adolescents (5 – 18) have estimated annual incidence of 134,959 sports and recreation-related TBI	Incidence rates were calculated based on the U.S. Census data during the study period from 2001 to 2009, using the weighted incidence from author’s calculations based on weighting samples based on inverse probability of	NEISS-AIP	The 10 to 14 age group has the highest rates of sports-related TBI ED visits for males and females, followed by the 15 to 19 age group. Males had higher rates than females across all ages, but especially in the 5 to 19 age range.

393. Ctrs. for Disease Control & Prevention, *Nonfatal Traumatic Brain Injuries Related to Sports and Recreation Activities Among Persons Aged ≤ 19 Years—United States, 2001—2005*, 56 MMWR: MORBIDITY & MORTALITY WKLY. REP. 733, 733-37 (2007). Cited by 158.

394. Bicycling, football, playground, basketball, soccer, baseball, all-terrain vehicle riding, skateboarding, swimming, hockey (ice, field, roller, street), miscellaneous ball games (lacrosse, rugby, handball, tetherball), horseback riding, moped/dirt bike riding (two-wheeled, powered, off-road vehicles, dune buggies), scooter riding, gymnastics (cheerleading, gymnastics), combative sports (boxing, wrestling, martial arts, fencing), golf (including relating to golf carts), softball, exercising, tobogganing/sledding, trampolining, ice skating, volleyball, amusement attractions (rides, water slides but not swimming pool slides), roller skating/unspecified skating, go-cart riding, in-line skating, track and field, racquet sports (tennis, badminton, squash), bowling, other specified (water skiing, surfing, personal watercraft, snow skiing, snowmobiling, snowboarding, camping, fishing, archery, darts, table tennis, nonpowder/BB gun, billiards).

						selecting the case.		
Bakhos et al. (2010) ³⁹⁵	Organized [football, basketball, baseball, ice hockey and soccer] and unorganized recreation and competitive sports, both individual and team / January 1, 1997 to December 31, 2007	<i>Concussion:</i> diagnosis of concussion in the NEISS or NEISS-AIP. The authors restricted location codes to school and place of recreation or sport.	Participation data was drawn from the National Sporting Goods Association (NSGA). ³⁹⁶ Population data was taken from U.S. Census data.	All 8- to 19-year olds diagnosed with a concussion diagnosis were included in the study population	Estimated 502,000 concussions (2001-2005) / 8-13 years old: 4 per 1,000 population 14-19 years old: 6 per 1,000 population	Estimated incidence is based on the likelihood of a specific case being selected, and weighted according to participation data. The incidence rates were determined based on U.S. Census population data.	NEISS (January 1, 1997) NEISS AIP (January 1, 2001 to December 31, 2005)	8- to 13-year olds had the highest risk of ED visit for concussion in football, followed by basketball, baseball, soccer and ice hockey. In 14- to 19-year olds, football remained the highest incidence, followed by soccer, basketball, ice hockey and baseball.
Shields & Smith (2006) ³⁹⁷	Cheerleading / 1990-2002	<i>Concussion:</i> coded as concussion or closed head	The Superstudy of Sports Participation data; includes	Cheerleading-related ED visits of	77 unweighted concussion and closed head injury events	Weighted incidence calculated based on nationwide	NEISS	The authors estimated that 208,800 of 5- to 18-year olds sustained

395. Lisa L. Bakhos, Gregory R. Lockhart, Richard Myers & James G. Linakis, *Emergency Department Visits for Concussion in Young Child Athletes*, 126 PEDIATRICS e550, e550-56 (2010). Cited by 218.

396. NSGA collects self-report sports participation data from annual mail-based surveys of 30,000 preselected US households; it includes those 7 years old and older who have participated in a sport at least once during the 12-month period.

397. Brenda J. Shields & Gary A. Smith, *Cheerleading-Related Injuries to Children 5 to 18 Years of Age: United States, 1990-2002*, 117 PEDIATRICS 122, 122-29 (2006). Cited by 65.

		injury in the NEISS, with addition cheerleading specific code of 3254	those age 6 and older who self-reported cheerleading participation at least once in the past 12 months	children aged 5 to 18	/ 3,170 weighted concussions and closed head injuries	cheerleading participation from “The Superstudy of Sports Participation”		cheerleading-related injuries leading to ED visits nationwide. Those injured were mostly female (97%), and had an average age of 14.4 years.
Rosenthal et al. (2014) ³⁹⁸	High school football, boys’ and girls’ soccer, boys’ and girls’ basketball, wrestling, baseball, volleyball, and softball / 2005-2006 and 2011-2012 academic years	<i>Concussion:</i> reported according to judgment of participating certified athletic trainer (ATC); only concussions that led to participation loss were reported between 2005-2006 and 2007-2008; from 2008-2009 to 2011-2012 all concussions regardless of participation loss were reported	<i>Athlete exposure (AE):</i> 1 athlete participating in 1 game or practice (n = 11,268,426 AEs) <i>Injury:</i> had to occur during organized training or competition, require medical attention from team ATC or a physician and result in restriction of athlete’s	High school athletes (~ ages 14 – 19)	4,024 concussions over study period / 0.23 per 1,000 AEs in 2005-2006; 0.51 per 1,000 AEs in 2011-2012	Incidence rate calculated by dividing concussions per year by AEs per year (per 1,000 AEs)	High School Reporting Information Online system (HS RIO)	Overall concussion incidence rate increased from 0.23 to 0.51 per 1,000 AEs; during the 2005-2006 school year all schools changed from 2 part-time ATC to 1 full-time and 1 part-time ATC.

398. Joseph A. Rosenthal, Randi E. Foraker, Christy L. Collins & R. Dawn Comstock, *National High School Athlete Concussion Rates from 2005-2006 to 2011-2012*, 42 AM. J. SPORTS MED. 1710, 1710-15 (2014). Cited by 87.

			participation in either practice or competition for 1 or more days [after, 2007-2008, included all dental injuries, concussions, or fractures]					
Marar et al. (2012) ³⁹⁹	High school football, boys' and girls' soccer, girls' and boys' volleyball, boys' and girls' basketball, wrestling, baseball, softball, boys' ice hockey, boys' and	<i>Concussion:</i> reported according to judgment of participating ATCs; Concussions do not require participation loss to report	<i>Athlete exposure (AE):</i> 1 athlete participating in 1 competition or practice <i>Injury:</i> had to occur during organized training or competition, require medical attention from team ATC or a physician and result in	High school athletes (~ ages 14 – 19) / 7,780,064 AEs	1,936 concussions (n = 1,289 during competition) / 0.25 concussions per 1,000 AEs (0.64 game concussions per 1,000 AEs, 0.11 practice concussions per 1,000 AEs)	Incidence rate calculated by dividing total concussions by total AEs (per 1,000AEs)	HS RIO and National High School Sports-Related Injury Surveillance convenience sample	In more 20% of cases across all sports, symptoms resolved within a day, 40% within a week and 80% within a month; 11.5% of athletes sustaining concussions during study reported a prior concussion.

399. Mallika Marar, Natalie M. McIlvain, Sarah K. Fields & R. Dawn Comstock, *Epidemiology of Concussions Among United States High School Athletes in 20 Sports*, 40 AM. J. SPORTS MED. 747, 747-55 (2012). Cited by 448.

	girls' lacrosse, girls' field hockey, cheerleading, girls' and boys' track and field, boys' and girls' swim/dive, and girls' gymnastics / 2008-2009 and 2009-2010 academic years		restriction of athlete's participation in either practice or competition for 1 or more days [included all dental injuries, concussions, or fractures]					
Meehan et al. (2011) ⁴⁰⁰	High school football, boys' and girls' soccer, girls' and boys' volleyball, boys' and girls'	<i>Concussion:</i> reported according to the judgment of participating ATC; concussions do not require loss	<i>Athlete exposure (AE):</i> 1 athlete participating in 1 competition or practice [n = 1,763,241] <i>Injury:</i> had to occur during	High school athletes (~ ages 14 to 19) from 192 schools included in HS RIO and extension [only boys'	1,056 concussions (14.6% of total injuries) / Football: 0.768 per 1,000 AEs	Concussions were calculated as a percent of total injuries sustained within each of the sports, and per 1,000 AEs	HS RIO	94.4% of concussions were managed by the ATC, and 58.8% by a primary care physician. Less than 5% were seen by orthopedic physicians, nurse

400. William P. Meehan III, Pierre d'Hemecourt, Christy L. Collins & R. Dawn Comstock, *Assessment and Management of Sport-Related Concussions in United States High Schools*, 39 AM. J. SPORTS MED. 2304, 2304-10 (2011). Cited by 97.

	basketball, wrestling, baseball, softball, boys' ice hockey, boys' and girls' lacrosse, girls' field hockey, cheerleading, girls' and boys' track and field, boys' and girls' swim/dive, and girls' gymnastics / 2009-2010 academic year	of participation time to report.	organized training or competition, require medical attention from team ATC or a physician and result in restriction of athlete's participation in either practice or competition for 1 or more days [included all dental injuries, concussions, or fractures] [n = 7,257 injuries]	volleyball and girls' gymnastics had fewer than 50 schools reporting]	Boys' ice hockey: 0.619 per 1,000 AEs Boys' lacrosse: 0.466 per 1,000 AEs Girls' soccer 0.33 per 1,000 AEs			practitioners or a neurologist. 21.2% of concussions had CT testing, and 41.2% involved computerized neuropsychological testing. 54.2% returned to play within 10 days. About 5% of concussions led to medical disqualification for the season, and 0.3% to career medical disqualification.
Castile et al. (2012) ⁴⁰¹	High school football, boys' and girls' soccer,	<i>Concussion</i> : reported according to judgment of	<i>Athlete exposure</i> (AE): 1 athlete participating in	High school athletes (~14 – 19) /	2,417 concussions (2,119 new concussions,	Incidence rate calculated by dividing total	HS RIO	A player with a recurrent concussion was more likely to take more than 3

401. Lianne Castile, Christy L. Collins, Natalie M. McIlvain & R. Dawn Comstock, *The Epidemiology of New Versus Recurrent Sports Concussions Among High School Athletes, 2005–2010*, BRIT. J. SPORTS MED. 603, 603-10 (2011). Cited by 83.

	boys' and girls' basketball, wrestling, baseball, volleyball, and softball / 2005-2006 through 2009-2010 academic years	participating ATC; concussions must lead to participation loss to report until 2007-2008, after which any can be reported	1 competition or practice <i>Injury</i> : had to occur during organized training or competition, require medical attention from team ATC or a physician and result in restriction of athlete's participation in either practice or competition for 1 or more days [after 2007-2008, included all dental injuries, concussions, or fractures]	9,503,641 AEs	282 recurrent concussions) / 0.253 concussions per 1,000 AEs (0.222 new concussions per 1,000 AEs, 0.031 recurrent concussions per 1,000 AEs)	concussions by total AEs (per 100,000 AEs)		weeks to return to play (7.5% versus 3.8%) or be medically disqualified than a player with a new concussion (16.8% versus 2.9%).
Meehan, d'Hemecourt & Comstock (2010) ⁴⁰²	High school football, boys' and girls' soccer,	<i>Concussion</i> : reported according to judgment of	<i>Athlete exposure</i> (AE): 1 athlete participating in	High school athletes (~ ages 14 – 19) /	544 concussions 309 (56.8%) occurred in football, 65	Incidence reported according to sport; no	HS RIO	10.5% of recorded concussions were recurrent; 27% had resolution within 24

402. William P. Meehan III, Pierre d'Hemecourt & R. Dawn Comstock, *High School Concussions in the 2008-2009 Academic Year: Mechanism, Symptoms, and Management*, 38 AM.

	boys' and girls' basketball, wrestling, baseball, volleyball, and softball / 2008-2009 academic year	participating ATC; Concussions do not require participation loss to report	1 competition or practice <i>Injury</i> : had to occur during organized training or competition, require medical attention from team ATC or a physician and result in restriction of athlete's participation in either practice or competition for 1 or more days [included all dental injuries, concussions, or fractures]	9,503,641 AEs	(11.9%) occurred in girls' soccer, 50 (7.4%) occurred in wrestling, 38 (7%) occurred in girls' basketball, 36 (6.6%) in boys' soccer, 22 (4%) in softball, 20 (3.5%) in boys' basketball, and 6 (1.1%) in girls' volleyball	incidence rates reported		hours, 26.3% resolved between 1 to 3 days, and 20.2% between 4 to 6 days; 1.5% had symptoms longer than a month (more likely with younger, not significant); neuropsychological testing was used in 25.7% of cases
Swenson et al. (2009) ⁴⁰³	High school football, boys' and	<i>Concussion</i> : reported according to	<i>Athlete exposure</i> (AE): 1 athlete	High school athletes (~ ages 14 – 19)	Concussions composed ~12% of 1,445	No incidence reported, just percentages that	HS RIO	Athletes who suffered recurrent injuries were 3 times

J. SPORTS MED. 2405, 2405-09 (2010). Cited by 210.

403. David M. Swenson, Ellen E. Yard, Sarah K. Fields & R. Dawn Comstock. *Patterns of Recurrent Injuries Among US High School Athletes, 2005-2008*, 37 AM. J. SPORTS MED. 1586, 1586-93 (2009). Cited by 103.

	girls' soccer, boys' and girls' basketball, wrestling, baseball, volleyball / 2005-2006 through 2007-2008 academic years	judgment of participating ATC; concussions must lead to participation loss to report until 2007-2008, after which any can be reported	participating in 1 competition or practice (n = 5,627,921 AEs) <i>Injury</i> : had to occur during organized training or competition, require medical attention from team ATC or a physician and result in restriction of athlete's participation in either practice or competition for 1 or more days (n = 13,755 injuries; 89.5% new injuries and 10.5% recurrent injuries)		recurrent and ~8% of 12,310 new injuries	were calculated based on national population estimates		as likely to discontinue sport participation (2.4% versus 7%); 13% of recurrent injuries leading to discontinuation were concussions.
Darrow et al. (2009) ⁴⁰⁴	High school football, boys' and	<i>Concussion</i> : concussions reported	<i>Athlete exposure</i> (AE): 1 athlete	High school athletes (~ ages 14 – 19)	~26,803 severe concussions (6% of national	Authors calculated a national estimate	HS RIO	Concussions represented a similar percentage of both

404. Cory J. Darrow, Christy L. Collins, Ellen E. Yard & R. Dawn Comstock, *Epidemiology of Severe Injuries Among United States High School Athletes*, 37 AM. J. SPORTS MED. 1798,

	<p>girls' soccer, boys' and girls' basketball, wrestling, baseball, volleyball / 2005-2006 and 2006-2007 academic years</p>	<p>according to judgment of participating ATC</p>	<p>participating in 1 competition or practice (n = 3,550,141 AEs) <i>Injury:</i> had to occur during organized training or competition, require medical attention from team ATC or a physician and result in restriction of athlete's participation in either practice or competition for 1 or more days <i>Severe injury:</i> must lead to > 21 days lost from participation (n = 1,378)</p>		<p>estimate of 446,715 severe injuries) / Boys' soccer: 11.8% of severe injuries Girls' volleyball: 8.9% of severe injuries Girls' soccer: 7.7% of severe injuries</p>	<p>of total severe injuries, based on the weights of individual cases. From this, they calculated the percentage of severe injuries that were concussions overall and per sport.</p>		<p>girls' and boys' severe injuries (6.7% and 5.7% respectively) but boys suffered significantly more severe injuries (n = 141,362 vs. 205,353) [both national estimates over the period]</p>
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Gessel et al. (2007) ⁴⁰⁵	High school football, boys' and girls' soccer, boys' and girls' basketball, wrestling, baseball, volleyball / 2005-2006 academic year	<i>Concussion:</i> concussions reported according to judgment of participating ATC; concussions must lead to participation loss to report	<i>Athlete exposure (AE):</i> 1 athlete participating in 1 competition or practice <i>Injury:</i> had to occur during organized training or competition, require medical attention from team ATC or a physician and result in restriction of athlete's participation in either practice or competition for 1 or more days	High school athletes (~ ages 14 – 19)/ 1,730,764 AEs (1,246,499 practices and 484,286 competitions)/ 4,431 injuries	396 concussions (8.9% of total injuries) / Boys' high school football had the highest incidence and highest incidence rate (201 and 0.47 concussions per 1,000 AEs)	Incidence rate calculated by dividing concussions by AEs and national incidence and incidence rate were calculated based on the weighted probability of the event occurring compared to the national population.	HS RIO	Symptoms resolved for 50% of athletes in all sports besides girls' basketball and softball within 3 days and 50% of athletes returned to play within 9 days.
Kerr et al. (2017) ⁴⁰⁶	High and collegiate	<i>Concussion:</i> defined in the NEISS via a	NEISS Included all ED cases with code	High school athletes (aged ~14 – 19) ,	14-17 year olds <i>HS RIO:</i> 603,371	National estimates were derived from	NEISS + NEISS-AIP, HS RIO and NCAA ISS	About 3.6% of ED cases for 10 – 13 year-olds were

405. Luke M. Gessel, Sarah K. Fields, Christy L. Collins, Randall W. Dick & R. Dawn Comstock, *Concussions Among United States High School and Collegiate Athletes*, 42 J. ATHLETIC TRAINING 495, 495-503 (2007). Cited by 670.

406. Zachary Y. Kerr, Lauren A. Pierpoint, Dustin W. Currie, Erin B. Wasserman & R. Dawn Comstock, *Epidemiologic Comparisons of Soccer-Related Injuries Presenting to Emergency Departments and Reported within High School and Collegiate Settings*, 4 INJURY EPIDEMIOLOGY 19 (2017). Not yet cited.

	<p>school soccer / NEISS: January 1st, 2004 - December 31st, 2013; HS RIO: 2005-2006 through 2013 academic years; NCAA ISS: 2009-2010 through 2013 academic years</p>	<p>diagnosis code of “concussion” [based on coders and the primary physician’s diagnosis] and for HS RIO/ NCAA ISS according to the discretion of individual ATCs/ physicians/etc.</p>	<p>for soccer aged more than 2 years (captured 63,258 soccer injuries over the period) HS RIO/ NCAA ISS Athlete exposure (AE): 1 athlete participating in 1 competition or practice <i>Injury:</i> had to occur during organized training or competition, require medical attention from team ATC or a physician and result in restriction of athlete’s participation in either practice or competition for 1 or more days</p>	<p>collegiate athletes (aged ~18 – 22) and ED cases aged 14 – 22</p>	<p>concussions nationally NEISS: 1,459 concussions nationally / 18-22 year olds NCAA ISS: 8,445 concussions nationally NEISS: 5,865 concussions nationally</p>	<p>each of the datasets by calculating national estimates based off the sample weights of individual cases within the data sets. The reported figures are the total for the whole study period.</p>		<p>concussions, as well as 2.5% of 5 to 9 year-olds. About 17.9% of injuries from the HS RIO were concussions, versus 7.6% of NEISS injuries for 14 - 17-year olds (2.75 IPR). From the NCAA ISS, 5.9% of injuries are concussions, with 4.6% of NEISS cases for 18 - 22 year-olds (IPR = 1.3)</p>
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Matic et al. (2015) ⁴⁰⁷	Boys' ice hockey / 2008-2009 through 2012-2013 academic years	<i>Concussion:</i> reported according to the discretion of individual ATCs at each high school	<i>Athlete exposure (AE):</i> 1 athlete participating in 1 competition or practice (n = 311,817 AEs) <i>Injury:</i> had to occur during organized training or competition, require medical attention from team ATC or a physician and result in restriction of athlete's participation in either practice or competition for 1 or more days	High school athletes (~ ages 14 – 19)	200 concussions (27.6% of 724 total injuries) / 0.64 per 10,000 AEs	Incidence rate was calculated from raw number of concussions divided by the total number of athlete exposures	HS RIO	Concussion was the most frequent reported injury (27.6% of injuries). Competitions had higher rates of injury than practices.
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407. George T. Matic, Mark F. Sommerfeldt, Thomas M. Best, Christy L. Collins, R. Dawn Comstock & David C. Flanigan, *Ice Hockey Injuries among United States High School Athletes from 2008/2009–2012/2013*, 43 PHYS. SPORTSMED. 119, 119-25 (2015). Cited by 3.

Kerr et al. (2014) ⁴⁰⁸	High school football / 2008-2009 through 2012-2013	<i>Concussions:</i> reported according to judgment of participating ATC; concussions do not need to lead to participation loss to be reported	<i>Athlete exposure (AE):</i> 1 athlete participating in 1 competition or practice	High school athletes (aged ~14 – 19)	2012-2013: 0.92 per 1,000 AEs	Concussion incidence rate was calculated based on total reported concussions divided by the total athlete exposures.	HS RIO	The incidence and incidence rate of concussions increased from previous years.
Borowski et al. (2008) ⁴⁰⁹	High school boys' and girls' basketball / 2005-2006 and 2006-2007 academic years	<i>Concussion:</i> reported according to judgment of participating ATC; concussions must lead to participation loss to report	<i>Athlete exposure (AE):</i> 1 athlete participating in 1 competition or practice (n = 780,651 AEs) <i>Injury:</i> had to occur during organized training or competition, require medical attention from team ATC or a	High school athletes (~14 – 19) / 1,518 injuries (745 girls, 735 boys)	7% of reported injuries were concussions / Girls: 5% of practice injuries; 14% of competition injuries Boys: 3% of practice injuries; 6% of competition injuries	Concussion proportion was calculated from the data reported.	HS RIO	Girls were twice as likely to sustain a concussion than boys.

408. Zachary Y. Kerr, Christy L. Collins, Jason P. Mihalik, Stephen W. Marshall, Kevin M. Guskiewicz & R. Dawn Comstock, *Impact Locations and Concussion Outcomes in High School Football Player-to-Player Collisions*, 134 PEDIATRICS 489, 489-96 (2014).

409. Laurel A. Borowski, Ellen E. Yard, Sarah K. Fields & R. Dawn Comstock, *The Epidemiology of US High School Basketball Injuries, 2005–2007*, 36 AM. J. SPORTS MED. 2328, 2328-35 (2008). Cited by 199.

			physician and result in restriction of athlete's participation in either practice or competition for 1 or more days (n = 1,518 injuries)					
O'Connor et al. (2017) ⁴¹⁰	High school boys' football, boys' wrestling, girls' field hockey, girls' gymnastics, girls' volleyball, boys' baseball, girls' softball,	<i>Sports-related concussion:</i> reported by ATCs using their state or local guidelines; in the absence of such guidelines, the Consensus Statement on Concussion in Sport ⁴¹¹	<i>Athlete exposure (AE):</i> 1 athlete participating in 1 competition or practice	High school athletes (~ ages 14 – 19)	2,004 concussions / 0.389 per 1,000 AEs	Incidence rates were calculated based on number of sports-related concussions reported divided by total AEs	National Athletic Treatment, Injury and Outcomes Network (NATION) ⁴¹² surveillance system Draws from convenience sample of 147 total high schools across 26 states; not all schools reported for all years	2.9% (n = 59) of reported concussions were recurrent. Competition rates overall were significantly higher than practice rates (3.3 time as high). In gender-comparable sports (baseball or softball, basketball, crew, cross-country, lacrosse, soccer, swim/dive, tennis, indoor and outdoor

410. Kathryn L. O'Connor, Melissa M. Baker, Sara L. Dalton, Thomas P. Dompier, Steven P. Broglio & Zachary Y. Kerr, *Epidemiology of Sport-Related Concussions in High School Athletes: National Athletic Treatment, Injury and Outcomes Network (NATION), 2011–2012 Through 2013–2014*, 52 J. ATHLETIC TRAINING 175, 175-85 (2017). Not cited yet.

411. "A complex pathophysiological process affecting the brain, induced by biomechanical forces." from Id. At page 176.

412. http://www.datalyscenter.org/nation/_2/

<p>boys' and girls' basketball, boys' and girls' crew, boys' and girls' cross-country, boys' and girls' lacrosse, boys' and girls' soccer, boys' and girls' indoor and outdoor track and field, boys' and girls' swimming and diving, boys' and girls' tennis, boys' and girls' golf / 2011-2012 through 2013-2014 academic years</p>							<p>track/field), girls had 1.56 times the rate of boys (0.264 per 1,000 for girls and 0.169 per 1,000 for boys); Girls and boys did not differ in distribution of number of symptoms in gender comparable sports</p>
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<p>Kerr et al. (2016)⁴¹³</p>	<p>Youth and high school football / 2012 – 2014 seasons</p>	<p><i>Concussion:</i> reported according to discretion of individual ATCs; they were encouraged to use the definition from the Consensus Statement on Concussion in Sport⁴¹⁴</p>	<p><i>Athletic exposure (AE):</i> 1 athlete participating in 1 competition or practice</p>	<p>118 youth (aged 5 to 14) teams reporting 310 team seasons (1 team completing 1 season) and 96 public high school (aged ~14 – 19) programs reporting 184 team seasons. NATION draws from a convenience sample of high schools with ATCs, and does not record demographic information (size, rural vs. urban, etc.) of</p>	<p>95 youth game and 87 youth practice concussions; 357 high school game and 478 high school practice concussions / 2.13 youth game concussions per 1,000 AEs and 0.53 youth practice concussions per 1,000 AEs; 1.61 high school game concussions per 1,000 AEs; and 0.47 high school practice</p>	<p>Concussion incidence and incidence rate were calculated per study (YFSS or NATION) and by games and practices. Total concussion incidence was divided by total AE of that particular type, then multiplied by 1,000.</p>	<p>The authors used data from the Youth Football Safety Study (YFSS)⁴¹⁵ and the National Athletic Treatment, Injury and Outcome Network (NATION)⁴¹⁶. ATCs recruited by Datalys Center⁴¹⁷ attended all games and practices, and used preferred electronic applications to record injuries.</p>	<p>One key limitation described by the study authors was that ATCs lacked familiarity with the youth population, who may have presented with different types of symptoms or had poorer understanding of concussion than older athletes. Almost all players (>98%) reported headaches, and very few players (1.7% of youth, 3.6% of high school) presented with loss of consciousness.</p>
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413. Zachary Y. Kerr, Scott L. Zuckerman, Erin B. Wasserman, Tracey Covassin, Aristarque Djoko & Thomas P. Dompier, *Concussion Symptoms and Return to Play Time in Youth, High School, and College American Football Athletes*, 170 JAMA PEDIATRICS 647, 647-53 (2016). Cited by 7.

414. 4th Consensus Statement on Concussion in Sport: <http://bjsm.bmj.com/content/47/5/250>

415. <http://www.datalyscenter.org/youth-football-safety-study/>

416. http://www.datalyscenter.org/nation/_2/

417. <http://www.datalyscenter.org/>

				individual high schools.	concussions per 1,000 AEs			
Glang et al. (2015) ⁴¹⁸	High school fall sports including football, soccer, cheer/spirit, volleyball, water polo, basketball, wrestling, color guard / 2014	<i>Concussion:</i> recorded according to the discretion of ATCs, who were legally obligated by Oregon state law to have annual concussion training	Fall sport athletes	4,804 high school athletes (~ ages 14 – 19) at 24 Oregon high schools	354 concussions / 47.4 concussions per 1,000 athletes / ~5% of fall athletes sustained a concussion	Incidence rate was calculated by dividing the number of concussions by the total number of fall sport athletes.	ATCs at 24 Oregon high schools kept a concussion log, where they recorded information about the injury, symptoms, number of days until return to play, whether or not a health care professional was seen for evaluation and treatment, and classroom accommodations received	Most (n = 297, 87%) of athletes who sustained a concussion returned to play by the end of the 90-day study period.
Kerr et al. (2015) ⁴¹⁹	Boys' recreational youth football / 2012-2013	<i>Concussion:</i> "any functional neurologic disturbance resulting from head	<i>Athlete-exposures (AE):</i> 1 player participating in 1 game or	Male football players (n = 3,167; 97.9% of total players) aged 5 to 15 across 210	141 concussions / 1.0 per 1,000 AEs	Incidence rate was calculated overall by dividing the total incidence of concussion by	The study was a 2-year prospective cohort design comparing two different types of leagues, one	In age-only leagues, concussions constituted 12.9% of total injuries, while they only composed 7.2% of total

418. Ann E. Glang, Michael C. Koester, James C. Chesnutt, Gerard A. Gioia, Karen McAvoy, Sondra Marshall & Jeff M. Gau, *The Effectiveness of a Web-Based Resource in Improving Post-Concussion Management in High Schools*, 56 J. ADOLESCENT HEALTH 91, 91-97 (2015). Cited by 20.

419. Zachary Y. Kerr et al., *Injury Rates in Age-Only Versus Age-and-Weight Playing Standard Conditions in American Youth Football*, Orthopaedic J. SPORTS MED. (Sept. 23, 2015) <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4622300/>. Cited by 9.

		acceleration/ deceleration.” ⁴²⁰	practice (n = 142,536)	teams in 6 states (Arizona, Indiana, Massachusetts, Ohio, South Carolina and West Virginia)		the total amount of athlete exposures.	limited by age and weight and the other just by age. ATCs were responsible for collecting injury and exposure data.	injuries in the age and weight-limited leagues.
Bompadre et al. (2014) ⁴²¹	High school baseball, basketball, cross- country, football, gymnastics, volleyball, and wrestling / 2008-2009 to 2010-2011	<i>Concussion</i> : up to the individual discretion of the high school trainers and had to be documented through SportsWare, an extant injury surveillance system.	<i>Athlete- exposures (AE)</i> : 1 athlete participating in 1 practice or game (n = ~300,000 annual AEs)	~4,500 Seattle public high school athletes (aged 13-19 years) annually during the study period across the studied sports	2008-2009: 48 2009-2010: 114 2010-2011: 111 / 2008-2009: 0.163 per 1,000 AEs 2009-2010: 0.34 per 1,000 AEs 2010-2011: 0.359 per 1,000 AEs	Incidence rate was calculated annually based on the number of documented concussions and the total number of documented athlete exposures	Comparison of retrospective and prospective analysis of an extant injury surveillance system in Seattle area public high schools. They evaluated the incidence of concussions prior to and following the implementation of the Lystedt law. ⁴²²	Concussion accounted for about 11.5% of injuries prior to the law; post- implementation, they represented about 20% of injuries. Athletes were kept out of play for ~6 days longer post- implementation of the law compared to pre-implementation.

420. Id. at 3.

421. Viviana Bompadre, Thomas M. Jinguji, N. David Yanez, Emma K. Satchell, Kaiulani Gilbert, Monique Burton, Ernest U. Conrad III & Stanley A. Herring, *Washington State’s Lystedt Law in Concussion Documentation in Seattle Public High Schools*, 49 J. ATHLETIC TRAINING 486, 486-92 (2014). Cited by 21.

422. 3 components: “1. Education of athletes and parents or guardians about concussion. The athlete and parent or guardian must sign and return a form that provides this information. The mandatory coach’s education occurs through the Washington Interscholastic Activities Association (Renton, WA).; 2. Removal of a youth athlete from practice or play at the time of a suspected concussion or head injury.; 3. Return to practice or play only with the written permission of a licensed health care provider trained in the evaluation and management of concussion.” Id. At 487.

McKeon et al. (2013) ⁴²³	High school baseball, basketball, cheerleading, cross country, football, golf, soccer, softball, swimming and diving, tennis, track and field, volleyball, and wrestling / 2007-2008 and 2008-2009 academic years	<i>Concussion:</i> assessed initially by the ATC; diagnosed according to Kentucky state guidelines ⁴²⁴ either than ATC or a medical professional (e.g. medical doctor, doctor of osteopathy, [both able to make RTP decisions] physician's assistant, or advanced registered nurse practitioner). Only new concussions were included in analysis (athlete had never	<i>Athlete exposure (AE):</i> 1 athlete participating in 1 practice or game (documented by ATC) [n = 442,123 AEs]	4,768 varsity high school athletes from 7 central Kentucky high schools	81 new concussions (out of 1,536 total injuries) / 0.169 concussions per 1,000 AEs	Incidence rate was based off the number of new concussions sustained during the study, divided by the total number of athlete exposures. Athlete exposures took into account athletes who ended their season early.	ATCs at each of the high schools uploaded data to an injury surveillance database using a standard report form.	It is unlikely (2.5% chance) that an athlete with a new concussion will return after 1 to 2 days; it rises to 35% by 3 days, 71% for 7 days and 88% for 10 days. At this point it stagnates past 22 days.
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423. Jennifer M. Medina McKeon, Scott C. Livingston, Ashley Reed, Robert G. Hosey, Williams S. Black & Heather M. Bush, *Trends in Concussion Return-to-Play Timelines among High School Athletes from 2007 through 2009*, 48 J. ATHLETIC Training 836, 836-43 (2013).

424. Kentucky High School Athletic Association and KHSAA Member Schools. Implementation of NFHS playing rules changes related to concussion and concussed athletes. <http://www.khsaa.org/sportsmedicine/concussion/concussion%20protocol.pdf>. Released June 2010. Accessed June 21, 2013.

		sustained a concussion before)						
O’Kane et al. (2014) ⁴²⁵	Girls’ youth soccer / 2008-2009 through 2011-2012 seasons	<i>Concussion:</i> operationalized based on symptoms ⁴²⁶ from the 3 rd International Conference on Concussion in Sport and a telephone interview with study personal confirming temporal association between hit to head and resulting symptoms [excluded if only symptom was brief headache,	<i>Athlete exposure hours (AEH):</i> total number of hours played by athletes, calculated from player minutes recorded by parent volunteers (n = 43,742 AEH)	351 (out of 422 total) female youth soccer players aged 11-14 in Washington State from 27 teams	59 concussions / 1.3 concussions per 1,000 AEHs / 13% average season incidence	Number of concussions was divided by the total number of athlete exposure hours. Average season incidence was calculated from the total number of concussed athletes per season.	Trained parent volunteers were responsible for determining the denominator (total player hours) and graduate assistants/ members of the study personal were responsible for collecting information on concussions and following up on the return to play.	Reported symptoms of light sensitivity, emotional lability, noise sensitivity, memory loss, nausea and concentration problems were all associated with longer recovery time. Rates were 22 times higher in games than practice.

425. John W. O’Kane, Amy Spieker, Marni R Levy, Moni Neradilek, Nayak L Polissar & Melissa A Schiff, *Concussion Among Female Middle-School Soccer Players*, 168 JAMA PEDIATRICS 258, 258-64 (2014). Cited by 24.

426. “[M]emory loss, difficulty concentrating, confusion or disorientation, dizziness, drowsiness, headache, more emotional than usual, irritability, losing consciousness, nausea, ringing in the ears, sensitivity to light or blurry vision, and sensitivity to noise.” From id. At 259.

		or onset not closely linked]						
Emery et al. (2011) ⁴²⁷	Male youth ice hockey / 2008 – 2009 season	<i>Injury</i> : any injury incurred during hockey requiring medical attention or leading to time loss/ inability to complete season <i>Concussion</i> – “met the study definition of a reportable injury based on the therapist’s assessment and the Sport Concussion Assessment Tool (SCAT) and the definition of concussion based on consensus guidelines.” ⁴²⁸	<i>Player hours (PH)</i> : total time spent practicing and competing by players during the season, measured by team designate or therapist (n = 96,907)	1,956 male and 15 female Bantam league (13 – 14 years old) ice hockey players in Alberta and Quebec, Canada; 995 with body checking experience, 976 without body checking experience	100 concussions (48 players with experience with body checking, 42 players with no experience with body checking) / Experience: 0.79 concussions per 1,000 PH No experience: 0.91 concussions per 1,000 PH	Incidence rates were calculated based on incidence of concussion in the two different sub-groups (experience with body checking and no experience with body checking). This incidence was then divided by the player hours in that particular sub-group.	Prospective cohort study using an injury surveillance system involving four forms – preseason baseline questionnaire (with SCAT); body checking attitudes questionnaire; weekly game and practice participation form to determine exposure; and injury report form. Data was collected by team designate or therapist, and team therapists (physiotherapist, certified athletic therapist or senior athletic therapy student)	25 players experienced concussions leading to more than 10 days of time loss. In total, 453 participants reported at least 1 prior concussion.

427. Carolyn Emery, Jian Kang, Ian Shrier, Claude Goulet, Brent Hagel, Brian Benson, Alberto Nettel-Aguirre, Jenelle McAllister & Willem Meeuwisse, *Risk of Injury Associated with Bodychecking Experience among Youth Hockey Players*, 183 CAN. MED. ASS’N J. 1249, 1249-56 (2011). Cited by 66.

428. Id. at 1250.

							trained by a study physician assessed players for injury or concussion.	
Lincoln et al. (2011) ⁴²⁹	6 high school boys' sports (football, lacrosse, wrestling, soccer, basketball, and baseball) and 6 high school girls' sports (field hockey, lacrosse, soccer, basketball, cheerleading, and softball) / 1997-1998 to 2007-2008	<i>Concussion:</i> evaluated by the certified ATCs according to the Standardized Assessment of Concussion (SAC), ⁴³⁰ and did not include loss of playing time as a necessary part of diagnosis	<i>Athlete exposure (AE):</i> one game or practice	158,430 high school athletes (~ ages 14 – 19) at 25 large Fairfax county public schools / 10,926,892 athletic-exposures (AEs)	2,651 concussions / 0.24 per 1,000 AEs	Concussion incidence rate was calculated based on concussions sustained per number of AEs	Data was collected by each school's two part-time ATCs through 2005, after which each school had one full-time and one part-time trainer. The schools shared an electronic record-keeping system (Sports Injury Management Systems Software) ⁴³¹ which trainers uploaded information to daily	Over the 11-year study period, there was a 4.2 fold increase overall in concussion incidence rate; there was an approximately 15.5% annual increase in incidence rate.

429. Andrew E. Lincoln, Shane V. Caswell, Jon L. Almquist, Reginald E. Dunn, Joseph B. Norris & Richard Y. Hinton, *Trends in Concussion Incidence in High School Sports: A Prospective 11-Year Study*, 39 AM. J. SPORTS MED. 958, 958-63 (2011). Cited by 341.

430. Michael McCrea, James P. Kelly, Christopher Randolph, Jon Kluge, Edward Bartolic, George Finn & Brian Baxter, *Standardized Assessment of Concussion (SAC): On-Site Mental Status Evaluation of the Athlete*, 13 J. HEAD TRAUMA REHAB. 27, 27-35 (1998).

431. <http://www.flantech.net/Products/SIMS>

	academic years							
Emery et al. (2010) ⁴³²	Youth ice hockey / October 2007 – March 2008 season	<i>Concussion:</i> “met the study definition of a reportable injury based on the therapist’s assessment and the definition of concussion based on consensus guidelines.” ⁴³³ <i>Injury:</i> any injury incurred during hockey requiring medical attention or leading to time loss/ inability to complete season	<i>Player hours (PH):</i> total time spent practicing and competing by players during the season, measured by team designate (n = 85,077)	1,108 players from 74 Peeewe (11 – 12 years old) teams in Alberta (body checking allowed) and 1,046 players from 76 Peeewe (11 – 12 years old) teams from Quebec (body checking not allowed); in total, 183 teams were approached (162 accepted)	78 concussions in Alberta 23 concussions in Quebec / 1.47 concussions per 1,000 PH in Alberta 0.39 concussions per 1,000 PH in Quebec	Incidence rates were calculated in the two leagues based on the incidence of concussion in each region, divided by player hours in that region.	Prospective cohort study using an injury surveillance system involving four forms – preseason baseline questionnaire (with SCAT); body checking attitudes questionnaire; weekly game and practice participation form to determine exposure; and injury report form. Data was collected by team designate, and study assigned team therapists (physiotherapist, certified athletic therapist or senior athletic therapy student) trained by	Body checking leagues had approximately 3 times the risk of concussion as non-body checking leagues. 328 players self-reported a prior concussion. Having a prior concussion led to increased risk of sustaining a concussion of 2.14 times, and a 2.76 times increased risk of sustaining a severe concussion.

432. Carolyn A. Emery, Jian Kang, Ian Shrier, Claude Goulet, Brent E. Hagel, Brian W. Benson, Alberto Nettel-Aguirre, Jenelle R. McAllister, Gavin M. Hamilton & Willem H. Meeuwisse, *Risk of Injury Associated with Bodychecking Amongst Youth Hockey Players*, 303 JAMA 2265, 2265-72 (2010). Cited by 157.

433. Id. at 2267.

							a study physician assessed players for injury or concussion. Therapists were present at 1 session per week.	
Shields & Smith (2009) ⁴³⁴	Organized cheerleading / 2006-2007	<i>Concussion:</i> defined as a diagnosed concussion or closed head injury that required medical attention and prevented completion of an event or practice	<i>Athlete exposure (AE):</i> 1 cheerleader participating in 1 practice or event (e.g. football game)	9,022 cheerleaders aged 3 to 29 from 412 US teams (113 All Star, 37 college, 180 high school, 39 middle school, 3 elementary school, and 40 recreation league) from 43 out of 50 states (803 officially enrolled; 243 completed, 173 partial, 387 failed to report data)	23 concussions or closed head injuries (out of 565 total)	The authors do not report incidence rates, or divide based on age	Cheerleading RIO (similar to the HS RIO); participants were recruited using flyers/ emails/etc. They trained designated team reporters (volunteers) in using the online software.	Collegiate cheerleaders had the highest injury rates, while recreation and middle school aged cheerleaders had the lowest injury rates.

434. Brenda J. Shields & Gary A. Smith, *Cheerleading-Related Injuries in the United States: A Prospective Surveillance Study*, 44 J. ATHLETIC TRAINING 567, 567-77 (2009). Cited by 35.

Lincoln et al. (2007) ⁴³⁵	Girls' and boys' high school lacrosse / 2000 – 2003 seasons	<i>Concussion:</i> defined according to discretion of individual ATCs <i>Injury:</i> required attention from trainer and led to participation restriction for 1 or more days (including the day of the injury)	<i>Athlete exposure (AE):</i> 1 athlete participating in 1 game or practice (n = 209,375 girls' AEs; n = 297,625 boys' AEs)	Boys' and girls' high school lacrosse players (n = 5,072 boys; n = 3,566 girls) at 23 public high schools in Fairfax County, Virginia	Boys: 83 concussions Girls: 45 concussions / Boys: 0.28 per 1,000 AEs Girls: 0.21 per 1,000 AEs	Concussion incidence rates were calculated by the pooled incidence of concussion in boys and girls divided by the pooled number of games and practices, then multiplied by 1,000.	The authors used online data from ATCs, which reported it daily as part of their duties. There were two ATCs per school. Trainers used the Injury Tracking Treatment System supplemented by a lacrosse specific injury form.	Concussions comprised the largest proportion of all head, face and eye injuries; however, there were significant differences between boys and girls. 72.8% of head, face and eye injuries in boys were concussions, versus 39.5% of girls' head, face and eye injuries.
Emery & Meeuwisse (2006) ⁴³⁶	Minor ice hockey / 2004 – 2005 season	<i>Concussion:</i> defined according to discretion of individual therapists or physician; combined with losing consciousness	<i>Player hours (PH):</i> total participation time across all players across season; missing or unreported weeks were replaced by mean of other	986 players across 17 Atom teams (9 – 11 years old), 20 Peewee teams (11 – 13 years old), 16 Bantam teams (13 -15 years old), and 18	Atom: 3 concussions Peewee: 13 concussions Bantam: 17 concussions Midget: 21 concussions /	Incidence rate was calculated based on the incidence per division divided by the total player hours per each of the different divisions.	Descriptive epidemiology study implementing an injury surveillance system with 5 forms: "preseason medical form, a weekly exposure sheet (WES)	Concussion was the largest specific injury type (~18% of injuries). Older players were more likely to suffer concussions and injuries than younger players.

435. Lincoln, Andrew E., Richard Y. Hinton, Jon L. Almquist, Sean L. Lager & Randall W. Dick, *Head, Face, and Eye Injuries in Scholastic and Collegiate Lacrosse*, 35 AM. J. SPORTS MED. 207, 207-15 (2007). Cited by 66.

436. Emery, Carolyn A. & Willem H. Meeuwisse, *Injury Rates, Risk Factors, and Mechanisms of Injury in Minor Hockey*, 34 AM. J. SPORTS MED. 1960, 1960-69 (2006). Cited by 189.

		<i>Injury</i> : any injury incurred during hockey requiring medical attention or leading to time loss/ inability to complete season	weeks; player time was classified as 100% or 75% participation (n = 71,727 PH [n = 12,526 Atom PH, n = 15,955 Pee wee PH, n = 17,552 Bantam PH, n = 25,694 Midget PH])	Midget teams (15 – 17 years old) all from Alberta, Canada [age range: 8 – 17]	Atom: 0.24 concussions per 1,000 PH Pee wee: 0.81 concussions per 1,000 PH Bantam: 0.97 concussions per 1,000 PH Midget: 0.82 concussions per 1,000 PH		for the documentation of daily individual player participation, an individual injury report form (IRF) for collection of injury-related information, a therapist injury assessment form, and a physician diagnosis/treatment plan form ⁴³⁷ Injuries were evaluated by ATCs or candidates, and exposure was recorded by designated team personal. Injury reports were also filled out by physicians in some cases.	
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437. Id. at 1961.

Hinton et al. (2005) ⁴³⁸	High school and recreational boys' and girls' lacrosse / 1999 – 2001 seasons and summer camps	<i>Concussion</i> : defined according to discretion of individual ATCs. <i>Injury (high school)</i> : required attention from trainer due to injury during organized play and led to participation restriction for 1 or more days (including the day of the injury) <i>Injury (summer camp)</i> : required attention from trainer due to injury during organized play	<i>Athlete exposure (AE)</i> : 1 athlete participating in 1 game or practice (n = 146,190 girls' AEs; n = 212,850 boys' AEs); Defined during summer camp play as 1 hour of game play or 2 hours of practice time (n = 20,331 boys' AEs, n = 7,987 girls' AEs)	Boys' and girls' high school lacrosse players (n = 3,870 boys' player seasons; n = 2658 girls' player seasons) at 23 public high schools in Fairfax County, Virginia / 1,141 girls from 300 elite summer camps and 2,259 boys from 205 elite summer camps over the course of 1999, 2000, and 2001 [~15 – 18 years old]	High school – Boys: 61 concussions Girls: 14 concussions Summer camp – Boys: 7 concussions Girls: 1 concussions / High school – Boys: 0.29 concussions per 1,000 AEs Girls: 0.1 concussions per 1,000 AEs Summer camp – Boys: 0.24 concussions per 1,000 AEs Girls: 0.13 concussions per 1,000 AEs	Incidence rates were calculated from incidence per gender and per situation, divided by total athlete exposures in that situation.	The authors used online data from ATCs, which reported it daily as part of their duties. There were two ATCs per school. Trainers used the Injury Tracking Treatment System supplemented by a lacrosse specific injury form. For summer camp, there was one ATC present throughout.	Boys had approximately 3 times the concussion incidence rate (2.99 for high school, 2.75 for summer camp) as girls.
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438. Richard Y. Hinton, Andrew E. Lincoln, Jon L. Almquist, Wiemi A. Douguieh & Krishn M. Sharma, *Epidemiology of Lacrosse Injuries in High School-Aged Girls and Boys*, 33 AM. J. SPORTS MED. 1305, 1305-14 (2005). Cited by 98.

Zemper (2003) ⁴³⁹	Male high school and collegiate varsity football / 1997 – 1998 seasons	<i>Concussion:</i> defined as “traumatically induced alteration in mental status,” ⁴⁴⁰ from the American Academy of Neurology (graded according to their guidelines of 1, 2 or 3) ⁴⁴¹ <i>Injury:</i> injuries during practice/ games leading to participation restriction of 1 or more days, as well as any head injury regardless of participation loss	<i>Athlete exposure (AE):</i> 1 athlete exposed to injury during 1 game or practice; based on weekly reports of participation by school certified ATCs (n = 475,589 high school AEs, n = 582,659 college AEs)	56 high schools and 42 colleges during the 1997 season and 33 high schools and 42 colleges during the 1998 season (sampled from 4 geographic regions and across 3 collegiate divisions)	572 concussions (240 high school, 332 college) / 0.54 concussions per 1,000 AEs (0.50 high school concussions per 1,000 AEs, 0.57 college concussions per 1,000 AEs)	Concussion incidence rate was calculated based on incidence of concussion in the population, divided by total athlete exposures during the study period for that population, multiplied by 1,000.	Data was taken from the Athletic Injury Monitoring System ⁴⁴² , which takes a stratified random sample of high school football teams based on geographic regions, including a criterion that the schools have an ATC. ATCs were asked how many athletes sustained concussions during the previous 5 years based on the medical history of individual players. Weekly responses were 98.5% for high school and 99.3% for college.	53 out of 240 high school players sustaining a concussion during the study had sustained a prior concussion. 108 of 332 collegiate players sustaining a concussion during the study had a prior concussion. Having a prior concussion increased the risk of a subsequent concussion by 6.6 times for high school players, and by 5.3 times for collegiate players. More than 95% of concussions did not involve a loss of consciousness.
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439. Eric D. Zemper, *Two-Year Prospective Study of Relative Risk of a Second Cerebral Concussion*, 82 AM. J. PHYSICAL MED. & REHAB. 653, 653-59 (2003). Cited by 188.

440. Id. at 654.

441. “Grade 1 on the American Academy of Neurology scale indicates transient confusion that resolves in _15 min (the “bell ringer”); grade 2 indicates symptoms (transient confusion) that last longer than 15 min, but there is still no loss of consciousness; and grade 3 is used for any concussion involving loss of consciousness.” From Id. At 655.

442. <http://www.exra.org/98hpresumm.htm>

Powell & Barber-Foss (1999) ⁴⁴³	High school varsity boys' football, wrestling, baseball and field hockey, girls' volleyball and softball, boys' and girls' basketball, and boys' and girls' soccer / 1995-1996 through 1996-1997 academic years	<i>mTBI</i> : defined as a head-injured player who was removed from participation and evaluated by an ATC or physician [for a traumatic or head injury by the ATC, physician, or both,] prior to returning to participation." ⁴⁴⁴	<i>Athlete exposure</i> (AE): one game or practice <i>Injuries</i> : "an incident that caused cessation of customary participation in the current session (game or practice) or on the day following the day of injury onset" ⁴⁴⁵	High school athletes (~14 – 19) / >4.4 million AEs / 23,566 injuries	1,219 mTBIs (5.5% of injuries) / Football had the highest incidence rate (0.59 per 1,000 AEs), followed by girls' soccer (0.23 per 1,000 AEs), wrestling (0.25 per 1,000 AEs), and boys' soccer (0.18 per 1,000 AEs).	Data was normalized via an incidence density ratio, based on the injury rate per 1,000 athlete exposures	National Athletic Trainer Association (NATA) surveillance system – 246 certified ATCs recorded injury and exposure data for high school varsity athletes at 235 US high schools during one or more of the 1995-1997 academic years; drew from convenience sample of 350 volunteers with distribution across 50 states and variable enrollment matching overall U.S. school enrollment	102 players experienced 2 mTBI during the study and most (n = 72) were football players; Authors calculated an overall, nationwide incidence of 62,816 mTBI across all sports in the U.S. based on nationwide player participation data
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443. John W. Powell & Kim D. Barber-Foss, *Traumatic Brain Injury in High School Athletes*, 10 JAMA 958, 958-963 (1999). Cited by 563.

444. Id. at 959.

445. Id. at 959.

<p>Kay et al. (2017)⁴⁴⁶</p>	<p>Collegiate varsity men's baseball, basketball, football, ice hockey, lacrosse, soccer, wrestling, cross-country, indoor and outdoor track/field, tennis, and swim/dive; and women's basketball, field hockey, gymnastics, ice hockey, lacrosse, soccer, softball, volleyball, cross-country,</p>	<p><i>Severe concussion:</i> required 21 or more days of restricted participation, premature end to season, recovery beyond end of season and medical disqualifications</p>	<p><i>Athlete exposure (AE):</i> one game or practice <i>Severe injuries:</i> injuries that—required 21 or more days of restricted participation, premature end to season, recovery beyond end of season and medical disqualifications</p>	<p>Collegiate varsity athletes (~18 – 23) / 3,183 severe injuries reported (9.5% of all reported injuries)</p>	<p>282 severe concussions / 8.9% of reported severe injuries</p>	<p>Incidence rate of severe concussion was calculated based on the total number of severe injuries reported and the number of AEs</p>	<p>National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS)</p>	<p>Most occurred in men's football (n = 74, 6.8%), followed by men's ice hockey (n = 70, 18.4%) and men's wrestling (n = 30, 17.3%) / Similar proportions of diagnosis for males (9.4%, n = 90) and females (9.2%, n = 70)</p>
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446. Melissa C. Kay, Johna K. Register-Mihalik, Aaron D. Gray, Aristarque Djoko, Thomas P. Dompier & Zachary Y. Kerr, *The Epidemiology of Severe Injuries Sustained by National Collegiate Athletic Association Student-Athletes, 2009–2010 Through 2014–2015*, 52 J. ATHLETIC TRAINING 117, 117-28 (2017). Not cited yet.

	indoor and outdoor track/field, tennis, and swim/dive / 2009-2010 through 2014-2015 academic years							
Hootman, Dick & Agel (2007) ⁴⁴⁷	NCAA men's baseball, men's basketball, women's basketball, women's field hockey, men's football, women's gymnastics, men's ice hockey, men's lacrosse,	<i>Concussion:</i> diagnosed according to discretion of individual ATCs	<i>Athlete exposure (AE):</i> 1 athlete completing 1 competition or practice <i>Injury:</i> had to be the result of participation in an organized intercollegiate practice or contest; (2) injury required medical attention by a team certified	Varsity NCAA athletes ~18 – 23) across D1, D2 and D3 / >1,000,000 AEs	>9000 concussions reported (~3,753 per year) / 0.28 per 1,000 AEs	The authors calculated approximate number of concussions per year based on the assumption that their sample draws from about 15% of total NCAA institutions	Data was collected from the National Collegiate Athletic Association Injury Surveillance System (NCAA ISS) which collects standardized injury and exposure data from collegiate sports across Divisions I, II and III.	Majority of concussions occurred in football (55%), but women's hockey had the highest incidence rate (0.91 per 1,000 AEs)

447. Jennifer M. Hootman, Randall Dick & Julie Agel, *Epidemiology of Collegiate Injuries for 15 Sports: Summary and Recommendations for Injury Prevention Initiatives*, 42 J. ATHLETIC TRAINING 311 (2007). Cited by 1262.

	women's lacrosse, men's soccer, women's soccer, women's softball, women's volleyball, and men's wrestling / 1988-1989 through 2003-2004 academic years Women's ice hockey (2000-2001 through 2003-2004 academic years)		ATC or physician; and (3) injury resulted in restriction of the student-athlete's participation or performance for one or more days beyond the day of injury." ⁴⁴⁸					
Gessel et al. (2007) ⁴⁴⁹	NCAA boys' football, soccer,	<i>Concussion:</i> reported according to	<i>Athlete exposure (AE):</i> 1 athlete	Varsity NCAA athletes (~18 –	482 concussions (5.8% of total injuries)	Incidence rate was calculated based on total	NCAA ISS	Concussion rates were generally higher for college

448. Id. at 311.

449. Luke M. Gessel, Sarah K. Fields, Christy L. Collins, Randall W. Dick & R. Dawn Comstock, *Concussions Among United States High School and Collegiate Athletes*, 42 J.

	basketball, wrestling, and baseball and girls' soccer, volleyball, basketball, and softball / 2005-2006 academic year	practices of individual ATCs	completing 1 competition or practice <i>Injury:</i> incident that fits following criteria: "(1) injury occurred as a result of participation in an organized intercollegiate practice or contest; (2) injury required medical attention by a team certified ATC or physician; and (3) injury resulted in restriction of the student-athlete's participation or performance for one or more days beyond the	23) across D1, D2 and D3 / 8,293 reported injuries	/ 0.42 concussions per 1,000 AEs	concussions divided by total AEs		sports than for high school sports, significantly so for all sports besides baseball; girls' soccer had highest incidence rate, and overall males had higher incidence rate than females (1.74 vs 0.74 per 1,000 AEs)
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			day of injury.” ⁴⁵⁰					
Covassin, Swanic & Sachs (2003) ⁴⁵¹	NCAA men’s football, ice hockey, wrestling, basketball, lacrosse, baseball, soccer and gymnastics as well as women’s lacrosse, soccer, baseball, softball, field hockey, volleyball and gymnastics / 1997-1998 through 1999-2000	<i>Concussion:</i> reported according to discretion of individual ATCs	<i>Athlete exposure (AE):</i> one game or practice <i>Injury:</i> incident that fits following criteria: “(1) injury occurred as a result of participation in an organized intercollegiate practice or contest; (2) injury required medical attention by a team certified ATC or physician; and (3) injury resulted in restriction of the student-athlete’s	Varsity NCAA athletes (~18 – 23) across D1, D2 and D3 / 40,457 reported injuries	2,502 concussions (6.2% of all reported injuries)	Incidence rates for specific sports were calculated on an annual basis based on the number of AEs	NCAA ISS	Concussion incidence rate and incidence varied by year, by sport and by gender; in general, men’s football, ice hockey, wrestling, and men’s & women’s soccer, and lacrosse had the highest risks

450. Taken from Hootman et al.’s (2007) description of reportable injuries for NCAA ISS.

451. Tracey Covassin, C. Buz Swanic & Michael L. Sachs, *Epidemiological Considerations of Concussions Among Intercollegiate Athletes*, 10 APPLIED NEUROPSYCHOLOG. 12, 12-22 (2003). Cited by 160.

	academic years		participation or performance for one or more days beyond the day of injury.” ⁴⁵²					
Strand et al. (2015) ⁴⁵³	Girls’ soccer (comparison: other sports/ activities) / ?	<i>Concussion:</i> self-reporting (via survey) one of the signs or symptoms of concussion ⁴⁵⁴ following a blow to the head during soccer	Total number of players in sample (n = 195 soccer players; n = 147 control group)	195 female soccer players aged 11 to 13 in an organized soccer league in major metropolitan areas in several regions of the U.S. Control group: 147 youth participants able to regularly complete physical education class	94 (48% of total) soccer players reported probable concussions 34 (23% of total) control group reported probable concussions [2.09 times the relative risk]	Incidence was represented as a percentage of the total number of players reporting back using the survey, as well as the number of control group. In addition, the relative risk was just the percentage of soccer athletes reporting probable concussion divided by the number of the	Surveys were distributed to youth soccer players as well as youth athletes/individuals to serve as a control group (unclear total approached sample). They were asked to report on whether they had sustained a blow to the head leading to signs/ symptoms of concussion during the previous season, and the last	Most players (84%) reported headache; other symptoms were reported in less than half of the players (38% balance problems, 19% ringing in ears, 12% sensitivity to light). Approximately 6% reported loss of consciousness.

452. Taken from Hootman et al.’s description of reportable injuries for NCAA ISS.

453. Sarah Strand, David Lechuga, Thomas Zachariah & Kathryn Beaulieu, *Relative Risk for Concussions in Young Female Soccer Players*, 4 APPLIED NEUROPSYCHOL.: CHILD 58, 58-64 (2015). Cited by 2.

454. Headache, balance problems or dizziness, ringing in the ears, drowsiness or fatigue, sensitivity to light, nausea or vomiting, feeling of confusion, loss of memory, sensitivity to noise, sleeping more than usual, vision problems, to lose consciousness or to be knocked out, irritability, difficulty sleeping, or difficulty concentrating From id. At 61.

						control group reporting probable concussion.	6 month for the control group.	
Register-Mihalik et al. (2013) ⁴⁵⁵	Varsity high school football, boys' and girls' lacrosse, boys' and girls' soccer, and cheerleading / November 2008 to February 2010	<i>Concussion</i> : defined according to self-report via survey; had to occur during high school competition/practice ⁴⁵⁶ <i>Bell-ringer/ding event</i> : defined according to self-report via survey; had to occur during a high school competition/practice	167 varsity athletes responding to survey	167 completed surveys (60.5% male) from 1,669 administered to varsity athletes from 28 high schools in 9 states	44 athletes (26.3% of respondents) reported at least 1 previous concussion event [84 concussions total]	Incidence was reported as the number of athletes reporting concussion events, as well as the total number of concussion events reported by athletes.	Surveys were distributed to high schools across various states, who were then required to mail in the survey to the study administrators. This process may account for the low response rate (10%)	Athletes reported reporting about 50% of concussion events, and only 12.3% of bell-ringer events. Due to the open-ended nature of the questions, it is possible that athletes did not solely report SRC.
McCrea et al. (2004) ⁴⁵⁷	Varsity high school football	<i>Concussion</i> : "A blow to the head	Varsity male football athletes (n = 1,659)	1,659 varsity football players in 20 high	229 players reported at least one concussion	Incidence was determined based	Athletes completed two surveys, one pre-season and one	Only 47.3% of athletes who said they had a

455. Johna K. Register-Mihalik, Kevin M. Guskiewicz, Tamara C. Valovich McLeod, Laura A. Linnan, Frederick O. Mueller & Stephen W. Marshall, *Knowledge, Attitude, and Concussion-Reporting Behaviors Among High School Athletes: A Preliminary Study*, 48 J. ATHLETIC TRAINING 645, 645-53 (2013). Cited by 131.

456. "In your high school years, how many concussions do you think you have experienced?"; "In your high school years, how many times have you had your 'bell rung' or been 'dinged'?"

457. Michael McCrea, Thomas Hammeke, Gary Olsen, Peter Leo & Kevin Guskiewicz, *Unreported Concussion in High School Football Players: Implications for Prevention*,

	/ 1999-2002	followed by a variety of symptoms that may include any of the following: headache, dizziness, loss of balance, blurred vision, “seeing stars,” feeling in a fog or slowed down, memory problems, poor concentration, nausea, or throwing up. Getting “knocked out” or being unconscious does <i>not</i> always occur with a concussion.” ⁴⁵⁸		schools in the Milwaukee, Wisconsin area	on the post-season survey (15.3% of respondents) / 505 participants reported prior history of concussion on pre-season; 458 participants reported prior history of concussion on post-season	on response of participants	post-season; both asked about prior history, and the second about those sustained during the season. The post-season survey also asked if/to whom the athletes had reported their concussion; they were also asked reasons for failing to report. ⁴⁵⁹	concussion during the season said that they reported it; probability of report was not tied to prior history of concussion.
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14 CLINICAL J. SPORTS MED. 13, 13-17 (2004). Cited by 789.

458. Id. at 17.

459. Athletes selected from the following list: “didn’t think it was serious enough, didn’t know it was a concussion, didn’t want to be pulled out of the game or practice, didn’t want to let down teammates, or other reason” Id. At 17.

Langburt et al. (2001) ⁴⁶⁰	High school football / 1996-1997	<i>Concussion:</i> defined according to player self-report via survey based on the signs and symptoms of concussion following a head injury; these were based on the Cantu guidelines ⁴⁶¹	High school football players (n = 233)	233 (out of 450 distributed surveys) high school football players (~14 – 19) from Pennsylvania high schools in 2 large districts	110 players reported concussions Mean of 3.41 concussions per concussed athlete / 1,610 concussions per 1,000 athletes per season	The authors calculated the incidence rate per season by taking the number of reported concussions and dividing them by the total athletes.	The authors distributed a survey that detailed concussion signs and symptoms to high school athletes in Pennsylvania. All surveys were anonymous and if not actually use the word concussion.	68% of concussed athletes (75 out of 110) did not stop play. In addition, a significant amount of individuals had multiple concussions during the past season with a mean of 3.41 concussions amongst those who sustained t least 1. There was a 2.79 rate ratio of a second concussion.
Gerberich et al. (1983) ⁴⁶²	High school varsity football / 1977	<i>Concussion:</i> identification of concussion as a diagnosis during the previous season, or reporting a blow to the head leading to loss of	Minnesotan varsity high school players (n = 3,083)	3,083 (81% response rate) varsity male high school football players from Minnesota high schools (selected based on 3 strata:	74 concussions / 507 players with loss of awareness/ consciousness / 190 concussions per 1,000 players	Incidence was calculated based on the total number of athletes reporting a concussion or a blow to the head followed by loss of consciousness/	The authors distributed a survey/ questionnaire to Minnesotan high schools selected based on a stratified random sample. Follow up	~24% of all injuries were concussions Experiencing loss of consciousness during the 1977 season was 4 times as likely for players who reported a prior loss of

460. Wayne Langburt, Bruce Cohen, Nadia Akhthar, Kelly O'Neill & Jar-Chi Lee, *Incidence of Concussion in High School Football Players of Ohio and Pennsylvania*, 16 J. CHILD NEUROLOGY 83, 83-85 (2001). Cited by 60.

461. The authors used exact phrasing from the Cantu guidelines for Grade I, II and III concussion, without directly using the word concussion; instead they specified head injuries with those symptoms.

462. Susan Goodwin Gerberich, James D. Priest, James R. Boen, Conrad P. Straub & Robert E. Maxwell, *Concussion Incidences and Severity in Secondary School Varsity Football Players*, 73 AM. J. PUB. HEALTH 1370, 1370-75 (1983). Cited by 364.

		consciousness or loss of awareness		public-private, suburban-rural and football class)		awareness, divided by the total number of athletes responding	was performed using sub-samples of that sample, in order to clarify diagnoses, match physician diagnosis with trainer diagnosis, and to rectify non-response	consciousness with head injury 112 loss of consciousness (77 RTP same day) 485 loss of awareness (393 RTP same day)
Kontos et al. (2016) ⁴⁶³	Competition level youth ice hockey / 2012 – 2014	<i>Concussion</i> : medically diagnosed by a licensed medical professional	<i>Athlete exposure</i> (AE): 1 athlete completing 1 competition or practice (n = 23,369)	401 of 449 youth ice hockey players aged 12 – 18 from three states (Western Pennsylvania; Boston, Massachusetts; Birmingham, Alabama) and 31 teams (11 high school, 10 midget, 7 bantam, 3 peewee); 330 boys	37 concussions / 1.58 concussions per 1,000 AEs (2.46 per 1,000 game AEs and 1.17 per 1,000 practice AEs)	Incidence rate was calculated based on total reported concussions divided by total AEs	All games and practices had licensed medical professionals present, and only concussions officially diagnosed by a medical professional were included. Exposure was recorded by team volunteers who were contacted 2 to 3 times a week regarding	105 of 397 participants who completed demographic information reported a prior concussion; younger players (12-14) had 2.4 times higher incidence rate than older players (15-18)

463. Anthony P. Kontos, R. J. Elbin, Alicia Sufrinko, Scott Dakan, Kylie Bookwalter, Ali Price, William P. Meehan & Michael W. Collins, *Incidence of Concussion in Youth Ice Hockey Players*, PEDIATRICS (Jan. 2016) <http://pediatrics.aappublications.org/content/early/2016/01/07/peds.2015-1633>. Cited by 7.

							suspected concussions ⁴⁶⁴	
McGuine et al. (2014) ⁴⁶⁵	High school football / 2012 and 2013 seasons	<i>Concussion:</i> defined according to the American Academy of Neurology definition ⁴⁶⁶ and evaluated to the discretion of the individual ATC with or without the help of a physician’s diagnosis	<i>Athlete-exposures (AE):</i> 1 football player participating in 1 practice or game (n = 134,437)	2,081 players (206 in both seasons) from Wisconsin high schools (n = 34 [2012]; n = 18 [2013]) participated in the study. Almost half were varsity, although all players were eligible (freshman, JV and varsity) [aged ~14 – 18]	211 SRC (across 206 players [9% of total players]) / 1.56 per 1,000 AEs Competition: 5.81 per 1,000 competition AEs Practice: 0.76 per 1,000 practice AEs	Incidence rate was calculated from the total number of athlete exposures, as well as within each type of exposure (e.g. practice versus game)	The study collected demographic information, helmet and mouth guard per player. Prior to the start of the season, the Concussion Symptom Index (CSI) was administered to each player by an ATC; any athlete with suspected concussion was administered the CSI directly post-injury.	There was an increased risk (2 times higher) amongst players who reported a SRC within the past 12 months. There was no correlation with other information measured.
Kontos et al. (2013) ⁴⁶⁷	Youth football	<i>Concussion:</i> operationalized	<i>Athlete-Exposure (AE):</i>	571 (82% participation)	20 medically diagnosed	Incidence rates were calculated	During the course of a season,	11-12 year olds (incidence rate: 2.53)

464. Participant exclusion criteria included history of brain surgery, moderate or severe TBI, neurologic/psychiatric disorder, and current or recent (last 6 month) concussion
⁷² Timothy A. McGuine, Scott Hetzel, Michael McCrea & M. Allison Brooks, *Protective Equipment and Player characteristics Associated with the Incidence of Sports-Related Concussion in High School Football Players: A Multifactorial Prospective Study*, AM, J. SPORTS MED. 2470, 2470-78 (2014). Cited by 31.

466. “[A]n injury resulting from a blow to the head or other applied forces (linear or rotational) causing an alteration in mental status and 1 or more of the following symptoms: headache, nausea, vomiting, dizziness/balance problems, fatigue, difficulty sleeping, drowsiness, sensitivity to light/noise, blurred vision, memory difficulty, and difficulty concentrating.” From id.

467. Anthony P. Kontos, R. J. Elbin, Vanessa C. Fazio-Sumrock, Scott Burkhart, Hasani Swindell, Joseph Maroon & Michael W. Collins, *Incidence of Sports-Related Concussion Among Youth Football Players Aged 8-12 Years*, 163 J. PEDIATRICS 717, 717-20 (2013). Cited by 48.

	/ 2011 season	as a suspected concussion based on coach/player/etc. that was subsequently confirmed by a medical professional's diagnosis	1 athlete participating in 1 game or 1 practice; a trained team reported tracked athlete exposures for players on their team (n = 11,338 AEs)	rate) youth players aged 8-12 on 18 teams across 4 non-scholastic tackle football leagues in western Pennsylvania (excluded based on current/prior concussion within 6 months)	concussions (2 in practice, 18 in games) / Overall: 1.76 concussions per 1,000 AEs Practices: 0.24 concussions per 1,000 AEs Games: 6.16 concussions per 1,000 AEs	based on the number of medically diagnosed concussions divided by the total athlete exposures; they calculated overall, by age group, and by type of play (game vs. practice)	researchers performed a prospective study. They watched all games and had trained reporters watch practices, to determine the number of concussions. Coaches, players and parents all underwent preseason concussion education and training.	per 1,000 AEs) were ~2.5 times as likely to sustain a concussion as 8-10 year olds (incidence rate: 0.93 concussions per 1,000 AEs)
McCrea et al. (2013) ⁴⁶⁸	Football, soccer, lacrosse, and ice hockey / 1999-2000 through 2007-2008	<i>Concussion:</i> defined according to American Academy of Neurology Guideline for Management of	<i>Player seasons:</i> one player competing during one season	18,531 player-seasons from 3 parallel multi-center studies; included 570 concussed athletes (n =) and 166 control athletes (n =)	570 concussed athletes	No incidence or incidence rate was directly reported	During the study, athletes underwent outcome measures on the sideline immediately post-injury, 2 to 3 hours later, throughout the first week post-injury; ⁴⁶⁹	The strongest associated factors with prolonged recovery were loss of consciousness, post-traumatic amnesia, retrograde amnesia and general symptom severity

468. Michael McCrea, Kevin Guskiewicz, Christopher Randolph, William B. Barr, Thomas A. Hammeke, Stephen W. Marshall, Matthew R. Powell, Kwang Woo Ahn, Yanzi Wang & James P. Kelly, *Incidence, Clinical Course, and Predictors of Prolonged Recovery Time Following Sport-Related Concussion in High School and College Athletes*, 19 J. INT'L NEUROPSYCHOL. SOC'Y 22, 22-33 (2013). Cited by 175.

469. Outcome measures: Graded Symptom Checklist; Standardized Assessment of Concussion; Balance Error Scoring System; Hopkins Verbal Learning Test; Trail-Making Test-B;

	academic years	Sports Concussion <i>Typical recovery:</i> change in an athlete's Graded Symptom Checklist (GSC) from baseline to 7 days post-injury had to be in the 95 th percentile of the change seen in a normal athlete <i>Prolonged recovery:</i> GSC change was 6 or higher 7 days post-concussion		105 high school, n = 61 collegiate)			additional, more intensive neuropsychological testing occurred 1 to 2 days and 1 week post-injury. Finally, athletes were evaluated at 45 or 90 days (shifted from 90 days to 45 days during the study period). Athletes were compared according to the length of their recovery.	within the first 24 hours It is unclear the total number of concussed athletes during the time period, and the total incidence
Meyers & Barnhill (2004) ⁴⁷⁰	Boys' varsity high school football / 1998 – 2002 seasons	<i>Injury:</i> any injury leading to missing part/all of a game, time out of competing, ATC/physician	<i>Team game:</i> 1 team game (n = 240 team games; n = 90 games on natural grass, n	8 varsity football teams from 8 Texas high schools (minimum 900 students); 4 participated for	26 concussions (1 athlete suffered from second impact syndrome, 1 athlete suffered from post-	Concussion incidence rate was calculated by grouping all of the grades of concussion on a field type and	An injury surveillance form was distributed to the certified ATCs at each of the schools, who were present at all team	Concussions constituted only 4.4% of all FieldTurf injuries, versus 12.8% of injuries on natural grass.

Stroop Color Word and Symbol Digit Modalities Test

470. Michael C. Meyers & Bill S. Barnhill, *Incidence, Causes, and Severity of High School Football Injuries on FieldTurf versus Natural Grass*, 32 AM. J. SPORTS MED. 1626, 1626-38 (2004). Cited by 158.

		reported or treated, and any reported cranial/cervical trauma (classified further into <i>minor</i> , <i>substantial</i> and <i>severe</i> based on time loss of participation) <i>Concussion</i> : evaluated according to discretion of onsite certified ATCs and team physicians (graded as either 1, 2 or 3)	= 150 games on FieldTurf)	all 5 years of the study, 4 were added just for the final season (2002).	traumatic headache) / 7 concussions per 100 team games on FieldTurf 18 concussions per 100 team games on natural grass	dividing it by the total number of team games played on that field type, then multiplied by 100.	games. This recorded specific mechanism of injury, type of injury, and other general demographic and exposure information for the players. All game-related injuries were evaluated by the school's head trainer and/or team physician.	
Field et al. (2003) ⁴⁷¹	Men's high school and NCAA football, men's high school soccer, women's	<i>Previous concussion</i> : defined and graded based on the American Academy of Neurology	College male football players (n = 370) and female soccer players (n = 23) from 4 Division 1A programs and varsity male	Participants in Concussion Safety Program; college male football players (n = 370) and female soccer	92 concussions (n = 39 high school [35 football, 4 soccer]; n = 53 college [51 football, 2 soccer])	Incidence calculated based on total reported concussions	Concussions were scored with the AAN Practice Parameter. Athletes who suffered concussions were referred for	About 53.7% of the sample reported at least one prior concussion; collegiate athletes were more likely to have had a previous concussions and

471. Melvin Field, Michael W. Collins, Mark R. Lovell & Joseph Maroon, *Does Age Play a Role in Recovery from Sports-Related Concussion? A Comparison of High School and Collegiate Athletes*, 142 J. PEDIATRICS 546, 546-53 (2003). Cited by 611.

	NCAA soccer / 1997-1998 through 2000-2001 academic years	(AAN) Practice Parameter ⁴⁷² <i>Concussion:</i> were reported according to sports medicine practitioners at each institution who were trained by the study's researchers	football players (n = 161) and varsity male soccer players (n = 22) from 5 high schools in Shiawassee County, Michigan High school (14 – 18); college (17 – 25)	players (n = 23) from 4 Division 1A programs and varsity male football players (n = 161) and varsity male soccer players (n = 22) from 5 high schools in Shiawassee County, Michigan High school (14 – 18); college (17 – 25)			neurophysiological evaluation within 24 hours, which was followed up 3, 5 and 7 days post-injury. These subjects were matched with an appropriate control from the baseline condition, based on sport, age, high school GPA/ college board examination scores, history of diagnosed learning disability and history of previous concussion.	high school players took longer to recover from symptoms (compared to normal controls).
Marshall & Spencer (2001) ⁴⁷³	Boys' high school rugby / 1998 – 2000 seasons	<i>Concussion:</i> concussions were graded based on the Cantu scale, and diagnosed with a team physician	<i>Athlete-exposure (AE):</i> 1 athlete participating in 1 practice or 1 game (recorded separately)	2 boys' varsity rugby teams from a Utah high school	17 concussions (24.6% of 69 total injuries) 12 game concussions 5 practice concussions	Incidence rate was calculated from the total incidence of concussion, divided by the	The authors used data from a computer database run by Spencer, who is the certified ATC at the rugby program. The	25.3% of participation days lost were due to concussions. There were 14 Cantu Grade 1, 2 Cantu

472. American Academy of Neurology, *Practice Parameter: The Management of Concussion in Sports (Summary Statement)*. Report of the Quality Standards Subcommittee, 48 NEUROLOGY 581, 581-85 (1997). Cited by 437.

473. Stephen W. Marshall & Richard J. Spencer, *Concussion in Rugby: The Hidden Epidemic*, 36 J. ATHLETIC TRAINING 334, 334-38 (2001). Cited by 83.

		and the study author who is a certified ATC <i>Injury:</i> any injury leading to time loss from games/practices, all fractures, and all concussions are maintained in the database			/ 3.8 per 1,000 AEs 11.1 per 1,000 player-games 1.5 per 1,000 player-practices	total athlete exposures.	database also maintains exposure data (practice and game information). The program has a medical staff and specifically a team physician that aided Spencer with diagnosis and recognition of injuries and concussions.	Grade 2 and 1 Cantu Grade 3.
Guskiewicz et al. (2000) ⁴⁷⁴	High school and collegiate football / 1995-1997	<i>Concussion:</i> defined as head injury with immediate post-traumatic neural impairment (e.g. blurred vision, alteration of consciousness, etc.); graded according to Cantu guidelines	<i>Athlete exposure:</i> 1 athlete participating in 1 game or practice; this was calculated from a sub-sample of 45 schools matching the size/divisions/levels	117 high schools (n = 6,089 [aged 14-19]) and 125 colleges (n = 11,460); across 10 NATA districts and all 3 NCAA collegiate divisions	1,003 total concussions 400 high school concussions (n = 343 concussed athletes [5.6%]) / 0.7 concussions per 1,000 AEs overall High school: 1.03 concussions per 1,000 total AEs	Incidence was calculated both as a function of total athlete exposures, and based on the subset of "live plays".	The authors performed a stratified random sample (based on division and district/geographic region) of certified ATCs; 242 of 392 provided full data. They were asked to complete a survey detailing information regarding concussions.	Across both college and high school athletes, a player sustaining 1 concussion during a season was 3 times as likely to sustain another concussion during that season. Also increases symptoms such as loss of consciousness and amnesia. 30.8%

474. Kevin M. Guskiewicz, Nancy L. Weaver, Darin A. Padua & William E. Garrett, *Epidemiology of Concussion in Collegiate and High School Football Players*, 28 AM. J. SPORTS MED. 643, 643-50 (2000). Cited by 734.

					1.63 concussions per 1,000 contact AEs			returned to play the day of.
Roberts, Brust & Leonard (1999) ⁴⁷⁵	Boys' and girls' ice hockey / 1993 – 1994 winter season	<i>Concussion:</i> defined according to individual ATC, and required at minimum cessation from game to seek treatment	<i>Player hours (PH):</i> time during game, calculated from 12 players on the ice, and 80% of total time clock ran and 100% of stop time (not adjusted for penalties) <i>Athlete exposure (AE):</i> total number of games multiplied by total number of players across rosters	695 boys and 112 girls, ages 11-19, in 5 Minnesota community-sponsored ice hockey tournaments. Boy players were from peewee (12 – 13 years old), bantam (14 – 15 years old), high school (15 – 19 years old), and Junior Gold levels (15 – 19 years old). Girl players were peewee A and B (12 – 15 years old).	9 boys' concussions (15%, out of 64 total injuries) 0 girls' concussions (out of 4 total injuries) / 17.6 boys' concussions per 1,000 PH	Incidence rate was calculated using number of concussions sustained overall divided by the total player hours; individual incidence rates were calculated for the four different levels of boys' hockey.	A certified ATC prospectively recorded injury reports, with collection by a graduate assistant to the study. This assistant also performed follow up to injuries by phone.	The incidence rate of concussions varied depending on the level of play; highest in peewee (23.1 concussions per 1,000 PH), followed by Junior Gold (18.7 per 1,000 PH) and high school (18.5 per 1,000 PH), and finally bantam (10.7 per 1,000 PH). 5 out of 9 players returned to play the same game, 1 was brought to the ED due to concerns about the cervical spine. He was cleared to play the next day.

475. William O. Roberts, Janny Dwyer Brust & Barbara Leonard, *Youth Ice Hockey Tournament Injuries: Rates and Patterns Compared to Season Play*, 31 MED. SCI. SPORTS EXERCISE 46, 46-51 (1999). Cited by 105.

Messina, Farney & DeLee (1997) ⁴⁷⁶	Boys' and girls' varsity high school basketball / 1996 – 1997 season	<i>Concussion:</i> operationalized by a checkbox on a sheet of specific injuries; diagnosed according to discretion of certified ATC with or a medical professional <i>Injury:</i> any injury during game/practice leading to loss of time (partial or full) from a game/practice, any physician-treated injuries, and any reported head/face injuries	<i>Hour of exposure:</i> 1 hour of 1 athlete participating in 1 game or practice; calculated from the number of practices per week times average practice duration, plus number of games per week times average game duration, all multiplied by number of athletes [calculated separately for male and female athletes; n = 169,885 for boys, n = 120,751 for girls]	Male (n = 973 athletes) varsity high school basketball players from 75 Texas public schools and female (n = 890 athletes) varsity high school basketball players from 71 Texas high schools [both out of 100 sampled schools with more than 740 students] [aged ~14 – 18 years]	Boys: 11 concussions (2% of 543 total injuries) Girls: 8 concussions (2% of 436 total injuries) / Boys: 3.2 total injuries per 1,000 hours Girls: 3.6 total injuries per 1,000 hours [no reported concussion incidence rate]	No concussion incidence rate was reported. The injury incidence rate was taken by dividing the total number of injuries sustained by each gender by the total number of hours of exposure for that gender.	State certified ATCs present at each of the practices and games of the football season were tasked with recording information on an injury report form for each injury that occurred. This was performed using a pegboard, then transferred to a weekly master sheet which was mailed to the study authors for electronic entry.	Little concussion specific incidence rate was given.
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476. Douglas F. Messina, William C. Farney & Jesse C. DeLee, *The Incidence of Injury in Texas High School Basketball*, 27 AM. J. SPORTS MED. 294, 294-99 (1999). Cited by 357.

Roberts et al. (1996) ⁴⁷⁷	Male ice hockey / 1994	<i>Concussion</i> : required ATC assistance and time loss from competition (no requirement of full game time loss)	<i>Player-game hours</i> : number of hours competing total (n = 213.9 hours) <i>Athlete exposures (AE)</i> : total competitions across all players and games, determined from number of players on each roster (1,099)	Male Minnesota high school hockey players in Junior Gold ice hockey tournament	4 concussions / 18.7 per 1,000 player-game hours 3.6 per 1,000 AEs	Incidence rate was calculated from the total number of concussions reported divided by the total hours played by all participants or the total number of AEs or player game hours.	The study used injury reports from certified ATCs, supplemented with reports from a trained independent observer and reports from 5 randomly selected players on each team. ATCs filled out injury reports, and athletes were followed up with by a member of the study team to evaluate severity.	The original study compared fair play rules with regular play rules; it is unclear from the reported data whether concussion incidence was affected by the two groups.
Lindenfield et al. (1994) ⁴⁷⁸	Indoor soccer / ? year	<i>Injury</i> : defined as “injured” if the player left game due to injury, led to play stop by referee or player,	<i>Player-hours</i> : calculated from total number of games observed times 12 players times 0.75; all hours were	Indoor recreational soccer players aged 7 to early 50s in Ohio. Skill level ranged from	2 concussions (unclear age group) / 1.3 per 1,000 player game hours ⁴⁷⁹	Incidence rate calculated by dividing total count of injuries observed by the total player game hours (per 100	Certified on-field examiners (medical doctor, physical therapist, or ATC) recorded injuries. The study recorded data for a	In terms of injury rate, men 25 and older suffered the highest rate of injuries.

477. William O. Roberts, Janny Dwyer Brust, Barbara Leonard & Brian J. Hebert, *Fair-Play Rules and Injury Reduction in Ice Hockey*, 150 JAMA PEDIATRICS 140, 140-45 (1996). Cited by 110.

478. Thomas N. Lindenfield, David J. Schmitt, Mary Pat Hendy, Robert E. Mangine & Frank R. Noyes, *Incidence of Injury in Indoor Soccer*, 22 AM. J. SPORTS MED. 364, 364-71 (1994). Cited by 352.

479. Jae O. Koh, J. David Cassidy & E. Jane Watkinson, *Incidence of Concussion in Contact Sports: A Systematic Review of the Evidence*, 17 BRAIN INJURY 901, 901-17 (2003).

		or led to requested medical attention Specific injuries were diagnosed by the on-field medical examiner according to individual discretion	during competition (n = 2,700 total; n = 1,548 male)	first time players to collegiate players.		player game hours); this was then performed for specific sub-groups (e.g. by age, sex, etc.). The incidence rate calculation for concussions was performed by Koh et al. according to supplementary data from the study authors, not reported in the original study.	7 week period that included 2 separate seasons, neither in their entirety.	
DeLee & Farney (1992) ⁴⁸⁰	Male varsity high school football / 1989 football season	<i>Injury</i> : any injury during game/practice leading to loss of time (partial or full) from a game/practice, any physician-treated injuries,	<i>Athlete-exposure (AE)</i> : 1 game or practice participated in by 1 student-athlete (n = 910 games, n = 5,572 practices)	86 varsity high school football teams (out of initial 100) in Texas (all schools had at least 740 enrolled students); n = 4,399 student-	101 concussions (5% of 2,228 total injuries) / 3 injuries per 1,000 hour of exposure [no reported incidence of concussion]	The rate of injury was calculated from the total incidence of injury divided by the total hours of exposure by each student-athlete. No incidence of	State certified ATCs present at each of the practices and games of the football season were tasked with recording information on an injury report form	There were 137 injuries that required hospitalization, but it is not clear if any are concussions.

Cited by 151.

480. Jesse C. DeLee & William C. Farney, *Incidence of Injury in Texas High School Football*, 20 AM. J. SPORTS MED. 575, 575-80 (1992). Cited by 149.

		and any reported head injuries <i>Concussion</i> – operationalized by a checkbox on a sheet of specific injuries; diagnosed according to discretion of certified ATC with or without input from physician	<i>Hour of exposure</i> : 1 hour spent participating in 1 game or practice by 1 student-athlete; calculated from average of trainer reported practice and game lengths (n = 2,156.7 game hours, n = 11,869.76 practice hours)	athletes [~15 – 18 years old]		concussion was given.	for each injury that occurred. This was performed using a pegboard, then transferred to a weekly master sheet which was mailed to the study authors for electronic entry. There was 75.5% participation (874 out of 1,161 weekly reports returned).	
Radelet et al. (2002) ⁴⁸¹	Community organized youth baseball, softball, football, and boys’ and girls’ soccer / 1999-2000 season	No explicit definition of concussion was given.	<i>Athlete exposure</i> (AE): one game or practice (“every player plays” policy) <i>Injury</i> : any event that brings a player off the field, brings any staff/coaching	1,659 children aged 7 to 13 across 47 boys’ baseball teams (n = 270), 29 girls’ softball teams (n = 391), 40 boys’ and girls’ soccer teams (n = 482), and 9 boys’ football	2 officially diagnosed concussions (emergency department) / 3% of specific injuries reported were concussions	The authors calculated AEs by sport by taking the average number of practices and games per team per season, based on coach-reported participation. Teams with less	The study was a prospective observational cohort format where coaches reported injuries and information weekly to the authors, and the authors also visited games and practices when	1 officially diagnosed concussion in football and 1 in baseball; it is unclear what other sports contributed to the 3%. In addition, there was only a 35% return rate of the secondary form

481. Marirose A. Radelet, Scott M. Lephart, Elaine N. Rubinstein & Joseph B. Myers, *Survey of the Injury Rate for Children in Community Sports*, 110 PEDIATRICS e28, e28 (2002). Cited by 162.

			member onto the field to check a player during game/ practice or requires first aid at any time during game/ practice	teams (n = 252) in the Pittsburgh area / 2,092 combined practices and games / 383 total injuries		than 0 injuries per 200 AEs were excluded from analysis.	coaches failed to report properly and in order to ensure accuracy. The coaches were trained in injury definitions prior to season	that detailed specific injuries.
Faude et al. (2017) ⁴⁸²	Male and female youth soccer / 2012 – 2015 (3 seasons)	<i>Concussion:</i> diagnosed according to discretion of coaches and/or parents, or medically diagnosed by a physician	<i>Player hour (PH):</i> 1 player participating in 1 hour of game or practice; recorded by designated contact person in terms of presence or absence from scheduled event (n = 688,045 hours [n = 18,586 female PH])	Male and female (<4% of sample) youth soccer players aged 7 to 12 years completing 9,933 (n = 394 girls') player seasons in Switzerland, Czech Republic, Germany and the Netherlands	11 concussions (7 medically diagnosed) out of 791 total injuries / 0.02 concussions per 1,000 PH	Concussion incidence rate was calculated overall, by dividing the total concussion incidence by the total number of player hours across all age groups. Since no concussions occurred in the under-9 age group, this means that the reported incidence rate is	Data collection was performed by a contact person in a club, usually a coach, who had access to an online injury record platform. Data collected included weekly practices, matches and player absence; injury information was recorded when it occurred. The contact person received detailed instructions	There were no concussions recorded in the under-9 age group. There was 1 female concussion, and 1 re-injury with a subsequent concussion in the same player, during the study. In addition, the small number of concussions makes it difficult to compare between age groups.

482. Oliver Faude, Roland Rössler, Astrid Junge, K. Fünten, Jiri Chomiak, Evert Verhagen, Florian Beaudouin, Jiri Dvorak & Nina Feddermann-Demont, *Head Injuries in Children's Football—Results from Two Prospective Cohort Studies in Four European Countries*, SCANDINAVIAN J. MED. SCI. SPORTS (2017). Cited by 1.

						lower than for the under-13 and under-11, and higher for under-9. However, the study authors do not report player hours by age group so it is unclear.	regarding using the platform, as well as injury information. However, no explicit definition of a concussion was given, and in many cases was solely diagnosed by a coach and/or parent. Individuals from the study centers did contact coaches, parents and injured children in the event of an injury to determine time lost from participation, medical diagnosis if one occurred (recorded as ICD-10 or Orchard code), and treatment.	
McIntosh et al. (2010) ⁴⁸³	Male rugby union football	<i>Concussion:</i> symptom based operational	<i>Game hours:</i> hours spent competing by	1,159 male youth rugby players under	199 concussions (out of 1,841 total injuries)	Incidence rates were calculated based on number	Trained university students recorded playing time for	Concussion rates peaked in the U-18 age group; 9.32 per

483. Andrew Stuart McIntosh, Paul McCrory, Caroline F. Finch & Rory Wolfe, *Head, Face and Neck Injury in Youth Rugby: Incidence and Risk Factors*, 44 BRIT. J. SPORTS MED. 188,

	players (U-13, U-15, U-18, U-20) / 2002 and 2003 seasons	definition, not explicitly given <i>Game injuries:</i> require on-field treatment or removal from game <i>Missed game injuries:</i> injury in 1 week requires missing a game the following week (~7 days post-injury)	players (n = 28,902 hours)	20 years old (~12-20) in New South Wales / (n = 82 teams for 2002, n = 87 teams for 2003)	/ 6.9 game injury concussions per 1,000 game hours; 1.9 missed game injuries per 1,000 game hours	of concussions divided by number of recorded game hours.	each player during competitions only, reason for leaving the field or the reason for absence from the game on a standard form. It contained defined fields for injured body region, nature/cause of injury, player details, concussion descriptors and whether the player was sent to the hospital.	1,000 game injuries and 2.28 missed game injuries per 1,000 game hours. These figures were taken from their supplementary material.
McIntosh & McCrory (2001) ⁴⁸⁴	Boys' high school elite rugby / n.d.	<i>Concussion:</i> medically verified concussion (unclear what limits of diagnosis)	<i>Athlete exposure (AE):</i> one game played by one player; determined based on reports from team recording officers of	294 male youth rugby players from 16 under 15 teams in metropolitan Sydney, Australia and surrounding region during the course of 1	9 concussions / 5.86 per 1,000 AEs	Incidence rate based on pooled concussions divided by total number of AEs, times 1,000	Data was collected by a team nominated "team recording officer" to record player participation, injury details, and head gear use for games. The study authors also	The study composed two sub-groups, one group of 9 teams with head gear and one group of 7 teams without. There was no significant difference in concussion rates

188-93 (2010). Cited by 70.

484. Andrew Stuart McIntosh & Paul McCrory, *Effectiveness of Headgear in a Pilot Study of Under 15 Rugby Union Football*, 35 BRIT. J. SPORTS MED. 167, 167-69 (2001). Cited by 107.

			player participation	high school season.			attended 3 games a week and videotaped 6 total games in order to ensure proper adherence to study protocol and reporting procedures.	between the two groups.
Bryan et al. (2016) ⁴⁸⁵	Sports and recreation related / 2013	Sports and recreation related concussions <i>MarketScan:</i> ICD-9-CM ⁴⁸⁶ codes excluding those for motor vehicle collisions, falls, and additional 15% <i>NEISS:</i> concussion code in conjunction with any sport, recreation	All children under the age of 18 in United States– based on 2013 population of the United States	Youth aged 18 and younger from 3 national databases (NEISS, MarketScan [n = 11,533,618], High School RIO)	377,978 outpatient visits, between 2,886 and 4,936 inpatient hospitalizations, between 115,479 and 166,929 ED visits and 73,002 ATC visits by the RIO / 0.04 to 0.06 hospitalizations and 1.48 to 2.14	Incidence rates were calculated based on NEISS and MarketScan counts, total estimated concussion incidence rate for children was based off of counts from the various databases, plus estimated values of non-report from the literature	Data was retrospectively collected from 3 national databases concerning the 2013 year.	Numbers for non-medically attended concussions are likely not accurate, or at least more variable. The authors used values from very specific, small scale non-report studies due to the lack of nationally representative studies in this area.

485. Mersine A. Bryan, Ali Rowhani-Rahbar, R. Dawn Comstock & Frederick Rivara, *Sports-and Recreation-Related Concussions in US Youth*, PEDIATRICS (June 2016) <http://pediatrics.aappublications.org/content/early/2016/06/16/peds.2015-4635>. Cited by 13.

486. International Classification of Disease, 9th Revision, Clinical Modification (ICD-9-CM) is an official system of designing codes to diagnoses and procedures put out by the World Health Organization (<https://www.cdc.gov/nchs/icd/icd9cm.htm>); codes are based off of cause and severity of injury amongst other factors

		activity or place of recreation (e.g. playground) was mentioned, regardless of mechanism of injury			ED visits per 1,000 children Total: 14.05 – 24.1 per 1,000 children			
Selassie et al. (2013) ⁴⁸⁷	Sports and recreation related / 1988 through 2011	<i>TBI</i> : E-codes 800–801, 803–804, 850–854, and 959.01, from the ICD-9 ⁴⁸⁸ <i>Concussion</i> : E-code 850.*	TBI cases at all 65 nonfederal hospitals and 67 civilian emergency department in South Carolina (n = 275,613)	Emergency department cases of sports-related TBI in South Carolina (n = 16,642)	10,191 cases of sports-related TBI for 0 – 18 year olds (61.3% of total sports-related TBI) / Incidence rate of 1.206 sports-related TBI per 1,000 for 12-18 year olds; 0.61 sports-related TBI per 1,000 sports for 6-11 year olds	Incidence rate were calculated from the count per age-group adjusted to the total population of South Carolina in that specific age group.	Prospective surveillance system in South Carolina ⁴⁸⁹	18.2% of severe TBI were a repetitive TBI, although only 6.1% of TBI were repetitive cases. 80% of the repetitive sport-TBI cases were 25 years old or younger.

487. Anbesaw W. Selassie, Dulaney A. Wilson, E. Elisabeth Pickelsimer, Delia C. Voronca, Nolan R. Williams & Jonathan C. Edwards, *Incidence of Sport-Related Traumatic Brain Injury and Risk Factors of Severity: A Population-Based Epidemiologic Study*, 23 ANNALS EPIDEMIOLOGY 750, 750-56 (2013). Cited by 45.

488. International Classification of Disease, 9th Revision (ICD-9) is an official system of designing codes to diagnoses and procedures put out by the World Health Organization (<https://www.cdc.gov/nchs/icd/icd9cm.htm>); codes are based off of cause and severity of injury amongst other factors

489. <http://academicdepartments.musc.edu/sctbifr/survey.htm>

					/ 49.2% of sports-related TBI were concussions			
Theadom et al. (2014) ⁴⁹⁰	Sports-related activities ⁴⁹¹ / March 1 st , 2010 through February 28 th , 2011	TBI: from World Health Organization: “an acute head injury resulting from mechanical injury to the head from external forces.” ⁴⁹²	Population of 1 rural district and 1 urban district in New Zealand (n = 173,214)	Total population of the districts (n = 173,214)	291 cases of sports-related TBI; 114 sports-related concussion in under-16 year olds / Incidence rate of 1.7 per 1,00 population	Incidence calculations were based on New Zealand census data and, for specific sports, on data from the Sport and Recreation Participation Levels in New Zealand report.	Evaluated sports-related traumatic brain injury (TBI) incidence and severity in New Zealand as part of a wider TBI surveillance study, including medically admitted TBI as well as self-report; all were checked with records and interview were conducted when possible.	Children under 18 account for over half of sports-related TBI (51%), and those under 16 account for 39% of all sports-related TBI (n = 114)

490. Alice Theadom, Nicola J. Starkey, Tony Dowell, Patria A. Hume, Michael Kahan, Kathryn McPherson, Valery Feigin & BIONIC Research Group, *Sports-Related Brain Injury in the General Population: An Epidemiological Study*, 17 J. SCI. MED. SPORT 591, 591-96 (2014). Cited by 12.

491. “1) purpose of competition/pleasure involving physical exertion and skill; 2) may follow rules or require the use of specific equipment; 3) excludes physical activities such as walking, gardening, cycling as means of transportation or playing on play-ground equipment.” From Theadom, Alice, Nicola J. Starkey, Tony Dowell, Patria A. Hume, Michael Kahan, Kathryn McPherson, Valery Feigin, and BIONIC Research Group. “Sports-related brain injury in the general population: an epidemiological study.” *Journal of science and medicine in sport* 17, no. 6 (2014): 591-596. Cited by 12. At 592.

492. Linda J. Carroll, J. David Cassidy, Lena Holm, Jess Kraus & Victor G. Coronado, *Methodological Issues and Research Recommendations for Mild Traumatic Brain Injury: The WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury*, 43 J. REHAB. MED. 113, 113-25 (2004). Cited by 549.

McKinlay et al. (2008) ⁴⁹³	Sports-related TBI, rugby / 1977 – 2002	<i>TBI:</i> operationalized via parental recall of official GP or specialist visits until age 16, then self-report was also allowed Only included cases where medical treatment was sought and minimum diagnosis of concussion	Birth cohort of 1,265 children	Surviving children from birth cohort (n = 1,003) at 25 years of age / Total of 458 head injuries	19 sports-related TBI from 0 – 14 years; 64 sports-related TBI from 15 – 25 years (n = 49 for rugby) / 23.6 TBI per 1,000 children for 15 – 20 year olds	Incidence rates were calculated based on the count of TBI sustained during the particular span of years, divided by the total number of children	Prospective birth cohort study with participants assessed at birth, 4 months, 1 year, annual intervals to age 16 years, and at ages 18, 21 and 25 years using parental interview, self-report, psychometric assessments, teacher questionnaire, medical records and other official record data.	226 individuals sustained 1 concussion, 71 sustained 2 concussions, 14 sustained 3 concussions, 4 sustained 4 concussions and 3 sustained more than 4. Trends also indicate that males become more likely to experience a TBI than females after age 5, particularly TBI requiring inpatient admission; there were approximately equal proportions of males and females in the study. By age 25, 38.47% of males had experience a TBI, versus 24.4% of females
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493. A. McKinlay, R. C. Grace, L. J. Horwood, D. M. Fergusson, Elizabeth M. Ridder & M. R. MacFarlane, *Prevalence of Traumatic Brain Injury Among Children, Adolescents and Young Adults: Prospective Evidence from a Birth Cohort*, 22 BRAIN INJURY 175, 175-81 (2008). Cited by 223.

Annegers et al. (1980) ⁴⁹⁴	1935 – 1974	<i>Head trauma with evidence of brain involvement:</i> head injury with loss of consciousness, posttraumatic amnesia, or skull fracture (used diagnostic codes, but unclear which ones)	Population of U.S., based on 1970 census	Head trauma cases in Olmstead County presenting to medical services with diagnosis of head trauma	1965 – 1974: 1,626 cases 1935 – 1974: 3,587 Recreation-related: 333 (9.4%) / 1965 – 1974: M: 0.33 per 1,00 population [highest incidence rate in 15 – 24 age group] F: 0.09 per 1,000 population [highest incidence rate in 5 – 14 age group]	Age adjusted rates of incidence were calculated based on the population of Olmstead County	The authors used medical records from the Rochester Project at the Mayo Clinic and reviewed medical records and fatality records of Olmstead County residents between 1935 and 1974.	Evidence of increasing sports and recreation-related incidence rates (as well as motor vehicle), while other mechanisms remained stable over the study period. Incidence rates overall increased progressively each decade – per 100,000 males, rates were 117, 215, 221 and 270; per 100,000 females, rates were 46, 82, 88 and 116
Williamson & Goodman (2006) ⁴⁹⁵	Male and female youth ice hockey /	<i>Official injury reports:</i> league defined explicit	1 season /	Males' age divisions pee-wee (11 – 12), bantam (13 –	Male: 60 concussions Female: 7 concussions	Calculated incidence based on an assumption that all	Data collection from official records, performed by British	Official records were significantly lower than both direct observation

494. John F. Annegers, Jack D. Grabow, Leonard T. Kurland & Edward R. Laws, *The Incidence, Causes, and Secular Trends of Head Trauma in Olmsted County, Minnesota, 1935–1974*, 30 NEUROLOGY 912, 912-19 (1980).

495. I. J. S. Williamson & D. Goodman, *Converging Evidence for the Under-Reporting of Concussions in Youth Ice Hockey*, 40 BRIT. J. SPORTS MED. 128, 128-32 (2006). Cited by

2003-2004 season	concussion reports	<i>Athletic exposure (AE):</i> 1 game <i>Player Game Hours (PGH):</i> 1 player playing 1 hour of a game	14), and midget (15 – 17), as well as females’ aged 12 – 19 [males (n = 19,548); females (n = 5,017)] in British Columbia	/ Males: 0.06 – 0.15 concussions per 1,000 AEs, or 0.25 – 0.61 concussions per 1,000 PGH	concussion occurred during games, and estimated player hours and player exposures based on minimum and maximum games per age group and level, each with 0.25 of	Columbia Amateur Hockey Association of Hockey Canada	and athlete self-report
Male and female youth ice hockey / 2002-2003 season	<i>Direction observation:</i> “head incidents of concern”, i.e. physician diagnosed concussion, or episode seriously indicative of concussion based on observed signs or symptoms	3.5 months / <i>Athletic exposure (AE):</i> 1 game <i>Player Game Hours (PGH):</i> 1 player playing 1 hour of a game	792 players across pee-wee, bantam and midget divisions in British Columbia	22 concussions or incidents of concern / 1.11 – 1.98 per 1,000 AEs, or 4.44 – 7.94 per 1,000 PGHs	played hours per player	44 team volunteers (coaches, managers or safety personal) reported physician diagnosed concussion, or episode seriously indicative of concussion based on observed signs or symptoms	

	Male and female youth ice hockey players / Elite (2001 – 2003) Recreational (2004)	<i>Self-report:</i> hockey induced hit to the head inducing signs or symptoms of a concussion (only included current and directly prior season)	2 seasons / <i>Athletic exposure (AE)</i> – 1 game <i>Player Game Hours (PGH)</i> – 1 player playing 1 hour of a game	107 players across peewee, bantam, and midget age divisions in British Columbia Elite male (n = 475) and elite female (n = 309) in British Columbia	26 concussions/ incidents of concern / 2.43 – 6.07 concussions per 1,000 AEs, or 9.72 – 24.3 concussions per 1,000 PGH M: 79 concussions/ incidents of concern F: 69 concussions/ incidents of concern / M: 1.66 – 2.08 per 1,000 AEs and 6.65 – 8.32 per 1,000 PGH F: 2.23 – 2.79 per 1,000 AEs and 8.93 – 11.17 per 1,000 PGH		Self-report questionnaires- players were asked to report any hockey induced hit to the head inducing signs or symptoms of a concussion; only those from the current and prior seasons were included in analysis	
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Fife (1987) ⁴⁹⁶	1977 – 1981	<i>Head injury:</i> included skull fracture or damage to the cranial contents (ICD codes 800.0-801.9, 803.0-803.9, and 850.0-854.9)	Population of the United States	Approximately 200,00 families surveyed during the 1977-81 years of the National Health Interview Survey; includes all ages	Estimated 1.87 million annual head injuries Estimated 307,000 hospitalizations annually for head injury	Unclear what U.S. population estimates were used to calculate total estimated head injuries from survey counts (may come from the National Center for Health Statistics)	Used data from the National Health Interview Survey, which collects information on injuries occurring during the previous two weeks of the interview of currently living household members (excluding institutionalized or military). The authors pooled the data from 5 years (1977 – 1981)	It is less likely for children, individuals from low-income families, and those injured in home, recreation or school setting to be hospitalized.
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496. Daniel Fife, *Head Injury with and without Hospital Admission: Comparisons of Incidence and Short-Term Disability*, 77 AM. J. PUB. HEALTH, 810, 810-12 (1987). Cited by 86.