Epidemiology of concussion in sport: a literature review

Michael B. Clay DC^{a,*}, Kari L. Glover PT, DPT^b, Duane T. Lowe DC^c

^a Clinical Lead, Chiropractic Clinic, Naval Hospital Camp Lejeune, Camp Lejeune, NC

^b Staff Clinician, Bodies in Balance Physical Therapy, Wilmington, NC

^c Staff Clinician, Inter-Disciplinary Pain Management Clinic, Madigan Army Medical Center, Fort Lewis, WA

Received 7 August 2012; received in revised form 19 November 2012; accepted 30 November 2012

Key indexing terms:

Concussion;
Sport;
Incidence;
Epidemiology;
Traumatic brain injury

Abstract

Objective: The purpose of this study was to summarize sport concussion incidence data, identify sports that present higher injury frequency, reveal the degree of risk in some lesser-known sports, and outline specific details within the sports literature that raise additional concerns, such as helmet-to-helmet contact and player positions that experience frequent impact.

Methods: A systematic literature review of Pub Med using keyword search on injury, concussion, and sports was performed through May 2012. Abstracts were identified, selections were made based upon inclusion criteria, and full-length articles were obtained. Additional articles were considered following review of reference sections. Articles were reviewed and tabulated according to sport.

Results: Two hundred eighty-nine articles were screened, and 62 articles were reviewed. The overall incidence of concussion in sport ranged from 0.1 to 21.5 per 1000 athletic exposures. The lowest incidence was reported in swimming and diving. Concussion incidence was highest in Canadian junior ice hockey, but elevated incidence in American football remains a concern because of the large number of participants.

Conclusions: The literature reviewed included incidence of concussion on the field of play under real-world conditions and influenced by the current culture of sport. The studies examined in this article show that there is risk of concussion in nearly every sport. Some sports have higher concussion frequency than others, which may depend upon the forces and roles of the positions played in these sports. Younger athletes have a higher incidence of concussion, and female incidence is greater than male in many comparable sports. Headgear may reduce concussion in some sports but may also give athletes a false sense of protection.

© 2013 National University of Health Sciences.

Disclaimer: The views expressed are those of the authors and do not reflect the official policy of the Department of the Navy, the Department of the Army, the Department of Defense, or the US Government.

* Corresponding author. Michael B. Clay, DC, Clinical Lead, 409 Ravenswood Rd Hampstead, NC 28443.

E-mail address: mnclay2000@yahoo.com (M. B. Clay).

Introduction

According to the Centers for Disease Control, from 2001 to 2009, the estimated number of visits to hospital emergency departments for sports- and recreation-related concussions increased 62%, from 153,375 to 248,418, in persons 19 years or younger.¹ The increasing frequency of sport-related concussion and the emerging possible long-term health risks continue to raise concern in the health care community, in the general public, and to those who set public policy. Although it has been widely believed that athletes are fit to return to play when observed symptoms resolve, researchers are also examining the possible prolonged effects of concussion, subconcussive impacts, and repeated concussions on cognitive difficulties, emotional disturbances, depression, and behavioral issues as well as chronic or recurring physical symptoms, such as headache.²⁻⁵

An increased awareness in concussion has caused changes in how organized sports are played. In response to recent concussion research, Pop Warner Football, the largest and oldest youth football league in the United States, adopted rule changes for the 2012 season that limit contact during practices. In 2012, Kentucky became the 38th state to enact a youth concussion law when their governor signed legislation mandating training for coaches and concussion monitoring for players.⁶ In June of 2012, a lawsuit was filed against the National Football League (NFL) on behalf of more than 2000 former players suffering from long-term effects of concussions sustained during their careers in the NFL.⁷ More than 13 scientific articles concerning the epidemiology of concussion in sport have been published in the last year alone.

There are variations in the definition of *concussion*, and various guidelines have been proposed.⁸ Current evidence-based guidelines for sport were developed in 2008 by international consensus.⁹ The guidelines state that “Concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces.” The diagnosis is based on symptoms and examination of the patient/player. Neurological imaging and laboratory tests have not revealed corresponding abnormalities. This underscores the importance of training first responders in recognizing the signs and symptoms of concussion.

Health care professionals and those involved with sport such as coaches, officials, and lawmakers must understand the frequency of this injury in various athletic activities. They also need to be cognizant of factors that improve recognition of mild concussions to diminish the risk to players. Accurate knowledge of the incidence of concussion in athletes and the factors affecting the risk of

concussion will be instrumental in evaluating current rules, regulations and safety equipment and in guiding future changes in various sports.

The purpose of this article is to summarize current sport concussion incidence data, highlight sports that present higher injury frequency, reveal the degree of risk in some lesser-known sports, and outline specific details within the sports literature that raise additional concern, such as helmet-to-helmet contact, player positions that experience frequent impact, and limitations of study methods. This article also discusses the difficulty in evaluating and determining the true rate of concussion across multiple sports and demographics.

Methods

Our methods followed the Meta-analysis of Observational Studies in Epidemiology and the Preferred Reporting Items for Systematic Reviews guidelines that cover systematic reviews of the type of studies that explore concussion in sport.^{10,11}

Search

National Center for Biotechnology Information Pub Med keyword searches were conducted without restriction of date until May 18, 2012. Only published articles were used. Medical Subject Headings (MeSH) terms pertaining to epidemiology of concussion in sport were used as search terms and are listed in [Appendix A](#).

Abstract exclusion criteria

Studies included described epidemiology or incidence of accidental concussion in sport. Athletes who train specifically to render opponents unconscious as in boxing or other martial art sports were excluded from our search. No constraints were placed upon language. One abstract written in Dutch was excluded because of lack of sport specificity. Translation was arranged with a Dutch speaker for this article.

Full-length article criteria

Full-length articles were obtained and read by all authors. Studies that listed “sport injury” as the cause of concussion, and no specific sport, were excluded. Prospective or retrospective cohort studies, cross-sectional studies, or interventional studies were included. Systematic reviews were excluded. Data were extracted independently based upon an agreed upon format for the tables. Incidence of concussion was the primary finding sought, along with target population, sport, study

design, author, date of publication, and study strengths and weaknesses. Concerns of bias were recorded under weaknesses, but no analysis tool was used. The primary measure of incidence was concussions per 1000 athletic exposures (AEs), but risk ratios were included as available and appropriate. Contact with author Christy Collins clarified surveillance methods and national high school (HS) sports database use.

Results

Overview

Screening of 289 abstracts resulted initially in 52 articles. Reference review resulted in 10 additional articles that were added to the full-length review, for a total of 62 articles. Exclusion criteria based upon study type and sport specificity were applied, and 17 articles

were eliminated (Fig 1).^{8,12-27} The 45 studies were summarized, divided by sport, and placed in Tables 1 to 5. Multiple sport studies were separated and placed in Table 6, with incidence data in Table 7. These tables allow for ease of comparison but do not represent meta-analysis or resynthesis of data.

Multisport incidence data was converted to concussions per 1000 AEs. The concussion/1000 AEs reporting method facilitated ease of comparison.

Tables 8 and 9 reprint the 2007 tables of Gessel et al⁶³ and demonstrate the most recent overview of sport-related concussion incidence and mechanisms at both HS and collegiate levels in the same study.

Bias

Cochrane risk of bias tool was considered, but we felt that it was not appropriate to the studies included.

Fig 1. Method flowchart. *MESH*, medical subject headings.

Nearly all of the studies used open cohorts, somewhat ambiguous diagnosis, and depended upon participants' "self report." These methods frequently result in self-selection, non-respondent, insensitive measurement, recall, loss of follow-up, attention, and withdrawal biases.

Overall incidence of concussion

Overall incidence of concussion ranged from Schulz's⁶⁰ reported 0.17 concussion/1000 AEs 95% confidence interval (CI) (0.13-0.21) in HS to the 0.43/1000 AEs 95% CI (0.27-0.28) college figure from Gessel et al.⁶³ Caution should be exercised when interpreting this information in that none of these studies used the exact same sports, methods of reporting differed, and the reports span a 10-year period in which concussion research was evolving.

Football

High school incidence ranged from an estimated 0.48/1000 AEs³⁶ to a reported 1.03/1000 AEs,²⁸ and college incidences ranged from an estimated 0.52³⁷ to a reported 0.81/1000 AEs.³¹ An NFL incidence estimated at 4.56/1000 game AEs³² did not include practice data.

Concussion incidence from the multisport studies ranged from 0.33/1000 AEs CI (0.25-0.41) in HS⁶⁰ to 0.64/1000 AEs.⁶⁹ The highest incidence in collegiate football was 0.61/1000 AEs.⁶³

Rugby and Australian rules football

Amateur Australian footballers' concussions comprising 15% of all injuries were the most frequent injury.⁴⁷ Incidence in male nonprofessional rugby players was 7.97/1000 player hours.⁵¹ Hollis et al⁵³ reported an incidence of 14% per 20-hour season in experienced rugby players. Haseler et al⁵² reported community rugby club player incidence at 1.8/1000 player hours. Shuttleworth-Edwards et al⁵⁰ reported annual rugby concussions between 4% and 14% at school level and between 3% and 23% at adult level.

Hockey

Concussions ranged from 21.52/1000 AEs in junior hockey⁴⁴ to 1.55/1000 AEs in collegiate players.⁴⁰ Agel and Harvey⁴³ reported lower incidence in collegiate men at 0.72/1000 AEs than women at 0.82/1000 AEs.

The report of Echlin et al⁴⁴ of 21.52/1000 AEs in junior hockey is 7 times higher than previously reported in the NHL.

Multisport studies incidence ranged from 0.41/1000 AEs CI (0.37-0.44) in collegiate male hockey⁶⁴ to 0.54/1000 AEs in HS males.⁶⁹ Hootman et al⁶⁴ reported collegiate female hockey incidence at 0.91/1000 AEs CI (0.71-1.11).

Lacrosse

Dick et al reported an overall incidence in collegiate men of 1.08 CI (0.92-1.25)/1000 AEs⁵⁴ and 0.52 CI (0.41-0.64)/1000 AEs in women.⁴¹ Concussion was 8.6% of all game injury in men and 9.4% in women. Lincoln et al⁵⁶ reported an incidence in HS males of 0.28/1000 AEs and 0.21/1000 AEs in females, and college males at 0.87/1000 AEs and females at 0.32/1000 AEs.

Multisport study incidences ranged from 0.26/1000 AEs CI (0.23-0.29) in collegiate males⁶⁴ to 0.40/1000 AEs in HS males.⁶⁹ Concussion spanned from 0.25/1000 AEs CI (0.22-0.28) in collegiate females⁶⁴ to 0.35/1000 AEs in HS females.⁶⁹

Soccer

Concussion in the multisport studies ranged from 0.13 CI (0.0-0.27)/1000 AEs⁶⁰ in HS females to 0.41 CI/1000 AEs (0.38-0.44) in college females.⁶⁴ Male incidence spanned from HS at 0.17⁶⁸ to college at 0.49/1000 AEs.⁶³

Discussion

Problems defining concussion

Acceptance of the Third Zurich consensus statement definition of concussion for use by medical professionals, coaches, and others involved in the care of injured athletes at the recreational, elite, or professional level allows examination of concussion from a uniform perspective.⁹ This definition of concussion is not uniformly used throughout the 46 studies reviewed from 1999 to 2012.

Associated variables such as headache following observed head trauma, loss of consciousness, loss of playing time, missing school, and missing sport activities have all been used to define reporting criteria; but a change in definition changes the data that are

Table 1 Football concussions

First author and year	Target population and sport	Design and source of information	Findings	Study strength	Study weakness
Guskiewicz et al, 2000 ²⁸	17,549 football players from 249 HSs and Div 1-3 colleges from 1995 to 1997.	Prospective cohort study. Data recorded by 1 trainer immediately after injury occurred for each school.	Overall incidence of 0.71 concussion/1000 AEs HS = 1.63/1000 AEs Div 1 = 0.94/1000 AEs Div 2 = 1.34/1000 AEs Div 3 = 1.31/1000 AEs.	Large sampling of players. Used Cantu guidelines for definition of concussion. Games and practices were considered for AE calculations. 14.7% of the concussed sustained a second concussion during the same season. Grade 1 88.9% Grade 2 10.6% Grade 3 0.4%.	Only 62% (242 out of 392) of trainers provided complete data. Only schools with athletic trainers participated. AE to contact and noncontact events was determined by telephone interview and mailed surveys from a subsample of 45 schools.
Langburt et al, 2001 ²⁹	HS football players in Pennsylvania and Ohio after the 1996-1997 season.	Retrospective questionnaire data reported by players. Only 234/450 responses were returned, and 1 was excluded.	47.2% players reported evidence of concussion. 34.8% reported multiple concussions. 87.8% were classified as Cantu Grade I. Most did not stop playing.	Anonymous questionnaires. Did not use term <i>concussion</i> but used <i>head injury</i> to avoid misconception that unconsciousness was required.	Self-reported, retrospective, questionnaire at the end of the season could produce recall and self-selection bias. Only slightly more than half of players responded, but no effort to characterize nonrespondents.
Delaney et al, 2002 ³⁰	328 football and 201 soccer athletes reporting to 1999 Canadian university fall training camps. Study included 110 females and 9 undetermined.	Retrospective survey. Players reporting on 1998 season. Response rate was 86% for football and 84% for soccer.	70.4% of football and 62.7% of soccer players reported symptoms of concussion during the previous year. Soccer players had over 3× greater chance of concussion if they had previous concussion.	Only 23.4% of the football players and 19.8% of the soccer players realized that the symptoms they had suffered represented a concussion. Goalies were most likely to be concussed in soccer and tight-ends and defensive linemen in football. Female soccer players had 2.6× greater odds of concussion.	Retrospective design increases recall bias, and self-selection bias is also a concern when self-report is used and nonreports are not examined.
Guskiewicz et al, 2003 ³¹	2905 Division 1, 2, and 3 collegiate football players.	Prospective cohort study collected by ATCs.	0.81 concussion per 1000 AEs overall. 3.81/1000 AEs in games and 0.47 in contact practice. Linebacker had highest incidence of concussion at 0.99/1000 AEs	Used graded symptom checklist to quantify symptoms at baseline and postinjury. Increased risk associated with concussion incidence established at 0.66 for 0 concussions, 0.96 for 1 concussion, 1.85 for 2 concussions, and 2.23/1000 AEs for 3+ concussions.	Exposure data were estimated.
Pellman et al, 2004 #3 ³²	Entire population of NFL league players from 1996 to 2001. Adult, male, professional football players.	Prospective, 6-y epidemiology study. Data gathered by team physicians of the NFL ISS.	Concussion incidence of 0.41 concussion/game could be converted to concussions/AEs by assuming an active roster of 45 equates to 90 AEs	Standardized form used. Multiple years of data. Player position, type of play, and impact object data available. Detailed symptom analysis. Most vulnerable	Methodology changes several times throughout the study. No data on practices. May not be generalizable to nonprofessional populations.

Pellman et al, 2004 ^{#533}	NFL football player's average age was 27.6 (±3.6 y). 1996 to 2001.	6-y cohort of population with 7+ d out of play collected by team doctors.	for the 2 teams, and this suggests a concussion incidence of 4.56/1000 AEs. 8.1% of players had concussion involving 7+ d out from play, and highest frequency occurred in quarterbacks at 14.8%.	positions to concussion are quarterback, wide receiver, and defensive secondary. Establishes a gradient of disability and leads to a discussion of postconcussion syndrome.	Players could have sustained a concussion, but not have been included because of a lack of cooperation or transient and unrecognized episode.
Wisniewski et al, 2004 ³⁴	NCAA division 1 football players for the 2001 season.	Prospective intervention cohort and descriptive epidemiology study. Data gathered by athletic trainers.	0.73 concussion per 1000 AEs in 791 games, 2839 contact practices, and 1708 noncontact practices. No advantage found in wearing a custom mouthpiece.	Large size. Differentiated concussions in contact (0.39/1000 AEs) and noncontact (0.02/1000 AEs) practices from games (5.49/1000 AEs). Relates greatest frequency of concussion to player position (linebacker), as well as mechanism of injury (head to head contact).	No explanation for 24% of teams that did not elect to participate. No explanation for the 7 trainers that did not report any data or the 17 that reported incomplete data.
Collins et al, 2006 ³⁵	2141 HS male football players from western Pennsylvania 54 practices and 11 games per team/y, over a 3-y period 2002-2004.	3-y prospective naturalistic case control cohort study reported by ATCs.	5.3% of athletes wearing the Revolution helmet were concussed per season. 7.6% of athletes wearing a standard helmets were concussed per season. $\chi^2(1, 2, 141) = 4.96, P.$	Clear definition of concussion given to ATCs and physicians present at time of injury. "International return-to-play standards" were followed.	Sample of Revolution athletes were older by 0.4 y and had a higher number of prior concussions than the traditional helmet group. Athletes' concern of prior concussion may have created self-selection bias based upon the perception that the Revolution helmet was safer. Author Ide, as a vice president for Riddell, may have had conflict of interest.
Shankar et al, 2007 ³⁶	100 HS football and 55 NCAA Div 1, 2, and 3 teams representing 833,174 AEs in 2005-2006.	Descriptive epidemiology study using RIO and ISS uses ATCs to collect data.	0.48/1000 AEs HS and 0.68/1000 AEs. NCAA rate was not calculated by authors, but could be calculated from data on concussions, head/face injuries, and AE for HS and college.	Large national sample of varying sizes of HSs and multiple NCAA divisions. Used only trained reporters to improve data quality. Running plays were the leading cause of HS concussion. HS concussions were a greater proportion of practice injuries (13%) than in the NCAA (10%).	Only schools with certified ATCs participated. Study data are not specific to concussion and is difficult to interpret in context. Reported data required 1 d missed because of injury.
Yard et al, 2009 ³⁷	HS football players. No disclosure of female players.	Descriptive epidemiology study using 2005-2006 RIO samples of 100 US HS reported by ATCs.	0.52 concussion/1000 AEs were not calculated by authors, but are 12% of 1880 reported injuries/431,242 exposures.	Size of study. Injuries established by ATCs. Study identified elevated risk of concussion during mid and late phase of play. Kickoff or punt play resulted in higher likelihood of concussion IPR 1.86 CI (1.05-3.30).	ATCs did not attend all practices or competitions. Use of AEs limits comparison between other sports, as AEs will not be an equivalent measure.

(continued on next page)

Table 1 (continued)

First author and year	Target population and sport	Design and source of information	Findings	Study strength	Study weakness
Crisco et al, 2010 ³⁸	188 players from 3 NCAA football teams.	Cohort study. Instrument data downloaded by authors.	Players receive 6.3 helmet impacts per practice and 14.3 impacts per game. Frequency and location differed by position.	Most frequent impacts were found in linebackers and offensive and defensive linemen. Data on individual impacts were collected.	No correlation of helmet impacts with injury or concussion.
Mansell et al, 2010 ³⁹	168 male college football players and 33 female soccer players.	Retrospective case control study data collected by questionnaire from players.	59% of control group reported signs and symptoms of concussion following head impact in the previous year but were undiagnosed. 80% of case group reported signs and symptoms following head impact in the prior year.	Includes athlete anthropometric and age data. Correlation between head-neck length and signs and symptom frequency, as well as between body mass and signs and symptom frequency.	Self-reported, retrospective questionnaire. Self-selection and recall bias possible. No description of recruitment or follow-up on those who refused to participate. Questionnaire signs and symptoms were not referenced to any prior concussion-related research questionnaires.

Confidence interval: 95% unless otherwise stated.

AE, athletic exposures; ATC, certified athletic trainer; CI, confidence interval, 95% unless otherwise stated; HS, high school; IPR, injury proportion ratio; ISS, injury surveillance system; NCAA, National Collegiate Athletic Association; NFL, National Football League; RIO, reporting information online, National High School Sports-Related Injury Surveillance Study; US, United States.

gathered.^{29,37,47,48,64} Lack of uniformity in selection criteria may result in deviation from reporting the true number of concussions.

Players, coaches, and providers do not always recognize the spectrum of posttraumatic symptoms that identify concussion.^{30,42} Players are often unaware that symptoms of a concussion should prevent play.⁴² Ignorance of symptoms may be complicated by fear of exclusion from the game⁵⁰ or a “win at all costs” attitude, and researchers should be aware of this complication to reporting consistency.⁴²

Concussion incidence trends

Several multisport studies report incidence of concussion ranging from 0.01/1000 AEs in track⁶⁹ to 0.91/1000 AEs in women’s ice hockey.⁶⁴ The general consensus is that concussion incidence is rising.⁷⁰ However, one study reported that game injury rates have shown an average annual 2.5% decline over 15 years.¹² The highest reported incidences of concussion, in descending order, are football, female and male soccer, wrestling, and female basketball.^{59,60,63,64,67-70} Overall, football accounts for the highest proportion of concussion.^{27,59,63,64,66-70}

Study comparisons

Articles can be divided into 2 groups: surveillance studies like the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) or High School Reporting Information Online (RIO; National High School Sports-Related Injury Surveillance Study) and more traditional cohort studies. Foreign studies have trended toward cohorts.^{49,52,53} Differences that impact conclusions about concussion, such as reporting method, exist and are highlighted in Table 10.^{28,31,49,53,56,60} An ideal study would blend advantages of both approaches.

Data capture

The much higher hockey incidence of Echlin et al⁴⁴ appears to be related to independent physicians diagnosing concussions and using multiple trained data collectors compared with other studies who did not.^{21,40,44,64,69} Lincoln et al⁶⁸ attributed an increase in concussions reported across all sports and sexes in 2005 to a 50% increase in Certified Athletic Trainer (ATC) coverage. This demonstrates that increased training and observation may result in greater capture of concussions.

Table 2 Hockey concussions

First author and year	Target population and sport	Design and source of information	Findings	Study strengths	Study weaknesses
Benson et al, 1999 ⁴⁰	642 male Canadian university hockey players 1997-1998 with mean age 22 y.	Prospective cohort study. Data recorded by team doctor or therapist.	Concussion incidence 1.55/1000 AEs was not impacted by players wearing half- or full-face shields, but time lost to concussion was greater than that of half shields.	Suggests that the additional protection of a full shield that reduces facial and dental injuries did not increase risk of concussion. Weekly recording of data by team therapists present at every game or practice.	Potential for nondifferential misclassification reporting bias due to no method of verifying completeness of reporting for injuries that did not result in time lost from play. Data may not be generalizable to HS or younger players.
Dick et al, 2007 ⁴¹	Collegiate women's field hockey using NCAA ISS data from seasons 1988-1989 through 2002-2003.	Descriptive Epidemiology study 15-y review of data recorded by ATCs.	Concussions were >5.4% of severe game injuries. Game concussion risk was 6× higher than practice (rate ratio= 6.1 95% CI (4.3-8.7). 9.4% of game injuries and 3.4% in practice were concussions. Game injury rates declined an average 2.5% annually over 15 y.	NCAA ISS data on field hockey injuries used standardized case definitions for injuries or exposure classification in a clearly defined population of collegiate athletes for a prolonged period. Study advocated need for helmets. Pointed out that mouth guards were the only above-the-neck equipment required for nongoalies.	17.6% of schools sponsoring varsity women's field hockey programs participated in annual NCAA ISS data collection.
Benson et al, 2002 ²¹	642 male Canadian university hockey players 1997-1998 with mean age 22 y.	Prospective cohort with multivariate analysis. Data collected by team therapists and doctors.	Incidence of concussion was 1.5/1000 AEs. ½ shields missed 2.4× practices and games than those with full shields.	Injury report form filled out on each eligible injury. Suggests that concussion severity can be mitigated through use of protective equipment.	Study reuses data from 1999 article and may be susceptible to same bias.
Cusimano et al, 2009 ⁴²	Players, coaches, trainers, and parents of 10-to 14-y-old hockey players.	Questionnaire was self-reported.	Significant confusion regarding concussion in hockey, its treatment symptoms, and safe return to play suggests that underreporting is likely.	Suggests that people associated with concussed athletes should not be relied upon for data and should be properly trained in appropriate care.	No proposal for improvement in training of people involved with concussion care.

(continued on next page)

Table 2 (*continued*)

First author and year	Target population and sport	Design and source of information	Findings	Study strengths	Study weaknesses
Agel et al, 2010 ⁴³	NCAA men's and women's hockey.	Retrospective ISS database reported by ATCs.	Concussion incidence of 0.72/1000 AEs for men and 0.82/1000 AEs for women.	Large study size included 7 seasons. Rate remained stable over the study. Player contact was the cause of concussions in games for 41% of women and 72% of men.	Concussion rates reported here may be artificially low because of a requisite of time loss for data reporting.
Echlin et al, 2010 ⁴⁴	67 male Canadian 4th-tier ice hockey players 16-21 y old, during the 2009-2010 season.	Prospective cohort study observed by physicians.	Concussion incidence of 21.52/1000 AEs in 4th-tier junior hockey was 7× higher than the highest rate previously reported. The 36.5% rate of concussion observed per game was far higher than the 3.1% previously reported in the National Hockey League.	Suggests that concussion incidence may be significantly higher than previously reported and accurate data require independent data collection. Assumption that athletic trainers that work with HS teams are free of bias may be inaccurate. Trained data collectors, independent of the teams, are much less likely to introduce bias.	Small study size. Loss of significant data due to failure of team to comply with study.
Cusimano et al, 2011 ⁴⁵	Male hockey league players aged 6-17 y for 10 seasons.	Retrospective study.	Rule change to allow body checking in 10- and 11-y-olds resulted in an increased odds ratio to 2.27 CI (1.42-3.65) of ED visit due to concussion in the 10- to 11-y-olds.	10-y study was 5 y before rule change and 5 y after. This allows the impact of rule changed to be examined.	ED data capture was limited, and concussion was only counted because of body checking. League participation was not captured, so injury rate is unknown.
Brainard et al, 2012 ⁴⁶	88 NCAA hockey athletes: 37 male and 51 female.	Prospective cohort data were collected by helmet sensors.	Female players sustain fewer impacts and lower head acceleration than males.	Eliminates frequency of impact as the source of greater incidence of concussion in female hockey players.	Study size and scope limited by having only 2 teams. Concussion data not collected.

AE, athletic exposures; *ATC*, certified athletic trainer; *CI*, confidence interval, 95% unless otherwise stated; *ED*, emergency department; *HS*, high school; *ISS*, injury surveillance system; *NCAA*, National Collegiate Athletic Association.

Table 3 Rugby concussions

First author and year	Target population and sport	Design and source of information	Findings	Study strengths	Study weaknesses
Shawdon et al, 1994 ⁴⁷	80 amateur Australian rules footballers.	Single season cohort data recorded by team doctor in 1993.	Concussion comprised 15% of all injuries and was the most frequent injury. 14.4 concussions/1000 player hours can be calculated.	A single team doctor recorded all injuries. Use of hours in method allows for comparison to other sports.	Small size of study. Concussion not specifically defined. Injury required missing a game to be reported.
Collins et al, 2008 ⁴⁸	HS rugby players in the US in 2005-2006 sample of 121 boys and girls.	Descriptive epidemiology study. Data collected by a mix of personnel, but 77.7% coaches.	Concussion comprised 15.8% of injuries. 10.2% of season- or career-ending injuries were concussion.	Data collectors were trained. Impact with another player composed 50.8% of all injuries.	Only 22.3% of data reporters were medically trained. Clubs self-selected inclusion. Reportable injury required "restriction of the HS rugby player's participation in regular school or rugby activities for 1 or more days beyond the day of injury."
Kemp et al, 2008 ⁴⁹	757 English male rugby union players over 3 seasons.	Prospective cohort study data collected by team medical personnel.	Incidence of match concussions was 4.1/1000 player hours. Incidence of concussions by players not wearing headgear was significantly higher than those wearing headgear.	Concussion was associated with tackling head-on (28%), collisions (20%), and being tackled head-on (19%). Incidence of concussions sustained by players not wearing mouth guards did not reach statistical significance.	Players only included while considered 1st team. Relied upon player and medical recall. 17% of concussed players were not removed during match play.
Shuttleworth-Edwards et al, 2008 ⁵⁰	1366 South African rugby union players from 5 boys' HS (2 private and 3 public), 1 university, 1 premiere club, and 1 group of provincial players.	Retrospective statistical analysis data collected by psychologists working with team doctors, coaches, players, and other sports personnel between 2002 and 2006.	Annual rates of concussion varied from 4% to 14% at the school level and between 3% and 23% at adult level.	Compared HS age, collegiate, club-level, and professional players.	No homogenous standard of reporting concussions. Some institutions relied on player reporting. Problems with player follow-up due to successive concussion. Article admits that incidence of concussion cannot be accurately implied from the article. Authors have conflicting interest.
Hollis et al, 2009 ⁵¹	3207 Australian male nonprofessional rugby players aged 15+.	Prospective cohort study data collected by a mix of doctors, coaches, and other trained recorders.	Incidence of mTBI 7.97/1000 player hours CI (6.94-9.11).	Established benefit of wearing protective head gear at IRR 0.57 CI (0.40-0.82) and additional risk of 1 mTBI in the year before recruitment at IRR 1.75 CI (1.11-2.76)	Mix of data reporters. Despite being a 3-y study, data collection per athlete was only 1 season long for 85% of players.
Haseler et al, 2010 ⁵²	2008-2009. 1636 player hours of an English community rugby club. 210 male players in U9-U17 age groups.	Prospective cohort study data collected by coach or first aid personnel.	Concussion incidence of 1.8/1000 player hours.	Observers were trained and concussion defined.	Data collectors were not independent. Study not specific to concussion.
Hollis et al, 2011 ⁵³	3207 Australian male community rugby players ages 15-48 in 2005-2007.	Prospective cohort data collected by a mix of doctors, coaches, and trained recorders.	10% of overall cohort had an mTBI. 14% of population experienced an mTBI in a 20-h season.	Established increased likelihood of concussion when BMI < median HR=1.7 CI (1.30-2.42) and if training <3 h/wk HR 1.48 CI (1.06-2.08).	Mix of data reporters. 1249 participants removed from cohort were 1.5 y younger than remaining players.

BMI, body mass index, *CI*, confidence interval, (95% unless otherwise stated); *HR*, hazard ratio; *HS*, high school; *IRR*, incidence rate ratio; *mTBI*, mild traumatic brain injury; *U9-U17*, under age 9 to under age 17; *US*, United States.

Table 4 Lacrosse concussions

First author and year	Target population and sport	Design and source of information	Findings	Study strengths	Study weaknesses
Dick et al, 2007 ⁵⁴	Collegiate Division 1-3 men's lacrosse using NCAA ISS 1988-1989 through 2003-2004.	Descriptive epidemiology study of 16 y. Data collection by ATCs.	Overall incidence of concussion 1.08 CI (0.92-1.25)/1000 AEs. Concussion was 8.6% of all game injury and 9× more likely in games than practice. 1.08 vs 0.12/1000 AEs; rate ratio=9.0, 95% CI (7.1-11.5).	Concussion rate rose after introduction of a new helmet in the 1996-1997 season. Large sample of NCAA ISS data. 78.5% of concussion related to player-to-player contact.	ISS only looks at 18% of NCAA institutions participating in the annual data collection for this sport. Intro and methods in separate article.
Dick et al, 2007 ⁵⁵	Collegiate Division 1-3 women's lacrosse using NCAA ISS 1988-1989 through 2003-2004.	Descriptive epidemiology study of 16 y. Data collection by ATCs.	0.52 CI (0.41-0.64)/1000 AEs overall incidence of concussion. Concussions were 9.4% of game injuries.	Participants had 6× the risk of concussion in games as in practice. 0.52 vs 0.09 per 1000 AEs, rate ratio =6.1, 95% CI (4.3-8.7). Concussions increased after new helmet in 1996-1997.	Only 23.1% of schools sponsoring varsity women's lacrosse programs participated in the NCAA ISS data collection.
Lincoln et al, 2007 ⁵⁶	5072 male and 3566 female lacrosse players in 23 Virginia HS and national collegiate ISS data.	4-y prospective epidemiology study in 2000-2003 using ISS for college data collected by ATCs.	Concussion incidence of 0.28/1000 AEs HS males, 0.21/1000 AEs in HS females, 0.87/1000 AEs college males, and 0.32/1000 AEs in college females.	Comparison of male and females as well as HS to college. Identified highest concussion frequency due to player-to-player contact in males and player-to-stick contact in females.	Definition of <i>concussion</i> not specified by study. May not capture concussions not brought to ATC's attention. AE is not equivalent between sports or sexes. Injury counted differently in college and HS

AE, athletic exposures; ATC, certified athletic trainer; CI, confidence interval, 95% unless otherwise stated; HS, high school; ISS, injury surveillance system; NCAA, National Collegiate Athletic Association.

Table 5 Soccer concussions

First author and year	Target population and sport	Design and source of information	Findings	Study strength	Study weakness
Matser et al, 1999 ⁵⁷	33 amateur soccer players and 27 amateur swimming and track athletes in 1997-1998.	Cross-sectional study data via interview of players and their physicians.	Self-reported amateur soccer concussion was associated with impairment in memory and planning functions.	Data adjusted for level of education, alcohol intake, number of times under general anesthesia, and the number of concussions not due to soccer play.	Concussion questionnaire data based on memory of players.
Delaney et al, 2002 ³⁰	201 soccer athletes and 328 football players reporting to 1999 Canadian university included 110 females.	Retrospective survey. Players self-reported on 1998 season. Response rate was 84% for soccer.	62.7% of soccer players had concussion symptoms in the previous year. Players had over 3 × greater risk of concussion with history of previous concussion.	Only 19.8% of the soccer players realized that the symptoms they had suffered represented a concussion. Goalies were most likely to be concussed in soccer. Female soccer players had 2.6 × greater odds of concussion.	Retrospective design increases recall bias, and self-selection bias is also a concern when self-report is used and nonreports are not examined.
Yard et al, 2008 ⁵⁸	HS male and female soccer players 2005-2007.	Descriptive epidemiology study using RIO data.	Concussion made up 10.8% of injuries in 637,446 total AEs. Comparison of competition to practice resulted in an IPR of 3.25 CI (1.99-5.31).	Differentiates the incidence of various mechanisms of injury in practice and competition, but not specific to concussion. Boy's result of 9.3% and girl's 12.2% concussion proportion of injury are higher than previously reported.	Rates of injury vary from similar studies and suggest that either injuries are decreasing or differences in injury definition resulted in the decrease in the injury rate.

AE, athletic exposures; *CI*, confidence interval, 95% unless otherwise stated; *HS*, high school; *IPR*, injury proportion ratio; *RIO*, reporting information online, National High School Sports-Related Injury Surveillance Study.

Table 6 Multisport concussions

First author and year	Target population and sport	Design and source of information	Findings	Study strength	Study weakness
Powell and Barber-Foss, 1999 ⁵⁹	235 US HS males and females in 10 varsity sports during 1 or more of 3 academic years 1995-1997.	Observational cohort study data recorded by 246 ATCs.	5.5% of all injuries were mTBIs. Football accounted for 63.4% of cases, wrestling 10.5%, girl's soccer 6.2%, boy's soccer 5.7%, girl's basketball 5.2%, boy's basketball 4.2%, softball 2.1%, baseball 1.2%, field hockey 1.1%, and volleyball 0.5%.	Demonstrates that practice concussion rates are substantially lower than game rates. Establishes football as the sport with most concussions by a large margin.	Loss of athletes from the study was not detailed. Characterizing the lost athletes for differences from the study group would be beneficial.
Schulz, 2004 ⁶⁰	100 North Carolina HS with male and female athletes in 12 sports from 1996 to 1999.	Prospective cohort study using data collected by 1 ATC or athletic director per school.	Overall rate of concussion was 17.15 CI (13.30-21.00)/100,000 AEs. Concussion rates ranged from 9.36 CI (1.93-16.80) cheerleading to 33.09 CI (24.74-41.44) in football.	Cheerleading was the only sport for which the practice rate was greater than the game rate. Initial screening and follow-up performed. Used North Carolina HS Athletic Injury Study data.	No postseason data collection. Only 1/3 of data collected by ATCs. Volleyball listed as a sport, but not found in results.
LaBotz et al, 2005 ⁶¹	93 male and 79 female athletes participating in collegiate contact or collision sports.	Retrospective survey with self-report.	71% reported symptoms consistent with concussion but were not identified as having a history of head injury on the PPE form.	Recognizes difficulty in properly identifying concussion via single, self-reported, preparticipation questionnaires and advocates symptom-specific inquiries.	Supplanted by the 2008 Zurich convention's use of SCAT2.
Dick et al, 2007 ⁶²	NCAA male and female athletes.	Methodology summary for NCAA ISS.	NA	Provides more detail on methodology than would be present in an average study.	Separate methodology article for multiple NCAA studies.
Gessel et al, 2007 ⁶³	Male and female US HS and collegiate athletes.	Descriptive epidemiology study data collected by ATCs via the RIO and NCAA ISS systems.	Overall HS concussions occurred at 0.23/1000 AEs and college 0.43/1000 AEs. Concussions represented 8.9% of all HS athletic injuries and 5.8% of all collegiate athletic injuries.	Uses data from very large national databases for HS and collegiate athletes. Estimates national practice and game rates of concussion.	Only time loss injuries coming to the attention of ATC were captured. Data from schools without an ATC may differ.
Hootman et al, 2007 ⁶⁴	NCAA male and female athletes for 16 y in 15 sports.	Retrospective cohort study day reported by ATCs.	Concussion rate was 0.28/1000 AEs. 55% of all concussions reported were for football at 0.54/1000 AEs. Women's ice hockey had the highest incidence at 0.91/1000 AEs.	Large study population over a longer period. Has data on practices as well as games.	Injuries reported that required medical attention and at least 1-d time loss. Concussions on Friday may not have been reported because of weekend eliminating 1 d lost.

Swenson et al, 2009 ⁶⁵	HS sports injury data for the 2005-2008 academic years.	Descriptive epidemiology study data recorded by ATCs.	Concussions were 3rd most common diagnosis of recurrent injury at 11.6%. Specific data on concussion incidence not reported.	Large study. Percentages of concussion injury and reinjury rates for each sport were recorded.	Percentages of concussion injury and reinjury for each sport were recorded, but total no. of injuries for each sport not listed. Injury incidence for sports listed, but concussion was not separated out.
Yard et al, 2009 ³⁷	Male and female athletes in 18 HS sports.	Prospective injury surveillance study data reported by ATCs and varsity coaches.	Participating ATCs submitted 96.7% of expected exposure reports, but coaches submitted only 36.5%. All ATCs reported AEs correctly as opposed to only 2 of 3 coaches.	Numerous discrepancies in coach injury reports were not found in ATC reports, which suggested benefit in using ATCs for data collection.	This study was funded by the National Athletic Trainers' Association Research and Education Foundation.
Meehan et al, 2010 ⁶⁶	US male and female HS athletes in 9 sports.	National HS Sports-Related Injury Surveillance Study during 2008-2009 academic year data collected by ATCs.	68.5% of concussions occurred during competition as opposed to practice. 89% were first concussion, and 10.5% were recurrent.	ATCs work for team and gather data for the RIO. In 13- to 18-y-olds, age 16 had the greatest number of concussions at 28%.	Only captures injuries that require medical attention from an ATC.
Castile et al, 2012 ⁶⁷	US male and female HS athletes from 2005 to 2010 in 9 sports of the National High School Sports-Related Injury Surveillance Study.	Epidemiology review data collected by ATCs.	The overall rate of new concussion was 22.2/100,000 AEs and recurrent concussion was 3.1/100,000 AEs. 13.2% of concussions were recurrent.	Demonstrated that recurrent concussion results in greater disability and greater potential for long-term impairment. Overall rates of new or recurrent concussion were higher among girls when compared with boys in sex-comparable sports.	Definition of concussion not specified by study. May not capture concussions not brought to ATC's attention. Comparison of AEs may not be equivalent between sports or sexes.
Lincoln et al, 2011 ⁶⁸	158,430 HS male and female athletes in 12 sports.	Prospective descriptive epidemiology study from 1997 to 2008.	Overall 0.24 concussions per 1000 AEs.	Large dataset outlines detailed incidence data specific to concussion only. Rates increased significantly after 2005.	Definition of concussion not specified by study. May not have captured concussions not brought to ATC's attention. AE is not equivalent between sports or sexes.
Marar et al, 2012 ⁶⁹	US male and female athletes in 20 HS sports during the 2008-2010 academic years. Boy's volleyball not reported because of zero concussions reported.	Descriptive epidemiology study using ATCs to report data via RIO.	Overall injury rate of 2.5/10,000 AEs and overall rate of concussion were higher in competition than in practice. Concussions represented 13.2% of all reported injuries.	Latest study to include information on concussions in this broad collection of HS sports. Concludes girl's concussion RR of 1.7 to boy's 1.0 CI (1.4-2.0) and player-to-player-contact was the most frequent mechanism.	Only includes academic year, but no summer practices. These data came only from schools with ATCs. Caution should be used interpreting results from sports with fewer than 10 reported concussions.

Confidence interval: 95% unless otherwise stated.

AE, athletic exposures; *ATC*, certified athletic trainer; *CI*, confidence interval, 95% unless otherwise stated; *HS*, high school; *ISS*, injury surveillance system; *mTBI*, mild traumatic brain injury; *NA*, not applicable; *NCAA*, National Collegiate Athletic Association; *PPE*, pre-participation physical; *RIO*, reporting information online, National High School Sports-Related Injury Surveillance Study; *RR*, rate ratio; *SCAT2*, Sport Concussion Assessment Tool 2; *US*, United States.

Table 7 Multisport concussion incidence

	Powell and Barber-Foss, 1999 ⁵⁹	Schulz, 2004 ⁶⁰	Gessel et al, 2007 ⁶³	Hootman et al, 2007 ⁶⁴	Lincoln et al, 2011 ⁶⁸	Castile et al, 2012 ⁶⁷	Marar et al, 2012 ⁶⁹
	HS	HS	NCAA/HS	NCAA	HS	HS	HS
Male baseball	0.05 CI (0.02-0.07)	0.12 CI (0.03-0.21)	0.05/0.09	0.07 CI (0.06-0.08)	0.06	0.037	0.05
Male basketball	0.11 CI (0.08-0.15)	0.10 CI (0.04-0.16)	0.07/0.27	0.16 CI (0.14-0.17)	0.10	0.1	0.16
Female basketball	0.16 CI (0.12-0.21)	0.17 CI (0.01-0.34)	0.21/0.43	0.22 CI (0.20-0.24)	0.16	0.196	0.21
Female field hockey	0.09 CI (0.04-0.15)	NA	NA/NA	0.18 CI (0.15-0.21)	0.10	NA	0.22
Male football	0.59 CI (0.19-1.04)	0.33 CI (0.25-0.41)	0.47/0.61	0.37 CI (0.36-0.38)	0.60	0.539	0.64
Female gymnastics	NA	NA	NA/NA	0.16 CI (0.12-0.20)	NA	NA	0.07
Male ice hockey	NA	NA	NA/NA	0.41 CI (0.37-0.44)	NA	NA	0.54
Female ice hockey	NA	NA	NA/NA	0.91 CI (0.71-1.11)	NA	NA	NA
Male lacrosse	NA	NA	NA/NA	0.26 CI (0.23-0.29)	0.30	NA	0.40
Female lacrosse	NA	NA	NA/NA	0.25 CI (0.22-0.28)	0.20	NA	0.35
Male soccer	0.18 CI (0.14-0.22)	0.23 CI (0.08-0.38)	0.22/0.49	0.28 CI (0.25-0.30)	0.17	0.197	0.19
Female soccer	0.23 CI (0.18-0.28)	0.13 CI (0.0-0.27)	0.36/0.63	0.41 CI (0.38-0.44)	0.35	0.298	0.34
Female softball	0.10 CI (0.06-0.14)	0.10 CI (0.01-0.19)	0.07/0.19	0.14 CI (0.12-0.16)	0.11	0.099	0.16
Female volleyball	0.02 CI (0-0.3)	No result	0.05/0.18	0.09 CI (0.07-0.10)	NA	0.068	0.06
Male wrestling	0.25 CI (0.24-0.29)	0.09 CI (0.0-0.19)	0.18/0.42	0.25 CI (0.22-0.27)	0.17	0.181	0.22
Male spring football	NA	NA	NA/NA	0.54 CI (0.50-0.58)	NA	NA	NA
Cheerleading	NA	0.09 CI (0.02-0.17)	NA/NA	NA	0.06	NA	0.14
Male track	NA	0.10 CI (0.0-0.25)	NA/NA	NA	NA	NA	0.02
Female track	NA	0.14 CI (0.0-0.43)	NA/NA	NA	NA	NA	0.02
Male swim/dive	NA	NA	NA/NA	NA	NA	NA	0.01
Female swim/dive	NA	NA	NA/NA	NA	NA	NA	0.02
Total concussions	NA	0.17 CI (0.13-0.21)	0.23/0.43	0.28 CI (0.27-0.28)	0.24	0.22	0.25

Athletic exposures have all been converted to per 1000 for consistency and ease of comparison.

CI, confidence interval, (95% unless otherwise stated); HS, high school; NA, not applicable; NCAA, National Collegiate Athletic Association.

Table 8 Example of multisport study of concussions in HS and college athletes

Concussion rates among US HS and collegiate* athletes, High School Sports-Related Injury Surveillance Study and NCAA ISS, United States, 2005-2006 school year

Sport	Division	No. of concussions	National estimates ^a	Rates per 1000 AEs			Overall Rate Comparison		
				Practice	Competition	Overall	Collegiate vs HS		
Football	HS	201	55,007	0.21	1.55	0.47	NA	NA	NA
	Collegiate	245		0.39	3.02	0.61	0.31	1.09-1.58	<.01
Boy's soccer	HS	33	20,929	0.04	0.59	0.22	NA	NA	NA
	Collegiate	42		0.24	1.38	0.49	2.26	1.43-3.57	<.01
Girl's soccer	HS	51	29,167	0.09	0.97	0.36	NA	NA	NA
	Collegiate	57		0.25	1.80	0.63	1.76	1.21-2.57	<.01
Volleyball	HS	6	2568	0.05	0.05	0.05	NA	NA	NA
	Collegiate	14		0.21	0.13	0.18	3.63	1.39-9.44	<.01
Boy's basketball	HS	16	3823	0.06	0.11	0.07	NA	NA	NA
	Collegiate	33		0.22	0.45	0.27	0.65	2.01-6.63	<.01
Girl's basketball	HS	40	12,923	0.06	0.60	0.21	NA	NA	NA
	Collegiate	49		0.31	0.85	0.43	1.98	1.31-3.01	<.01
Wrestling	HS	30	5935	0.13	0.32	0.18	NA	NA	NA
	Collegiate	15		0.35	1.00	0.42	2.34	1.26-4.34	.01
Baseball	HS	9	1991	0.03	0.08	0.05	NA	NA	NA
	Collegiate	12		0.03	0.23	0.09	1.88	0.79-4.46	.22
Softball	HS	10	3558	0.09	0.04	0.07	NA	NA	NA
	Collegiate	15		0.07	0.37	0.19	2.61	1.17-5.82	.03
Boy's sports total	HS	289	87,685	0.13	0.61	0.25	NA	NA	NA
	Collegiate	347		0.30	1.26	0.45	1.78	1.52-2.08	<.01
Girl's sports total	HS	107	48,216	0.07	0.42	0.18	NA	NA	NA
	Collegiate	135		0.23	0.74	0.38	2.04	1.59-2.64	<.01
Overall total	HS	396	135,901	0.11	0.53	0.23	NA	NA	NA
	Collegiate	482		0.28	1.02	0.43	1.86	1.63-2.12	<.01

Reprint is courtesy of the *Journal of Athletic Training*.⁶³

AE, athletic exposures; CI, confidence interval; HS, high school; NA, not applicable.

^a National estimates for the NCAA data were not available.

Vulnerabilities

Overall, the linebacker is the position most associated with frequent concussions, but variation in the literature does exist and may be explained by changes in style of play over the 10 years covered by the studies.^{31,34,59} The most frequently concussed in the NFL are quarterbacks.^{32,33} Delaney et al³⁰ found goalies at greatest concussion risk in soccer.

Most concussions occur during player-to-player contact.⁶⁶ High-speed player-to-player impact appears to be the most likely reason for concussion in football. Most frequent impacts occur at linebacker and linemen positions.³⁸

Athletes experience 68.5% of concussions during competition and increased game risk is from 3 to 14 times higher than practice across a variety of sports and both sexes.^{12,34,41,48,49,54,66,69}

Football concussion was 4 times higher in contact compared with noncontact practices.³⁴ Head impact

examined with accelerometer telemetry demonstrated nearly 3 times more impacts in games than in practice.³⁸

Younger athletes

Despite less exposure and fewer cumulative concussions, which are established risk factors, younger athletes report higher incidence.^{28,63} Injury capture of HS athletes should be lower because of less medical staff coverage in HS than in college, so the data are somewhat counterintuitive.⁷⁰

High school athletes' prolonged memory dysfunction recovery due to immature neuroanatomy may explain the greater frequency.^{27,70} Shankar et al³⁶ postulate that HS players may be at greater risk because teams run more and pass less than in college and players are less skilled in tackling and blocking techniques. Immature neurological, vascular, and musculoskeletal physiology combined with less experience, training, and tackling

Table 9 Example of reporting mechanisms of sport concussion

National estimates of activity associated with concussion injury by sport, High School Sports-Related Injury Surveillance Study, United States, 2005-2006 school year

Sport ^a	Activity	Proportion	
Football		(n = 55,007) ^b	
	Blocking drill	2225 4.1%	
	General play	1866 3.4%	
	Kickoff coverage/return	3238 5.9%	
	Passing play (offense/defense)	8928 16.3%	
	Punt coverage/return	1497 2.7%	
	Running play (offense/defense)	30,418 55.4%	
	Tackling drill	2833 5.2%	
Wrestling	Other	3895 7.1%	
		(n = 5935)	
	Conditioning	608 10.2%	
	Escape	377 6.4%	
	Fall 200	3.4%	
	Riding	153 2.6%	
	Sparring	1297 21.9%	
	Takedown	2526 42.6%	
Soccer	Other	774 13.0%	
		Boys (n = 20,929) ^b	Girls (n = 29,167)
	Attempting a slide tackle	959 4.6%	0
	Ball handling/dribbling	0	1760 6.0%
	Blocking shot	673 3.2%	0
	Chasing loose ball	286 1.4%	3423 11.7%
	Defending	780 3.7%	4408 15.1%
	General play/other	2203 10.6%	2475 8.5%
	Goaltending	4268 20.5%	2440 8.4%
	Heading ball	8433 40.5%	1014 436.7%
	Receiving a slide tackle	0	1482 5.1%
	Receiving pass	2180 10.5%	864 3.0%
Basketball	Other	1045 5.0%	1601 5.5%
		Boys (n = 3823)	Girls (n = 12,923)
	Ball handling/dribbling	399 10.4%	2456 19.0%
	Chasing loose ball	994 26.0%	1367 10.6%
	Defending	513 13.4%	2872 22.2%
	General play/other	0	226 1.8%
	Passing	0	257 2.0%
	Rebounding	1164 30.5%	2151 16.6%
	Receiving pass	259 6.8%	147 1.1%
	Screening	0	690 5.3%
	Shooting	494 12.9%	2069 16.0%
	Other	0	688 5.3%
Baseball and softball		Baseball (n = 1991)	Softball (n = 3558)
	Batting	1008 50.6%	246 6.9%
	Catching	171 8.6%	1057 29.7%
	Fielding	100 5.0%	398 11.2%
	General play	171 8.6%	104 2.9%
	Pitching	100 5.0%	246 6.9%
	Running bases	0	152 4.3%
	Other	441 22.1%	1355 38.1%

National estimates of activity associated with concussion injury by sport, HS Sports-Related Injury Surveillance Study, United States, 2005-2006 school year.

Reprint is courtesy of the *Journal of Athletic Training*.⁶³^a Because of the small sample size of concussions suffered by volleyball players, volleyball was excluded from analyses of activity involving nationally weighted data.^b Excludes injuries in which activity associated with concussion was not reported.

Table 10 Study characteristics

Study characteristics	Surveillance studies	Cohort studies
Longer data tracking period	Yes	Less likely
Uniform method across many sports	Yes	No
High precision of incidence data	Yes	Less likely
Tighter control of data collection	Less likely	More likely
Use of time-based data collection	Less likely	More likely
Able to address lower-income schools	Less likely	More likely
Independent data collection	Less likely	More likely
Highly trained diagnosticians	Less likely	More likely
Sophisticated data management tools	Yes	Less likely
Use of concussions/1000 AEs reporting measure	More likely	Less likely
Loss of follow-up tracked	Less likely	More likely
Logistical issues impact data collection	More likely	Less likely

AE, athletic exposures.

skill may result in more absolute force to the brain per hit and result in higher incidence.⁷⁰

Alternatively, older athletes may become resistant to report injury because of scholarships, scouting, or progression to professional status. Independent and objective data capture methods at older ages may eliminate these concerns.

Return to play and concussion recurrence

The Third Zurich recommends that athletes diagnosed with concussion not return to play until free of symptoms. Specifically, adolescent athletes should have “cognitive rest” and limit exertion until asymptomatic and return to play only when completely free of symptoms.⁹ Recurrent concussions demonstrate longer symptom resolution time, increased time out of play, and higher likelihood of loss of consciousness than the first concussed.⁶⁷

Although guidelines are in place, there is concern that missed diagnoses result in premature return to play.^{29,44,49,66} This may explain the higher incidence of repeat concussion in individuals with a history of a prior concussion.^{28,30,31,35,51,65,70}

Male vs female concussions

In sex-comparable sports, female incidence is consistently higher than male,^{59,60,63,64,67-69} excepting lacrosse, where concussions were more frequent in males than females.^{54,56,64,68,69} Player contact was the cause of concussions for 72% of men but 41% of

women.⁴³ Frommer et al⁷¹ reported little difference between sexes in severity or outcome of concussions.

Female hockey players sustain fewer impacts and lower head acceleration than males.⁴⁶ This suggests that frequency of impact may not be the source of greater incidence in female hockey players.

Daneshvar et al⁷⁰ suggested that patterns in reporting by athletes may explain the greater incidence.

Studies have speculated that females have more concussions because of intrinsic differences between the sexes, such as height, weight, head and neck size, or strength.^{70,72}

Protective gear

Changes to protective equipment are of uncertain benefit according to the literature. Collins et al³⁵ reported that 5.3% of athletes wearing new helmets vs 7.6% wearing standard helmets were concussed per season, but a coauthor may have had a conflict.

Padded headgear did not reduce concussions in rugby union players.⁴⁹ Universal use of headgear may cause players to develop a false sense of security, tackle harder, or cause more aggressive heading and head challenges, leading to increased risk of injury.⁷² In NCAA men's and women's lacrosse studies, concussions rose after the introduction of a new helmet in 1996-1997.^{41,54}

Summary of findings

Surveillance research methods that allow an open cohort, a wider definition of concussion, and exposure data that are not time based may cloud accuracy and make some comparisons difficult. There appears to be a place in future research for smaller, tightly controlled studies. Growing concern about the long-term consequences of brain injury makes understanding the “true” incidence within sport subpopulations even more important. The current trend of increased attention on concussion is likely to result in higher reported incidence.

Concussion risk includes modifiable risk factors such as use of protective gear, prevention through strength training, improved education, rules modification, and changes to player position techniques. Non-modifiable risk factors include sex (female/male), age, and history of prior concussion. Concussion research to date has identified higher-risk groups such as football quarterbacks and linebackers, but management of concussion and return to play guidelines need to be universally adopted to improve concussion research and consistently train all personnel involved in sports.

Guidelines may improve by using time-based AEs coupled to real-time accelerometer helmet data. An intensity scale based upon measured impact force could be correlated to concussion and used to guide practice or drill intensity. Studies that objectively delineate the mechanisms of injury should guide rule or equipment changes for at-risk player positions, player-to-player contact sports, sex-specific conditioning, and youth. Following these modifications to sports, concussion incidence should be reassessed with the same method used before the changes.

Study of the incidence of concussion has identified this injury as a risk to athletes and resulted in changes in attitudes of players, coaches, medical support personnel, and researchers. Based upon current findings, alterations to equipment, rules, and policies are making the field of play safer for athletes; but advancements in research are sure to result in additional improvement.

Increased research representation of at-risk groups such as females and youth is needed. Continued emphasis on contact sports appears reasonable; but factors that increase risk, such as player positions, should be specifically targeted. Evaluating research methods and data reporting objectivity will likely improve incidence accuracy.

Study limitations

Motor sports and “extreme” sports such as skateboarding are likely to result in concussion, but were not represented in this study because of a lack of literature examining these groups as sport subpopulations. Search by name of all individual sports would have likely resulted in additional capture. We used only PubMed as our search engine, so it is possible that other relevant studies were not included. We frequently did not have access to raw data sets in which to verify all calculations, and rounding error may have occurred when adjusting data to conform to a standard measure of concussions (per 1000 AEs). We did not use a statistician to verify the appropriateness of reported data.

Conclusion

The studies examined in this article show that there is risk of concussion in nearly every sport. Some sports have higher concussion frequency than others, which may depend upon the forces and roles of the positions played in these sports. Younger athletes have a higher incidence of concussion, and female incidence is greater than male in many comparable sports. Headgear

may reduce concussion in some sports but may also give athletes a false sense of protection.

Funding sources and conflicts of interest

No funding sources or conflicts of interest were reported for this study.

References

1. Gilchrist J, Thomas KE, Xu L, McGuire LC, Coronado VG. Nonfatal sports and recreation related traumatic brain injuries among children and adolescents treated in emergency departments in the United States, 2001–2009. *MMWR* 2011; 60(39):1337–42.
2. Slobounov S, Gay M, Johnson B, Zhang K. Concussion in athletics: ongoing clinical and brain imaging research controversies. *Brain Imaging Behav* 2012;6(2):224–43.
3. Iverson GL, Echemendia RJ, Lamarre AK, Brooks BL, Gaetz MB. Possible lingering effects of multiple past concussions. *Rehabil Res Pract* 2012;2012:316575 [Epub 2012 Feb 26].
4. Tremblay S, De Beaumont L, Henry LC, et al. Sports concussions and aging: a neuroimaging investigation. *Cereb Cortex* 2013 May;23(5):1159–66.
5. Stern RA, Riley DO, Daneshvar DH, Nowinski CJ, Cantu RC, McKee AC. Long-term consequences of repetitive brain trauma: chronic traumatic encephalopathy. *PM R* 2011;3(10 Suppl 2):S460–7.
6. New law on concussions takes effect in Kentucky [Internet]. WKRC Cincinnati [cited 2012 Jun 23] Article from: <http://www.local12.com/news/local/story/New-Law-on-Concussions-Takes-Effect-in-Kentucky/I2ZCdZ2kJkaazW9J9cYqMA.cspcx>.
7. ESPN. NFL NATION BLOG: NFL bracing for concussion lawsuit [Internet]. Brandt, A. [cited 2012 Jun 19]. Article from: http://espn.go.com/blog/nflnation/post/_/id/59485/nfl-bracing-for-concussion-litigation.
8. Maroon JC, Lovell MR, Norwig J, Podell K, Powell JW, Hartl R. Cerebral concussion in athletes: evaluation and neuropsychological testing. *Neurosurgery* 2000;47(3):659–69 discussion 669–72.
9. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on concussion in sport—the 3rd International Conference on concussion in sport, held in Zurich, November 2008. *J Clin Neurosci* 2009;16(6):755–63.
10. Stroup DF, Berlin JA, Morton SC, et al. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. *JAMA* 2000;283(15):2008–12.
11. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Ann Intern Med*. 2009; 151(4):264–9, W64.
12. Reche JA, Yard EE, Comstock RD. An epidemiologic comparison of high school sports injuries sustained in practice and competition. *J Athl Train* 2008;43(2):197–204.

13. Cantu RC, Mueller FO. The prevention of catastrophic head and spine injuries in high school and college sports. *Br J Sports Med* 2009;43(13):981–6.
14. Boohar MA, Wisniewski J, Smith BW, Sigurdsson A. Comparison of reporting systems to determine concussion incidence in NCAA Division I collegiate football. *Clin J Sport Med* 2003;13(2):93–5.
15. Meerhoff SR, de Kruijk JR, Rutten J, Leffers P, Twijnstra A. Incidence of traumatic head or brain injuries in catchment area of Academic Hospital Maastricht in 1997. *Ned Tijdschr Geneesk* 2000;144(40):1915–8 [Dutch].
16. Dick RW. Is there a gender difference in concussion incidence and outcomes? *Br J Sports Med* 2009;43(Suppl 1):i46–50.
17. Echemendia RJ, Julian LJ. Mild traumatic brain injury in sports: neuropsychology's contribution to a developing field. *Neuropsychol Rev* 2001;11(2):69–88.
18. Laker SR. Epidemiology of concussion and mild traumatic brain injury. *PM R* 2011;3(10 Suppl 2):S354–8.
19. Bazarian JJ, McClung J, Shah MN, Cheng YT, Flesher W, Kraus J. Mild traumatic brain injury in the United States, 1998–2000. *Brain Inj* 2005;19(2):85–91.
20. Grindel SH. Epidemiology and pathophysiology of minor traumatic brain injury. *Curr Sports Med Rep* 2003;2(1):18–23.
21. Benson BW, Rose MS, Meeuwisse WH. The impact of face shield use on concussions in ice hockey: a multivariate analysis. *Br J Sports Med* 2002;36(1):27–32.
22. Tait RJ, Anstey KJ, Butterworth P. Incidence of self-reported brain injury and the relationship with substance abuse: findings from a longitudinal community survey. *BMC Public Health* 2010;10:171.
23. Daneshvar DH, Nowinski CJ, McKee AC, Cantu RC. The epidemiology of sport-related concussion. *Clin Sports Med* 2011;30(1):1–17.
24. Yang J, Phillips G, Xiang H, Allareddy V, Heiden E, Peek-Asa C. Hospitalisations for sport-related concussions in US children aged 5 to 18 years during 2000–2004. *Br J Sports Med* 2008;42(8):664–9.
25. Schatz P, Moser RS. Current issues in pediatric sports concussion. *Clin Neuropsychol* 2011;25(6):1042–57.
26. McCrea M, Guskiewicz KM, Marshall SW, et al. Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. *JAMA* 2003;290(19):2556–63.
27. Kimbler DE, Murphy M, Dhandapani KM. Concussion and the adolescent athlete. *J Neurosci Nurs* 2011;43(6):286–90.
28. Guskiewicz KM, Weaver NL, Padua DA, Garrett Jr WE. Epidemiology of concussion in collegiate and high school football players. *Am J Sports Med* 2000;28(5):643–50.
29. Langburt W, Cohen B, Akhthar N, O'Neill K, Lee JC. Incidence of concussion in high school football players of Ohio and Pennsylvania. *J Child Neurol* 2001;16(2):83–5.
30. Delaney JS, Lacroix VJ, Leclerc S, Johnston KM. Concussions among university football and soccer players. *Clin J Sport Med* 2002;12(6):331–8.
31. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *JAMA* 2003;290(19):2549–55.
32. Pellman EJ, Powell JW, Viano DC, et al. Concussion in professional football: epidemiological features of game injuries and review of the literature—part 3. *Neurosurgery* 2004;54(1):81–94 discussion 94–6.
33. Pellman EJ, Viano DC, Casson IR, Arfken C, Powell J. Concussion in professional football: injuries involving 7 or more days out—part 5. *Neurosurgery* 2004;55(5):1100–19.
34. Wisniewski JF, Guskiewicz K, Trope M, Sigurdsson A. Incidence of cerebral concussions associated with type of mouthguard used in college football. *Dent Traumatol* 2004;20(3):143–9.
35. Collins M, Lovell MR, Iverson GL, Ide T, Maroon J. Examining concussion rates and return to play in high school football players wearing newer helmet technology: a three-year prospective cohort study. *Neurosurgery* 2006;58(2):275–86 discussion 275–86.
36. Shankar PR, Fields SK, Collins CL, Dick RW, Comstock RD. Epidemiology of high school and collegiate football injuries in the United States, 2005–2006. *Am J Sports Med* 2007;35(8):1295–303.
37. Yard EE, Comstock RD. Effects of field location, time in competition, and phase of play on injury severity in high school football. *Res Sports Med* 2009;17(1):35–49.
38. Crisco JJ, Fiore R, Beckwith JG, et al. Frequency and location of head impact exposures in individual collegiate football players. *J Athl Train* 2010;45(6):549–59.
39. Mansell JL, Tierney RT, Higgins M, McDevitt J, Toone N, Glutting J. Concussive signs and symptoms following head impacts in collegiate athletes. *Brain Inj* 2010;24(9):1070–4.
40. Benson BW, Mohtadi NG, Rose MS, Meeuwisse WH. Head and neck injuries among icehockey players wearing full face shields vs half face shields. *JAMA* 1999;282(24):2328–32.
41. Dick R, Hootman JM, Agel J, Vela L, Marshall SW, Messina R. Descriptive epidemiology of collegiate women's field hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2002–2003. *J Athl Train* 2007;42(2):211–20.
42. Cusimano MD, Chipman ML, Volpe R, Donnelly P. Canadian Minor Hockey Participants' Knowledge about Concussion. *Can J Neurol Sci* 2009;36:315–20.
43. Agel J, Harvey EJ. A 7-year review of men's and women's ice hockey injuries in the NCAA. *Can J Surg* 2010;53(5):319–23.
44. Echlin PS, Tator CH, Cusimano MD, et al. A prospective study of physician-observed concussions during junior ice hockey: implications for incidence rates. *Neurosurg Focus* 2010 Nov;29(5):E4. Erratum in. *Neurosurg Focus* 2010;29(5).
45. Cusimano MD, Taback NA, McFaull SR, et al. Effect of bodychecking on rate of injuries among minor hockey players. *Open Med* 2011;5(1):e57–64.
46. Brainard LL, Beckwith JG, Chu JJ, et al. Gender differences in head impacts sustained by collegiate ice hockey players. *Med Sci Sports Exerc* 2012;44(2):297–304.
47. Shawdon A, Brukner P. Injury profile of amateur Australian rules footballers. *Aust J Sci Med Sport* 1994;26(3–4):59–61.
48. Collins CL, Micheli LJ, Yard EE, Comstock RD. Injuries sustained by high school rugby players in the United States, 2005–2006. *Arch Pediatr Adolesc Med* 2008;162(1):49–54.
49. Kemp SP, Hudson Z, Brooks JH, Fuller CW. The epidemiology of head injuries in English professional rugby union. *Clin J Sport Med* 2008;18(3):227–34.

50. Shuttleworth-Edwards AB, Noakes TD, Radloff SE, et al. The comparative incidence of reported concussions presenting for follow-up management in South African Rugby Union. *Clin J Sport Med* 2008;18(5):403–9.
51. Hollis SJ, Stevenson MR, McIntosh AS, Shores EA, Collins MW, Taylor CB. Incidence, risk, and protective factors of mild traumatic brain injury in a cohort of Australian nonprofessional male rugby players. *Am J Sports Med* 2009;37(12):2328–33.
52. Haseler CM, Carmont MR, England M. The epidemiology of injuries in English youth community rugby union. *Br J Sports Med* 2010;44(15):1093–9.
53. Hollis SJ, Stevenson MR, McIntosh AS, et al. Mild traumatic brain injury among a cohort of rugby union players: predictors of time to injury. *Br J Sports Med* 2011;45(12):997–9.
54. Dick R, Romani WA, Agel J, Case JG, Marshall SW. Descriptive epidemiology of collegiate men's lacrosse injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train* 2007;42(2):255–61.
55. Dick R, Lincoln AE, Agel J, Carter EA, Marshall SW, Hinton RY. Descriptive epidemiology of collegiate women's lacrosse injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train* 2007;42(2):262–9.
56. Lincoln AE, Hinton RY, Almquist JL, Lager SL, Dick RW. Head, face, and eye injuries in scholastic and collegiate lacrosse: a 4-year prospective study. *Am J Sports Med* 2007;35(2):207–15.
57. Matser EJ, Kessels AG, Lezak MD, Jordan BD, Troost J. Neuropsychological impairment in amateur soccer players. *JAMA* 1999;282(10):971–3.
58. Yard EE, Schroeder MJ, Fields SK, Collins CL, Comstock RD. The epidemiology of United States high school soccer injuries, 2005–2007. *Am J Sports Med* 2008;36(10):1930–7.
59. Powell JW, Barber-Foss KD. Traumatic brain injury in high school athletes. *JAMA* 1999;282(10):958–63.
60. Schulz MR, Marshall SW, Mueller FO, et al. Incidence and risk factors for concussion in high school athletes, North Carolina, 1996–1999. *Am J Epidemiol* 2004;160(10):937–44.
61. LaBotz M, Martin MR, Kimura IF, Hetzler RK, Nichols AW. A comparison of a preparticipation evaluation history form and a symptom-based concussion survey in the identification of previous head injury in collegiate athletes. *Clin J Sport Med* 2005;15(2):73–8.
62. Dick R, Agel J, Marshall SW. National Collegiate Athletic Association Injury Surveillance System commentaries: introduction and methods. *J Athl Train* 2007;44(2):173–82.
63. Gessel LM, Fields SK, Collins CL, Dick RW, Comstock RD. Concussions among United States high school and collegiate athletes. *J Athl Train* 2007;42(4):495–503.
64. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train* 2007;42(2):311–9.
65. Swenson DM, Yard EE, Fields SK, Comstock RD. Patterns of recurrent injuries among US high school athletes, 2005–2008. *Am J Sports Med* 2009;37(8):1586–93.
66. Meehan III WP, d'Hemecourt P, Comstock RD. High school concussions in the 2008-2009 academic year: mechanism, symptoms, and management. *Am J Sports Med* 2010;38(12):2405–9.
67. Castile L, Collins CL, McIlvain NM, Comstock RD. The epidemiology of new versus recurrent sports concussions among high school athletes, 2005–2010. *Br J Sports Med* 2012;46(8):603–10.
68. Lincoln AE, Caswell SV, Almquist JL, Dunn RE, Norris JB, Hinton RY. Trends in concussion incidence in high school sports: a prospective 11-year study. *Am J Sports Med* 2011;39(5):958–63.
69. Marar M, McIlvain NM, Fields SK, Comstock RD. Epidemiology of concussions among United States high school athletes in 20 sports. *Am J Sports Med* 2012;40(4):747–55.
70. Daneshvar DH, Nowinski CJ, McKee AC, Cantu RC. The epidemiology of sport-related concussion. *Clin Sports Med* 2011;30(1):1–17, vii.
71. Frommer LJ, Gurka KK, Cross KM, Ingersoll CD, Comstock RD, Saliba SA. Sex differences in concussion symptoms of high school athletes. *J Athl Train* 2011;46(1):76–84.
72. Niedfeldt MW. Head injuries, heading, and the use of headgear in soccer. *Curr Sports Med Rep* 2011;10(6):324–9.

Appendix A. Search terms

((“brain concussion”[MeSH Terms] OR (“brain”[All Fields] AND “concussion”[All Fields]) OR “brain concussion”[All Fields] OR “concussion”[All Fields]) OR mild[All Fields] AND traumatic[All Fields] AND (“brain”[MeSH Terms] OR “brain”[All Fields]) AND (“wounds and injuries”[MeSH Terms] OR (“wounds”[All Fields] AND “injuries”[All Fields]) OR “wounds and injuries”[All Fields] OR “injury”[All Fields])) AND (((“athletes”[MeSH Terms] OR “athletes”[All Fields] OR “athlete”[All Fields]) OR (“sports”[MeSH Terms] OR “sports”[All Fields] OR “sport”[All Fields])) AND (((“epidemiology”[Subheading] OR “epidemiology”[All Fields] OR “epidemiology”[MeSH Terms]) OR (“supply and distribution”[Subheading] OR (“supply”[All Fields] AND “distribution”[All Fields]) OR “supply and distribution”[All Fields] OR “distribution”[All Fields] OR “demography”[MeSH Terms] OR “demography”[All Fields]))—95 results.

comstock[All Fields] AND (“brain concussion”[MeSH Terms] OR (“brain”[All Fields] AND “concussion”[All Fields]) OR “brain concussion”[All Fields] OR “concussion”[All Fields]) AND (“sports”[MeSH Terms] OR “sports”[All Fields] OR “sport”[All Fields])—11 results.

(“football”[MeSH Terms] OR “football”[All Fields]) AND (“brain concussion”[MeSH Terms] OR (“brain”[All Fields] AND “concussion”[All Fields]) OR “brain concussion”[All Fields] OR “concussion”[All Fields]) AND (“epidemiology”[Subheading] OR “epidemiology”[All Fields] OR “epidemiology”[MeSH Terms])—160 results.

ncaa[All Fields] AND (“brain concussion”[MeSH Terms] OR (“brain”[All Fields] AND “concussion”[All Fields]) OR “brain concussion”[All Fields] OR “concussion”[All Fields]) AND (“epidemiology”[Subheading] OR “epidemiology”[All Fields] OR “incidence”[All Fields] OR “incidence”[MeSH Terms])—10 results.

lincoln[All Fields] AND (“brain concussion”[MeSH Terms] OR (“brain”[All Fields] AND “concussion”[All Fields]) OR “brain concussion”[All Fields] OR “concussion”[All Fields]) AND (“sports”[MeSH Terms] OR “sports”[All Fields] OR “sport”[All Fields]) AND (“epidemiology”[Subheading] OR “epidemiology”[All Fields] OR “epidemiology”[MeSH Terms])—7 results.

((“brain concussion”[MeSH Terms] OR (“brain”[All Fields] AND “concussion”[All Fields]) OR “brain concussion”[All Fields] OR “concussion”[All Fields]) OR (mild[All Fields] AND (“brain injuries”[MeSH Terms] OR (“brain”[All Fields] AND “injuries”[All Fields]) OR “brain injuries”[All Fields] OR (“traumatic”[All Fields] AND “brain”[All Fields] AND “injury”[All Fields]) OR “traumatic brain injury”[All Fields]))) AND (equestrian[All Fields] AND (“sports”[MeSH Terms] OR “sports”[All Fields])) AND (((“epidemiology”[Subheading] OR “epidemiology”[All Fields] OR “epidemiology”[MeSH Terms]) OR (“epidemiology”[Subheading] OR “epidemiology”[All Fields] OR “incidence”[All Fields] OR “incidence”[MeSH Terms]))—2 results.

(concussion[All Fields] OR (mild[All Fields] AND traumatic[All Fields] AND brain[All Fields] AND injury[All Fields])) AND motorsports[All Fields] AND (epidemiology[All Fields] OR incidence[All Fields])—0 result.