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The Epidemiology of Sport-Related Concussion

Daniel H. Daneshvar, MA [MD / PhD Graduate Student][a], **Christopher J. Nowinski [Co-Director, Co-Founder]**[b,h], **Ann McKee [Co-Director, Associate Professor of Neurology and Pathology]**[b,i], and **Robert C. Cantu, MD [Co-Director, Clinical Professor, Chief of Neurosurgery Service, Chairman, Director of Sports Medicine, Co-Director, Co-Founder]**[b,c,d,e,f,g,h]

[a]Boston University School of Medicine, Boston, MA

[b]Center for the Study of Traumatic Encephalopathy, Boston University School of Medicine, Boston, MA

[c]Department of Neurosurgery, Boston University School of Medicine, Boston, MA

[d]Emerson Hospital, Concord, MA

[e]Department of Surgery, Emerson Hospital, Concord, MA

[f]Emerson Hospital, Concord, MA

[g]Neurologic Sports Injury Center, Brigham and Women's Hospital, Boston, MA

[h]Sports Legacy Institute, Waltham, MA

[i]Boston University School of Medicine, Boston, MA

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Introduction

Each year, an estimated 38 million children and adolescents participate in organized sports in the United States.(1) In addition, 170 million adults participate in physical activities, including sports.(2) Table 1 presents the number of high school and collegiate athletes participating in each sport from the 1982–83 season through the 2007–08 season.(3) Many of these activities are associated with an increased risk of traumatic brain injury (TBI).(4) In the United States, an estimated 1.7 million people sustain a TBI annually, associated with 1.365 million emergency room visits and 275,000 hospitalizations annually with associated direct and

Daniel H. Daneshvar, MA, Center for the Study of Traumatic Encephalopathy, Boston University School of Medicine, 72 East Concord St, B7800, Boston, MA 02118, (617) 414-8382, (617) 414-1197 (fax), ddanesh@bu.edu
Christopher J. Nowinski, Center for the Study of Traumatic Encephalopathy, Boston University School of Medicine, 72 East Concord St, B7800, Boston, MA 02118, (617) 414-1197 (fax), nowinski@bu.edu
Ann C. McKee, Center for the Study of Traumatic Encephalopathy, Boston University School of Medicine, 200 Springs Rd, 182-B, Bedford, MA 01730, 781-687-2913, (617) 414-1197 (fax), amckee@bu.edu
Robert C. Cantu, MD, Department of Neurosurgery Emerson Hospital, John Cuming Building, Suite 820, 131 ORNAC, Concord, MA 01742, (978) 369-1386, (978) 287-0047, rcantu@emersonhosp.org

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indirect costs estimated to have been $60 billion in the United States in 2000.(5,6) Additionally, the Centers for Disease Control estimates that 1.6 to 3.8 million concussions occur in sports and recreational activities annually.(7) However, these figures vastly underestimate total TBI burden, as many individuals suffering from mild or moderate TBI do not seek medical advice. (5,7)

A concussion is a TBI induced by an impulsive force transmitted to the head resulting from a direct or indirect impact to the head, face, neck, or elsewhere.(8) These concussions may present with a wide range of clinical signs and symptoms, including physical signs (e.g., loss of consciousness, amnesia), behavioral changes (e.g., irritability), cognitive impairment (e.g., slowed reaction times), sleep disturbances (e.g., drowsiness), somatic symptoms (e.g., headaches), cognitive symptoms (e.g., feeling “in a fog”), and/or emotional symptoms (e.g., emotional lability).(9) Because these impairments in neurologic function often present with a rapid onset and resolve spontaneously, many concussions are neither recognized by athletes nor observed by coaches or athletic trainers.(10-13) As a result, a large proportion of concussions are simply unreported.

This issue is further complicated by the fact that many coaches, athletic trainers, and other sports medicine professionals do not properly utilize current guidelines for concussion assessment and management.(14,15) To help educate these professionals on proper concussion identification and treatment, the Centers for Disease Control and Prevention (CDC) launched the *Heads Up* program, which includes educational materials aimed at youth coaches, high school coaches, parents, athletes, school administrators, and medical professionals. These resources have been shown to improve high school coaches' knowledge regarding how to evaluate and properly manage concussions.(16,17) In part due to awareness measures like these, the number of concussions reported to the National Collegiate Athletic Association (NCAA) through its Injury Surveillance System (ISS) showed an average annual increase of 7.0% from the 1988–89 through 2003–04 seasons ($P < .01$).(18) Table 2 displays the concussion rate in each sport from the 2005–06 NCAA ISS database. Table 3 displays the rate of concussion stratified into high school school and collegiate play, and compares concussion rate in practice versus competition. Additionally, the concussion rate observed through the ISS doubled from 0.17 per 1000 athlete exposures (A-E, with an exposure defined as one athlete playing in one game or practice) in 1988–89 to 0.34 per 1000 A-Es in 2003–04.(18) This increased rate of concussion may also be due in part to an increase in the true rate of concussion over the past several decades. However, even with new resources, proper identification of concussion remains a problem.(16) Many of these concussions could be prevented outright with proper medical care and safety precautions, such as implementation of safer rules, proper conditioning, and standardized coaching techniques.

Sport Specific Findings

American Football

Participation—Of all sports played in the US, American football is the sport associated with the greatest number of traumatic brain injuries, but it also has the largest number of participants. As shown in Table 1, between the 1982–83 season and the 2007–08 season, a total of 35,641,573 high school athletes and 1,929,069 collegiate athletes competed in football.(3,19) For purposes of this article, an athlete is defined as one player playing one season. Because many high school and college players play multiple years of football, the number of unique participants is much lower. However, that data is not available. Currently, the National Federation of State High School Associations estimates that there are approximately 1,500,000 high school, junior high school, and non-federation school football participants. The NCAA, the National Association of Intercollegiate Athletics, and the National Junior College Athletic Association estimate that there are currently 75,000 collegiate football participants, including

estimates of athletes at schools not associated with any national organization. 225,000 participants are estimated to compete in fully padded, organized, non-professional football (sandlot) and professional football. Combined, these figures indicate that approximately 1,800,000 total athletes participated in football in the United States during the 2009 football season.(19)

Injuries—Because of the aforementioned difficulties in examining concussion specifically, total incidence of catastrophic head injuries may be a better comparator for injury trends over time. Catastrophic head injury is defined as a head injury caused by direct contact during competition resulting in a fatal, nonfatal permanent, or serious nonpermanent injury. Since the 1982–83 season, there have been 133 football players with incomplete neurological recovery from catastrophic head injury. 120 of these injuries occurred in high school athletes, eleven occurred in college participants, two occurred in sandlot players, and none occurred in professional football players. In 2009, all nine cerebral injuries with incomplete recovery were in high school athletes.(20)

Although there have been significant reductions in these injuries following rule changes in the 1970s, the rate of head injuries has been increasing in recent years. Over the ten-year span from 2000 to 2009, there was an average of 6.2 cerebral injuries annually with incomplete recovery in football. The prior ten years averaged 4.5 cerebral injuries annually. The ten cerebral injuries in 2008 and nine in 2006 and 2009 were the highest incidences since 1984.(20)

Because concussion awareness and diagnosis has changed significantly over the past few decades, there is wide variability in the literature on the rate of concussion in football athletes. One study, evaluating concussions reported to medical professionals over a three-season span from 1995 to 1997, found that high school football players had a rate of 3.66 concussions per 100 player-seasons, meaning that there were 3.66 concussions every season for every hundred athletes.(21) However, another study, a post-season retrospective survey of 233 football players after the 1996–97 season, found that 110 (47.2%) reported having experienced at least one concussion. Multiple concussions were noted in 81 (34.9%) of the athletes.(22) Additionally, the NCAA ISS found a concussion rate of 0.37 per 1000 A-E (95% CI = 0.36, 0.38) from the 1988–89 season through the 2003–04 season.(18) Recent studies indicate even higher rates of reported concussion in football players. In one study, examining the concussions reported by 425 athletic trainers from 100 US high schools and 180 US colleges, the rates of concussion were compared between high school and collegiate athletes. The high school athletic trainers reported 201 concussions over the 2005–06 season, which yielded a concussion rate of 0.21 per 1000 A-E in practice and 1.55 concussions per 1000 A-E in competitions. Together, these averaged a rate 0.47 per 1000 A-E overall. As expected, each game carries a statistically significant increased risk of concussion with an injury proportion ratio (PR) of 1.39 (95% confidence interval (CI) = 1.01, 1.91). 245 concussions were reported in the collegiate athletes, resulting in a concussion injury rate of 0.39 per 1000 A-E in practice, and a rate of 3.02 concussions per 1000 A-E in competitions (resulting in an overall rate of 0.61 per 1000 A-E).(23) These results indicate a statistically significant increase in rate of diagnosed concussion between high school and collegiate athletes. Because college athletes tend to have greater access to and more interaction with medical professionals, the increase may be due to medical infrastructure rather than differences in the number of actual concussions sustained.

The same study evaluated the types of collisions that resulted in concussions and found that tackling and being tackled were responsible for 67.6% of the concussions observed in these football players.(23) Concussive impacts may produce different signs based on the age of the athlete. Although the high school and college groups did not differ in presentation of symptoms such as confusion or retrograde amnesia, college athletes did experience a high rate of loss of consciousness (34%) compared to the high school athletes (11%). Despite this lower rate of

loss of consciousness, studies have shown that high school athletes who have experienced a concussion show worse recovery, in the form of prolonged memory dysfunction, as compared to concussed collegiate athletes. College athletes, despite having more concussions throughout the season, typically recover and match control subjects by day 3 following the concussive blow. However, the high school athletes continue to perform significantly worse than control subjects for up to seven days following the injury ($F = 2.90$; $P < .005$).(12) This age-based disparity in performance on neuropsychological testing is not correlated with self-report of postconcussion symptoms.(12)

Of note is the fact that high school athletes appear to recover more poorly as compared to collegiate athletes, despite the latter typically incurring more acutely severe injuries as a result of being bigger, faster, and stronger. There are several possible explanations for this disparity between high school and collegiate football players: the brain may not yet be fully developed, resulting in a lower injury threshold; the blood vessels may tear more easily in the less developed brain; the skull is thinner, which could provide less protection to the brain; there may be fewer medical staff members available at high school games; and/or poor body control and technique might make younger players more susceptible to brain injury following a poorly executed tackle.(24) In fact, one explanation may be that for various reasons, including having weaker necks, high school football players were found to sustain more absolute force to brain per hit while playing football that college athletes.(25) However, football players who have a history of previous concussions are at a greatly increased risk of experiencing future concussions as compared to athletes without a history of such impacts.(26)

Baseball/Softball

Participation—Between the fall of 1982 and the spring of 2008, 10,916,754 high school men and 23,517 high school women competed in baseball. An additional 616,947 men competed at the collegiate level.(3) Approximately 419,000 men and 900 women compete in baseball at the high school level annually.(4)

A similar number of athletes competed in softball. Between the 1982–83 season and the 2007–08 season, approximately 30,000 men and 8.1 million women competed in high school softball, and an additional 323,000 women competed at the collegiate level.(3) Annually, approximately 313,000 female and 1,100 male softball players compete at the high school level.(4)

Injuries—As addressed above, early reports of concussion incidence were complicated due to under-diagnosis by trainers, coaches, and medical professionals. From 1995 to 1997, 246 certified athletic trainers reported a rate of 0.23 concussions per 100 player-seasons in high school baseball players, meaning that there were 0.23 concussions every season for every hundred athletes.(21) A 15-year survey of the NCAA ISS from the 1988–89 academic year through 2003–04 academic year found that the rate of concussion was 0.07 per 1000 A-E (95% CI = 0.06, 0.08).(18) An analysis of both high school and collegiate athletes during the 2005–06 season, which stratified rates of injury by practice and competitive play, found that high school baseball players had a rate of concussion of 0.03 per 1000 A-E in practice and 0.08 per 1000 A-E in games (0.05 overall). This study reported similar findings to the NCAA ISS, with collegiate athletes experiencing 0.03 concussions per 1000 A-E in practice and 0.23 per 1000 A-E in games (0.09 overall).(23) Concussions account for 2.9% of all injuries that occur in practice and 4.2% of all injuries occurring in games (Injury PR = 3.8, $p < 0.01$).(27)

In softball, from the same group of athletic trainers studied from 1995 to 1997, a rate of 0.46 concussions per 100 player-seasons was reported.(21) A more recent study analyzing high school softball athletes over the 2005–06 season found a concussion rate of 0.09 injuries per 1000 A-E during practice and 0.04 injuries per 1000 A-E during games (overall 0.07 concussions per 1000 A-E).(23) This high school concussion rate is slightly less than that

observed in college. The NCAA ISS survey reported a concussion rate of 0.14 per 1000 A-E (95% CI = 0.12, 0.16) in collegiate athletes between the 1988–89 season and the 2003–04 season.(18) Furthermore, over the 2005–06 season, collegiate athletes experienced a rate of 0.07 concussions per 1000 A-E in practices, and 0.37 concussions per 1000 A-E in games (overall=0.19).(23) Concussions occurring in practice accounted for 4.1% of all softball injuries, whereas concussions in games constituted 6.4% of all softball injuries (Injury PR = 2.5, $p < 0.01$).(27)

Although differing in form, softball and baseball are related sports with similar methods of play. As such, a recent study comparing softball athletes to baseball athletes in high school found that players in both sports experienced similar rates of concussion (0.07 concussions and 0.05 concussions per 1000 A-Es, respectively, RR = 1.48, 95% CI = 0.60, 3.63, P = .53). However, concussions represented a significantly greater proportion of total injuries in softball players than in baseball players (5.5% and 2.9% respectively, Injury PR = 1.91, 95% CI = 1.81, 2.01, P < .01). Additionally, the concussive injury in baseball players was more typically due to contact with the ball than in softball players (91.4% and 59.1%, respectively, Injury PR = 1.55, 95% CI = 1.50, 1.59, P < .01). Therefore, as expected, concussions in baseball players were more associated with being hit by a pitch than in softball players (50.6% and 6.9% respectively, Injury PR = 7.32, 95% CI = 6.44, 8.32, P < .01).(23)

These differences in mechanism of injury manifest in differing rates of recovery between the two sports. By six days post-injury, symptoms were resolved in slightly more of the softball players than the baseball players (68.8% and 64.2% respectively, Injury PR = 1.07, 95% CI = 1.03, 1.11, P < .01). Despite this delayed course of symptom resolution, a greater proportion of baseball players versus softball players returned to play within six days (52.9% and 15.5% respectively, Injury PR = 3.42, 95% CI = 3.13, 3.73, P < .01).(23)

Basketball

Participation—One of the most popular sports across both genders, basketball was played by approximately 13.8 million men in high school, along with 11 million women in high school, between the fall of 1982 and the spring of 2008.(3) An additional 375,000 men and 328,00 women competed in college.(3)

Injuries—In a survey of high school athletic trainers evaluating athletes over the 1995–97 seasons, men experienced a rate of 0.75 concussions per 100 player-seasons. This was slightly less than the rate of 1.04 concussions per 100 player-seasons experienced by women.(21) In college athletes, a 15-year analysis of the NCAA ISS found that men had a rate of 0.16 concussions per 1000 A-E (95% CI = 0.14, 0.17) as compared to a rate of 0.22 concussions per 1000 A-E in women (95% CI = 0.20, 0.24).(18) An analysis over the 2005–06 season in high school showed a similar relationship between male and female basketball players, with men experiencing a lower concussion rate than women (0.07 and 0.21 concussions per 1000 A-Es respectively, RR = 2.93, 95% CI = 1.64, 5.24, P < .01). This difference was largely accounted for by concussions during competition. Whereas men and women both had a rate of 0.06 concussions per 1000 A-E in practice, women had a rate of 0.60 concussions per 1000 A-E in games as compared to 0.11 in men. In college basketball, men experienced fewer concussions in both practices (0.22 versus 0.31 concussions per 1000 A-E) and games (0.45 versus 0.85 concussions per 1000 A-E).(23)

Concussions represented a greater proportion of the total injuries experienced by women as compared to men (11.7% and 3.8% respectively, Injury PR = 3.09, 95% CI = 2.98, 3.20, P < .01).(23) In men's high school basketball, concussions accounted for 4.1% of all the injuries sustained during practices and 5.0% of those sustained during games; this difference was not significant.(27), Women, however, experienced 3.4 times the risk of suffering a concussion

during a game versus practice, with concussions accounting for 4.7% of all injuries during practice and 8.5% during games.(27) This relationship between practice and games was confirmed in another study, indicating that women have a significant increase in risk at games (Injury PR = 5.82, 95% CI = 2.06, 16.49), but men had no significant difference.(28)

While playing basketball, concussions are associated with different activities in men than in women. Women receive a greater proportion of their concussions while ball handling/dribbling (19.0% versus 10.4%, Injury PR = 1.83, 95% CI = 1.65, 2.02, P = .01) and while defending (22.2% versus 13.4%, Injury PR = 1.66, 95% CI = 1.52, 1.81, P < .01). Men, on the other hand, experience a greater proportion of their concussions chasing loose balls (26.0% versus 10.6%, Injury PR = 2.46, 95% CI = 2.28, 2.64, P < .01) and rebounding (30.5% versus 16.6%, Injury PR = 1.83, 95% CI = 1.72, 1.95, P < .01). A higher proportion of men than women experienced a concussion due to collision with the playing surface (34.0% and 22.0% respectively, Injury PR = 1.54, 95% CI = 1.46, 1.63, P < .01). Some women, but no men, reported a concussion due to contact with the ball (6.0%).(23)

Male and female basketball players also have differing rates of symptom resolution and return to play. Two days post-concussion, significantly more men returned to play than women (39% and 15% respectively, Injury PR = 38.21, 95% CI = 30.44, 47.96, P < .01).(23)

Cheerleading

Participation—The number of athletes participating in cheerleading is increasing as the sport becomes more popular. Annually, there are currently an estimated 3.5 million cheerleading participants who are at least six years of age. Based on these estimates, the number of cheerleading participants in the US has increased 18% since 1990.(29)

Injuries—In addition to becoming increasingly popular, cheerleading has become increasingly associated with risk catastrophic head and spine injury, especially for the flier. (3) In the past thirty years, cheerleading has transitioned from principally utilizing toe touch jumps, splits, and claps, to increasingly incorporating routines such as gymnastic tumbling runs, human pyramids, lifts, catches, and tosses.(30) These moves are associated with increasing risk of injury. The Consumer Product Safety Commission (CPSC) reported that cheerleading injuries had resulted in an estimated 4,954 hospital emergency room visits in 1980. This number rose to 21,906 by 1999, and reached 28,414 in 2004. In 2007, the numbers decreased slightly to 26,786, but remained five times higher than the number of emergency room visits 27 years earlier.(4,31,32) Many of these injuries are to the head and neck. Many result in concussions.(4)

A study looking at all injuries in North Carolina high school competitive cheerleaders from 1996 to 1999 found that 6.3% of all injuries were concussions.(33) In 2006, head injuries were associated with 1,070 concussions. In 2007, head injuries were associated with 783 concussions.(4) A one year study of 143 cheerleading teams from 2006 to 2007 found that the majority of concussions and closed head injuries occurred in practices rather than athletic events (82% and 18%, respectively). Additionally, college cheerleaders were significantly more likely to experience a concussion or closed head injury than were cheerleaders of different levels (P = 0.02, OR = 3.10, 95% CI = 1.20, 8.06).(34)

Gymnastics

Participation—From the fall of 1982 through spring 2008, nearly 100,000 men and 640,000 women competed in high school gymnastics. An additional 15,000 men and 40,000 women competed collegiately.(3) Approximately 3,800 men and 24,500 women participate in gymnastics annually.(4)

Injuries—A study of high school gymnasts from 1990 to 2005 found an incidence of concussion and closed head injury of 1.7%. These concussions and closed head injuries were more likely to occur while individuals were performing headstands than among individuals performing other skills (RR: 7.14; 95% CI: 3.15–16.19; P < .002). As the age of the athlete increased, the frequency of concussions and closed head injuries decreased.(35) From the 1988–89 season through 2003–04 season, the rate of concussions reported to the ISS was 0.16 per 1000 A-E (95% CI = 0.12, 0.20).(18)

Ice/Field Hockey

Participation—Total concussions in ice hockey athletes are low due to relatively lower participation in ice hockey at the high school and collegiate level. Approximately 723,000 men and 72,500 women competed in high school ice hockey between the fall of 1982 and the spring of 2008. Approximately 100,000 additional men and 17,000 additional women competed in college.(3) An average of approximately 27,800 men and 2,800 women play ice hockey each year.(4) Field hockey is also associated with relatively few total concussions, again due to relatively lower athletic participation. Between the fall of 1982 and the spring of 2008, approximately 3000 men and 1.43 million women competed in high school field hockey, while 145,000 additional women competed collegiately.(3)

Injuries—Both forms of hockey are associated with a relatively high rate of concussions, considering their comparatively lower participation rate. According to the information reported to the ISS from 1988 through 2004, the rate of concussions in male collegiate athletes was 0.41 per 1000 A-E (95% CI = 0.37, 0.44), compared to 0.91 per 1000 A-E in female collegiate athletes (95% CI = 0.71, 1.11).(18) Concussions in hockey players account for 6.3% of practice injuries and 10.3% of game injuries (Injury PR = 15.5, p < 0.01).(27) Although the relationship between age and concussion in hockey players remains unclear, recent evidence in youth hockey players indicates that players in Bantam (age 13–14) and Pee Wee (age 11–12) had a higher risk of concussion (RR=4.04 and 3.14, respectively) when compared with players in Atom (age 9–10).(36,37) There is also a question as to what extent league rules, such as body checking, are associated with concussion. A meta-analysis of four studies evaluating the effect of body checking rules found that body checking in a league is associated with an increased risk of concussions (odds ratio =1.71, 95% CI = 1.2, 2.44).(36-39)

Although there are some similarities between ice and field hockey, the proportion of concussion was higher in ice hockey players (3.9%) than in field hockey players (1.4%) (Injury PR = 2.75, 95% CI = 1.17, 6.46).(40) In a survey of athletic trainers from 1995 to 1997, concussions in high school field hockey were reported at a rate of 0.46 per 100 player-seasons.(21) In college, the NCAA ISS reported that female field hockey athletes had a rate of 0.18 concussions per 1000 A-E (95% CI = 0.15, 0.21) from the 1988–89 season through the 2003–04 season.(18) Concussions accounted for a higher proportion of all injuries in games as compared to those in practices (7.2% and 3.7% respectively, IDR 6.4).(27)

Lacrosse

Participation—From the fall of 1982 through the spring of 2008, approximately 860,000 men and 587,000 women played high school lacrosse, with an additional 151,000 men and 106,000 women competing at the college level.(3) High school lacrosse has approximately 33,000 male and 22,000 female participants each year. College participation figures reveal approximately 5,819 men and 4,000 women lacrosse players each year.(4)

Injuries—Although lacrosse is not associated with a large number of total concussions, the rate of concussion is relatively high when compared with other sports. The rate of concussion in collegiate athletes reported to the NCAA ISS was 0.26 per 1000 A-E in men (95% CI = 0.23,

0.39) and 0.25 per 1000 A-E in women (95% CI = 0.22, 0.28) from the 1988–89 season through 2003–04 season.(18) Concussions accounted for 8.6% of all injuries in lacrosse competitions, with athletes nine times more likely to experience a concussion in a game as compared to practice (1.08 versus 0.12 injuries per 1000 A-E, Injury PR = 9.0, 95% CI = 7.1, 11.5). 78.4% of concussions resulted from a collision with another person, whereas 10.4% resulted from collision with a stick.(41) Another study stratified concussion rate by gender, and confirmed that games are associated with significantly more concussions than practice in both genders (Injury PR = 13.32 in men, and 6.3 in women, $p < 0.01$).(27) Concussions accounted for 9.8% of all female injuries, and women had approximately five times the rate of concussion during games as compared with practices (0.70 and 0.15 injuries per 1000 A-E respectively, Injury PR = 4.6, 95% CI = 3.5, 6.0). More than half the time, the concussions in female lacrosse players resulted from contact with a stick.(42)

Although the rate of concussions has increased dramatically in many sports, some have argued that this observation in men's lacrosse may be, in part, explained by the introduction of a new helmet. One study compared the rate of concussion in the years immediately following the helmet's introduction (1996–97 to 2003–04) to the preceding years (1988–89 to 1995–96). In practices, the rate increased by 0.14 concussions per 1000 A-E (95% CI = 0.09, 0.19, $P < .01$). In games, the rate increased by 0.84 (95% CI = 0.52, 1.16, $P < .01$).(41) However, this increase is certainly due, in part, to improved detection and diagnosis of concussion during that time frame.

Soccer

Participation—In the US, soccer is growing in popularity. Between 1982 and 2008, approximately 7.2 million men and 5.2 million women played soccer at the high school level. An additional 430,000 men and 322,000 women competed in college.(3)

Injuries—In a study of athletic trainers from 1995 to 1997, the rate of concussions in male soccer players was found to be 0.92 injuries per 100 player-seasons.(21) According to data reported to the NCAA ISS, men in college had a rate of 0.28 concussions per 1000 A-E (95% CI = 0.25, 0.30) over the time period from the 1988–89 season through 2003–04 season.(18) One study examining the 2005–06 season found that high school men experienced a rate of 0.04 concussions per 1000 A-E in practice and 0.59 concussions per 1000 A-E in games (0.22 concussions per 1000 A-E overall). It was reported that college soccer players experienced 0.24 concussions per 1000 A-E in practice and 1.38 concussions per 1000 A-E in games (0.49 concussions per 1000 A-E overall).(23) Significantly more concussions occurred in games than in practice (Injury PR = 6.94, 95% CI = 2.01, 23.95).(28)

Concussions in male soccer players typically occur as a result of head to head collisions in the act of heading the ball (40.5%). As expected, concussions were responsible for 64.1% of injuries that occurred while heading the ball. Another common cause of concussions in soccer players was contact with another person (85.3%). Goalies were significantly more likely to experience a concussion, as 21.7% of all injuries to goalkeepers were concussions as compared with 11.1% of all injuries to other players (Injury PR = 1.96, 95% CI = 1.92, 2.00, $P < .01$). (23)

In the aforementioned study of athletic trainers from 1995 to 1997, the rate of concussions in women was 1.14 injuries per 100 player-seasons.(21) According to data from the NCAA ISS, women in college had a rate of 0.41 concussions per 1000 A-E (95% CI = 0.38, 0.44) from the 1988–89 season through the 2003–04 season.(18) In the aforementioned study of the 2005–06 season, high school women were shown to have a rate of 0.09 concussions per 1000 A-E in practice and 0.97 concussions per 1000 A-E in games (0.36 concussions per 1000 A-E overall). In college, female soccer players experienced 0.25 concussions per 1000 A-E in practice and

2.80 concussions per 1000 A-E in games (0.63 concussions per 1000 A-E overall).(23) Concussions accounted for 11.4% of the injuries experienced by women during games and 2.4% of all the injuries experienced during practice.(27) Like men, women were significantly more likely to experience concussions in games as opposed to practice (Injury PR = 16.7, $p < 0.01$).(28)

As with men, concussions in female soccer players typically occur as a result of head to head collisions while heading the ball (36.7%). Women experienced fewer concussions as a result of contact with another person (58.3%, Injury PR = 1.46, 95% CI = 1.45, 1.48, $P < .01$). On the other hand, women experienced more concussions than men as a result of contact with the ground (22.6% and 6.0% respectively, Injury PR = 3.77, 95% CI = 3.56, 4.00, $P < .01$) and contact with the soccer ball (18.3% and 8.2% respectively, Injury PR = 3.68, 95% CI = 3.45, 3.92, $P < .01$).(23)

There appear to be differences in the rate of recovery from concussion between high school and collegiate athletes. College athletes, despite experiencing a higher rate of loss of consciousness, recovered by the third day post-concussion. Interestingly, an athlete's self-report of post-concussion symptoms may not be associated with return to baseline performance on neuropsychologic testing, as most high school athletes reported recovery by the fifth day post-concussion, but experienced neuropsychological deficits seven days following injury.(12)

Skiing/Snowboarding

Participation—Between 1994 and 2007, approximately 155,000 men and 132,000 women participated in organized skiing in high school. An additional 17,000 men and 15,000 women skied in college during that time.(3) Annually, approximately 580 women participate in college skiing.(4) However, the majority of skiers and snowboarders are taking part recreationally, not as part of an organized sport.

Injuries—An estimated 15–20% of the approximately 600,000 annually reported skiing and snowboarding injuries are head injuries.(43) Most of these head injuries occurred early in the season and were mild traumatic brain injuries (TBI) (69.4%) as opposed to severe TBI based on Glascow Coma Scale.(44) Concussions represent 9.6% of all injuries in skiers, 14.7% of all injuries in snowboarders, and 5.7% of all injuries in snowbladers.(45) A comparison of skiers and snowboarders found that both have similar rates of head injury (0.005 and 0.004 per 1000 participants, respectively), but skiers had a greater proportion of concussions (60% versus 21%), while snowboarders had a much higher proportion of severe brain injuries (29% versus 15%).(46)

Additionally, there is evidence that more male than female skiers tend to be injured as a result of collisions with trees, whereas more female than male skiers tend to be injured as a result of collisions with other skiers.(44,45) Male skiers are more likely to sustain a head injury than female skiers (OR = 2.23).(44,45)

Volleyball

Participation—Between 1994 and 2007, approximately 540,000 men and 5.4 million women played volleyball in high school, with another 15,000 men and 182,500 women playing volleyball in college.(3)

Injuries—A study of athletic trainers from 1995 to 1997 found that high school volleyball players had a concussion rate of 0.14 injuries per 100 player-seasons.(21) Data reported to the NCAA ISS found that college volleyball athletes had a concussion rate of 0.09 per 1000 A-E

(95% CI = 0.07, 0.10) from the 1988–89 season through the 2003–04 season.(18) One study reported that concussions account for 1.3% of all injuries reported in volleyball players during practices and 4.1% of those reported during games. In the same study, volleyball athletes were at a 3.8 times greater risk of sustaining a concussion during a game than a practice session. (27)

Wrestling

Participation—Like hockey, wrestling has relatively low participation in comparison to the number of concussions sustained by wrestlers. Approximately 6.2 million men and 46,000 women wrestled in high school, and 175,000 additional men in college, from the fall of 1982 through the spring of 2008.(3) Annually, there is an average of approximately 239,000 male and 1,700 female high school wrestlers, and 6,700 male college wrestlers.(4)

Injuries—High school wrestlers accounted for the greatest number of direct injuries in all winter sports.(4) High school athletic trainers from 1995 to 1997 reported a concussion rate of 1.58 injuries per 100 player-seasons.(21) A study of high school athletic trainers from the 2005–06 season found that concussions occurred at a rate of 0.13 concussions per 1000 A-E in practice, as compared to 0.32 per 1000 A-E concussions in games (0.18 per 1000 A-E overall). (23) The NCAA ISS determined that college wrestlers experienced 0.25 concussions per 1000 A-E (95% CI = 0.22, 0.27) from 1988–89 through 2003–04.(18) In 2005–06, collegiate data was further analyzed and wrestlers were found to have experienced 0.35 concussion per 1000 A-E in practice and 1.00 concussions per 1000 A-E in games (0.42 concussions per 1000 A-E, overall).(23) Concussions accounted for 6.6% of all injuries that occurred during matches and 4.5% of those injuries that were reported during practice.(27)

In wrestling, takedowns were the most common cause of concussions (42.6%) and were more likely to lead to a concussion than other wrestling maneuvers (7.6% versus 4.5%, Injury PR = 1.69, 95% CI = 1.61, 1.78, $P < .01$). The majority of these concussions occurred as result of contact with another person (60.1%) while the remainder occurred as a result of contact with the ground (26.9%).(23)

Discussion

The rate of concussion has been increasing steadily over the past two decades. This trend is likely due to improvement in the detection of concussion, but may also reflect an increase in the true number of concussive impacts occurring. As athletes get bigger, stronger, and faster, it is logical that the forces associated with their collisions would also increase in magnitude. It is important to realize that there is currently no effective headgear that prevents concussions so, as the number of forceful collisions increase, the number of concussions would be expected to increase.

In general, athletes tend to have a higher risk of concussion in competition as compared to practice. However, given the higher frequency of practices compared to games, and the resulting total number of concussions occurring in practice, one way to quickly and drastically reduce a sport's concussion risk would be to limit unnecessary contact in practice. The majority of concussions in high school athletes resulted from participation in football, followed by girls' soccer, boys' soccer, and girls' basketball.

Within a given sport, females tend to report higher rates of concussion than males. Within comparable sports, evidence indicates that female athletes may be at a greater risk of concussions than male athletes.(47) The evidence also indicates that, in general, concussions result in cognitive impairment in females more frequently than in males.(48) These variations may be due to biomechanical differences, such as differences in body mass, head mass, or neck

strength. They may also be explained by cultural differences, such as reluctance among males to report injury, and physiologic differences, including hormones.

In general, there are simple things that can be done to reduce the incidence of concussion in sports. Pre-participation examinations should be mandatory. If a physician or coach has questions about an athlete's readiness to compete, the athlete's safety should not be risked. At this session, or at a stand-alone meeting, concussion education should be afforded all athletes, especially for those competing in a collision or contact sport. Proper strength and conditioning, especially focused on strengthening the muscles of the neck, is a suitable way to limit the forces experienced by the head. Properly trained coaches, athletic trainers, and medical staff are on the front line in concussion education, diagnosis, and management, and are key to reducing the incidence and severity of concussions. Finally, quality officiating can help to identify potentially dangerous situations and ensure the activity does not result in injury.

Conclusion

Concussions and head injuries may never be completely eliminated from sports. However, with better data comes an improved understanding of the types of actions and activities that typically result in concussions. With this knowledge can come improved techniques and rule changes to minimize the rate and severity of concussions in sports. This paper identifies the factors that affect concussion rate.

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Table 1
Athletic participation figures by gender for 1982-83 through 2007-08

	High School		College	
	Men	**Women**	**Men**	**Women**
Baseball	10,916,754	23,517	616,947	0
Basketball	13,796,973	11,041,039	374,600	328,237
Cross-Country	4,546,218	3,486,467	275,202	235,937
Equestrian	621 (‘04-’07)	4,322 (’04-’07)	1,268 (’03-’07)	6,245 (’03-’07)
Field Hockey	2,781	1,431,676	0	145,133
American Football	35,623,701	17,872	1,929,069	0
Golf	480,989 (’05-’08)	199,721 (’05-’08)	24,844 (’05-’08)	12,197 (’05-’08)
Gymnastics	98,169	637,467	15,298	38,775
Ice Hockey	722, 874	72,537	99,626	17,309
Lacrosse	858,712	589,973	151,309	106,153
Rowing	16,147 (’01-’07)	17,111 (’01-’07)	14,107 (’01-’07)	47,310 (’01-’07)
Skiing	154,979 (’94-’07)	131,660 (’94-’07)	16,923	15,052
Soccer	7,175,341	5,184,875	429,603	321,982
Softball	29,743	8,141,872	0	322,777
Swimming	2,242,814	2,919,225	203,271	231,394
Tennis	3,677,132	3,832,588	199,274	203,695
Track	13,266,497	10,747,774	933,764	728,059
Volleyball	536,747 (’94-’07)	5,364,475 (’94-’07)	15,391 (’94-’07)	182,530 (’94-’07)
Water polo	220,778	189,126	25,543	10,266 (’98-’06)
Wrestling	6,235,016	46,361	175,353	0
Total	100,602,986	54,067,623	5,501,432	2,953,051

Data from Mueller FO, Cantu RC. Catastrophic Sport Injury Research 26th Annual Report: Fall 1982-Spring 2008: *National Center for Catastrophic Injury Research*;Spring 2008.

Table 2
Frequency and rates of concussion in NCAA from 1988-89 through 2003-04

	Percentage of All Injuries	Injury Rate per 1000 Athletic-Exposures	95% Confidence Interval
Men's baseball	2.5%	0.07	0.06, 0.08
Men's basketball	3.2%	0.16	0.14, 0.17
Women's basketball	4.7%	0.22	0.20, 0.17
Women's field hockey	3.9%	0.18	0.15, 0.21
Men's football	6.0%	0.37	0.36, 0.38
Women's gymnastics	2.3%	0.16	0.12, 0.20
Men's ice hockey	7.9%	0.41	0.37, 0.44
Women' ice hockey*	18.3%	0.91	0.71, 1.11
Men's lacrosse	5.6%	0.25	0.23, 0.29
Women's lacrosse	6.3%	0.25	0.22, 0.28
Men's soccer	3.9%	0.28	0.25, 0.30
Women's soccer	5.3%	0.41	0.38, 0.44
Women's softball	4.3%	0.14	0.12, 0.16
Women's volleyball	2.0%	0.09	0.07, 0.10
Men's wrestling	3.3%	0.25	0.22, 0.27
Men's spring football	5.6%	0.54	0.50, 0.58
Total Concussions	5.0%	0.28	0.27, 0.28

*Data collection for women's ice hockey began in 2000-2001.

Data from Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train*. Apr-Jun 2007;42(2):311-319.

Table 3

Concussion rates in US High School and Collegiate athletes in practice and competition, 2005-06

		Rates over 1000 Athlete-Exposures			Overall Rate Comparison Collegiate versus High School		
Sport	**Division**	**Practice**	**Competition**	**Overall**	**Rate Ratio**	**95% CI***	***P* Value**
Football	High School	0.21	1.55	0.47			
	Collegiate	0.39	3.02	0.61	1.31	1.09, 1.58	< 0.01
Mens' soccer	High School	0.04	0.59	0.22			
	Collegiate	0.24	1.38	0.49	2.26	1.43, 3.57	< 0.01
Womens' soccer	High School	0.09	0.97	0.36			
	Collegiate	0.25	1.80	0.63	1.76	1.21, 2.57	< 0.01
Volleyball	High School	0.05	0.05	0.05			
	Collegiate	0.21	0.13	0.18	3.63	1.39, 9.44	< 0.01
Mens' basketball	High School	0.06	0.11	0.07			
	Collegiate	0.22	0.45	0.27	3.65	2.01, 6.63	< 0.01
Womens' basketball	High School	0.06	0.60	0.21			
	Collegiate	0.31	0.85	0.43	1.98	1.31, 3.01	< 0.01
Wrestling	High School	0.13	0.32	0.18			
	Collegiate	0.35	1.00	0.42	2.34	1.26, 4.34	0.01
Baseball	High School	0.03	0.08	0.05			
	Collegiate	0.03	0.23	0.09	1.88	0.79, 4.46	0.22
Softball	High School	0.09	0.04	0.07			
	Collegiate	0.07	0.37	0.19	2.61	1.17, 5.85	0.03
Mens' Sport Total	High School	0.13	0.61	0.25			
	Collegiate	0.30	1.26	0.45	1.78	1.52, 2.08	< 0.01
Womens' Sport Total	High School	0.07	0.42	0.18			
	Collegiate	0.23	0.74	0.38	2.04	1.59, 2.64	< 0.01
Overall Total	High School	0.11	0.53	0.23			
	Collegiate	0.28	1.02	0.43	1.86	1.63, 2.12	< 0.01

Collegiate data provided by the National Collegiate Athletic Association Injury Surveillance System

High School data provided by the High School Sports-Related Injury Surveillance System

*CI = Confidence Interval

Data from Gessel LM, Fields SK, Collins CL, Dick RW, Comstock RD. Concussions among United States high school and collegiate athletes. *J Athl Train*. Oct-Dec 2007;42(4):495-503.