Supplementary Online Content

Rivara FP, Tennyson R, Mills B, et al; Four Corners Youth Consortium. Consensus statement on sports-related concussions in youth sports using a modified Delphi approach. *JAMA Pediatr*. Published November 11, 2019.
doi:10.1001/jamapediatrics.2019.4006

This supplementary material has been provided by the authors to give readers additional information about their work.

eTable 1. Search Criteria

No.	Question	Databases	Search Terms*	Inclusion Criteria**	Exclusion Criteria***	Number of studies included
1	What is the risk of concussion in youth sport participants by sport, sex, level of play, and age, stated as concussions per 100 participants per season, per 1000 participant exposures or some other rate?	PubMed, Embase, PsycInfo, CINAHL	"concussion", "rates", "risk", "sports", "youth" (Included in all searches below)	Original analysis; Peer-reviewed publication; Reports concussions rates or risks for athletes younger than 19 years old (or rates for under 19 were clearly separable from older athletes based on data provided in publication)	Athletes older than 19 years of age, did not report rate or risk, Conference abstracts	140
	Is this risk modified by sex, ADHD, prior learning problems, pre-existing anxiety and/or depression?"	PubMed, Embase, PsycInfo, CINAHL	"concussion", "rates", "risk", "sports", "youth","sex", "gender", "learning problems", "depression", "anxiety", "mental health", "modifier", "modified"	Includes either a formal statistical test or clear comparison between rates over a potential modifying factor (e.g. sex, mental health status, etc.)	No clear comparison or formal statistical test of a potential modifier of risk	

No.	Question	Databases	Search Terms*	Inclusion Criteria**	Exclusion Criteria***	Number of studies included
2	What is the evidence that a specific age or time in the growth and development of children is safer, in terms of lower risk of concussion and lower risk of mid and long-term problems, for introducing them to contact or collision sports?	PubMed, Embase, PsycInfo, CINAHL	"development", "age", "contact sport", "contact sports", "collision sport", "collision sports", "age at first exposure"	Reported a formal statistical test or presented a clear comparison between ages with regards to: rates or risk of concussion, concussion symptoms, and recovery from concussion; reported a formal statistical test or presented a clear comparison between ages of introduction to contact or collision sports and health, including self-report (or familal report) and formal medical diagnosis (either from study personnel or medical records)	No clear comparison or formal statistical test of age and rates or risk of concussion, or no clear comparison or formal statistical test of age at first introduction to contact or collision sports and health	23
	What evidence exists for the developmental readiness of children to learn and perform proper contact-related techniques safely?	PubMed, Embase, PsycInfo, CINAHL	"techniques", "developmental readiness", "age"	Compared rates/risks between youth athletes who underwent specific training and those who did not	No comparison between groups (whether distinct or paired with data from themselves) with regards to fidelity of learned techniques or changes in rates or risks of concussion	

No.	Question	Databases	Search Terms*	Inclusion Criteria**	Exclusion Criteria***	Number of studies included
3	What evidence exists to suggest that employing modified sports rules, policies and practices (e.g., field size, equipment, rules of play, size of balls, team size, coaching practices) will make “developmental sports leagues” safer for children and adolescents, especially with regard to concussions?	PubMed, Embase, PsycInfo, CINAHL	"field size", "equipment", "helmet", "ball size", "team size", "coaching training", "coaching practices", "coaches", "coaching", "rules", "policies"	Formal statistical test or clear comparison between rates and risk of concussion across different rules, policies, and practices	No formal statistical test or clear comparison	17
	What evidence exists that teaching contact/collision techniques (e.g. making and taking tackles) at a younger age, improves efficacy and diminishes injury risk?	PubMed, Embase, PsycInfo, CINAHL	"age", "techniques",	Formal statistical test or clear comparison between rates and risk of concussion and: age at introduction to contact or collision, age at introduction to specific technique training (e.g. Heads Up Football)	No formal statistical test or clear comparison between ages or technique training	

No.	Question	Databases	Search Terms*	Inclusion Criteria**	Exclusion Criteria***	Number of studies included
4	What evidence exists to suggest that (a) repetitive head impact exposure incurred during youth participation in collision/contact sports results in long-term cognitive and neurological harm (e.g., prolonged recovery from concussion, cognitive impairment, mental health problems including depression and anxiety, chronic headaches, and chronic degenerative neurological diseases seen on imaging or at autopsy such as chronic traumatic encephalopathy)?	PubMed, Embase, PsycInfo, CINAHL	"repetitive head impact", "subconcussive blows", "harm", "recovery", "mental health", "depression", "anxiety", "psychiatric", "headaches", "neurological disease", "neuroimaging", "chronic traumatic encephalopathy", "health", "neurological health"	Formal statistical tests or clear comparisons between youth with differing exposures to repetitive head impact exposure, either through sport type, length of time playing a sport, age at introduction to a sport, estimated exposure over time. Dependent variable is health	No measure of exposure, no measures of health	49

No.	Question	Databases	Search Terms*	Inclusion Criteria**	Exclusion Criteria***	Number of studies included
	What evidence exists to suggest that (b) multiple documented concussions incurred during youth participation in collision/contact sports results in long-term cognitive and neurological harm (e.g., prolonged recovery from concussion, cognitive impairment, mental health problems including depression and anxiety, chronic headaches, and chronic degenerative neurological diseases seen on imaging or at autopsy such as chronic traumatic encephalopathy)?	PubMed, Embase, PsycInfo, CINAHL	"multiple concussions", "concussions", "diagnosed concussions", "harm", "recovery", "mental health", "depression", "anxiety", "psychiatric", "headaches", "neurological disease", "neuroimaging", "chronic traumatic encephalopathy", "health", "neurological health"	Formal statistical tests or clear comparisons between youth with differing numbers of diagnosed or self-reported concussions; health is the dependent variable	No formal statistical test or clear comparison on number of concussions	
5	What is the evidence that equipment can reduce the risk of concussion in youth athletes?	PubMed, Embase, PsycInfo, CINAHL	"equipment", "headgear", "helmet", "protective equipment", "risk homeostasis"	Comparison between specific equipment variable (e.g. helmet type, headgear vs. no headgear) and rates or risks of concussion	No formal statistical test or clear comparison	18
6	What proportion of contact/collision sport athletes go on to participate in non-contact sports after contact/collision options are removed?	PubMed, Embase, PsycInfo, CINAHL	"contact", "collision", "non-contact", "non-collision", "options", "flag football", "removed"	Include measures of a single population (real or synthesized), compare rates playing a contact/collision or non-contact/non-collision before and after removal of sport, comparison between two similar populations	No measure of total population, no individual-level data on sports participation, no changes over time	6

No.	Question	Databases	Search Terms*	Inclusion Criteria**	Exclusion Criteria***	Number of studies included
7	What is the evidence to recommend youth player retirement (or redirection to other sports) in the setting of multiple concussions?	PubMed, Embase, PsycInfo, CINAHL	"retirement", "youth", "youth sports", "sports", "redirection", "concussions", "multiple concussions", "Cantu algorithm", "contact sports", "collision sports", "brain"	Expert or panel opinion, discussed retirement decision making algorithms or processes	Not centered on sports-related concussions or decision making for youth athletes	12

* Searches included some combination of these terms or the appropriate MeSH terms depending on database searched
** All studies needed to focus on athletes that were 19 years or younger, or they had to focus on exposures that occurred when athletes were 19 years or younger; Only original, peer-reviewed analyses unless otherwise stated

*** Conference abstracts or presentations were not accepted in the reviews of any questions

eAppendix. Delphi Consensus Document Appendix of Narrative Findings

Question 1

"What is the risk of concussion in youth sport participants by sport, gender, level of play, and age, stated as concussions per 100 participants per season, per 1000 participant exposures or some other rate? Is this risk modified by gender, sex, ADHD, prior learning problems, pre-existing anxiety and/or depression?"

Findings

Overall Rates and Notes

The overall median risk of experiencing a sports-related concussion as a youth participant is approximately 0.230 per 1,000 Athlete Exposures (AE's) (Interquartile range: 0.100-0.540). Risk is higher in competition (median: 0.580/1,000 AE's; 0.153-1.500) compared to practice (0.130/1,000 AE's; 0.045-0.297), and varies considerably across sports (**note**: these rates are unadjusted for sample size of individual studies and time period in which they were published). The number of rates published in peer-reviewed studies has grown considerably over the past two decades (Figure A1.1), so knowledge of which players are at risk and to what extent is much more complete than even a few years ago. However, as the current literature is described below, it is important to note that comparisons of SRC risk across modifying factors such as sport, age, and sex are not entirely straightforward. This is due in part to differences in calculating rates across studies (e.g. using 1,000 Player Hours or Percent of total athletes surveyed), differences in concussion measurement and assessment across time (i.e. secular increases in reported SRCs) and space (i.e. influences of local cultures on reporting SRC symptoms), and differences in gameplay (i.e. are AE's in American football comparable to AE's in rugby and Taekwondo?). Work on clarifying these and related issues is important moving forward.

Overall sports

Our review of the literature found the highest reported risk of SRC in Martial Arts and Rugby followed by American Football, Boys Ice Hockey, Girls Soccer, and Boys Lacrosse with the specific order of these sports depending on the study and rate type reviewed (Figure A1.2; Tables 1.1 and 1.2). For example, American Football has the third highest SRCs per 1,000 Game Exposures (1.987) while Boys' Ice Hockey has the third highest SRCs per 1,000 Athlete Exposures (1.390) (Tables 1.1 and 1.2). This pattern holds when reviewing studies on children under the age of 13 (Table 1.3), but the number of published rates is much smaller and rates more uncertain.

Sex comparisons

Males have higher levels of median risk compared to females when all sports are reviewed (overall concussion rates: 0.245/1,000 AE's and 0.182/1,000 AE's, respectively). However, when sports with comparable rules and gameplay are considered, females have higher risk than males (0.474/1,000 AE's compared to 0.157/1,000 AE's). The reasons for this difference are unclear, but it may be related to the proportion of hits that are unexpected during gameplay, differences in neck strength, connections between gender roles/identity and symptom reporting, and other related factors (see [1] & [2] for more discussions of these potential moderating factors).

Age and levels comparisons

Comparisons between levels of play and across ages are difficult because they are inconsistently defined throughout the literature. This is due in part to the smaller number of studies investigating SRC risk in children younger than 13 years of age but also due to differences across countries, differences across sports, rule changes within a sport depending on age, and rule changes over time. For example, many US high school students play ice hockey for their high schools whereas high school students in Canada are more likely to play in leagues that include adults (i.e. Junior leagues). Further, ice hockey has "PeeWee" for ages 11-12 and "Bantam" levels for ages 13-14, while American football has "middle school" and "high school" leagues. Body checking is introduced in adolescence in ice hockey whereas football and rugby often allow contact at younger ages. Lastly, age groups and their associated rules change over time, as when Hockey Canada altered its age categories for Atom and PeeWee in the early 2000s (e.g. [3]).

This being said, there are studies examining SRC risk across multiple ages and levels of play simultaneously. Some of these studies have reported that older youth are at increased risk of concussion [4, 5, 6, 7, 8, 9, 10, 11], while others have failed to find a significant difference with age [12, 13, 14, 15]. Authors posit that youth may be at an increased risk of concussion as they become stronger and faster with age, which has been supported by positive associations between athlete size, head impact exposure, and concussion risk [11, 16]. Player characteristics are likely to play an important role because player-to-player contact is the most common mechanism of injury for SRC in contact/collision sports [4, 5, 17, 18] and often a leading mechanism of injury even in non-contact sports [19]. However, these age-related patterns depend on the nature of competition. For example, SRC risk appears to reduce with age in martial arts, possibly due to participants becoming more skilled at blocking and safe striking [20].

Modifiers of risk

The most consistent and strongest modifier of SRC risk is previous experience of an SRC, which has been associated with two or more times higher risk of experiencing an SRC (e.g. [21, 22, 23, 24, 25, 26, 27, 28]. This may impact SRC risk in youth as they age – possibly complementing the increased risk from greater size and strength. Our review found that youth athletes that have had an SRC are more likely to have been diagnosed with a mental health condition[29], but there are not clear tests of whether depression or anxiety predispose individuals to SRC risk (e.g. [30]). However, there is limited evidence that ADHD may increase SRC risk [31, 32]. It is difficult to assign causality or determine etiology with this modifier, though, because ADHD also leads to higher symptom scores on pre-concussion baseline tests (e.g. [33]). Elucidating whether this association occurs through these youth athletes playing more dangerously, structural/activational differences in the brain leaving them more susceptible to concussion symptoms, or broader sociocultural factors that covary with ADHD diagnosis will likely improve the understanding of SRC risk broadly.

Caveats when making comparisons

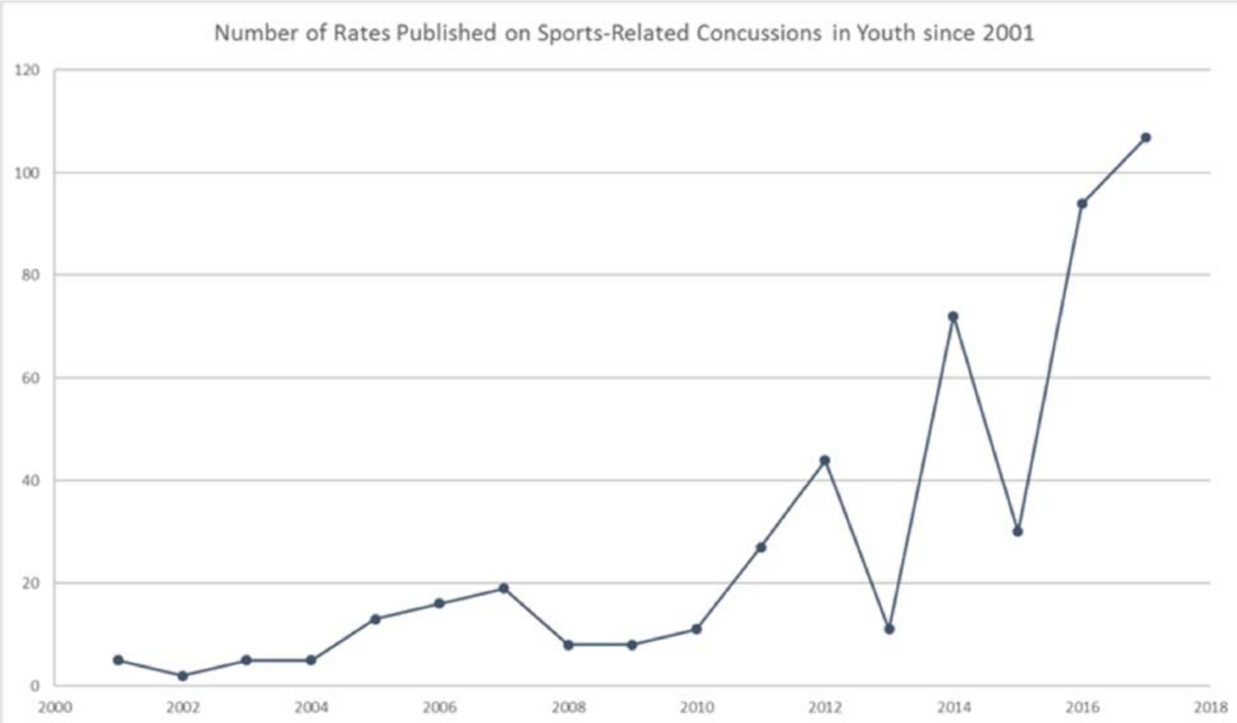
With these findings in mind, it is important to point out some important caveats when interpreting SRC rates and differences within and between sports that have arisen in the course of this literature review. First, there has been a secular increase in SRC reporting in youth. Most studies investigating SRC rates over time have found significant increases with multiple times more SRCs reported in recent years [17, 34, 35]. Moving forward, this will have to be taken into account when summarizing and comparing concussion risk across studies, in reviews, and meta-analyses.

Second, risk is patterned differently across sports. Sports where participants have specific and specialized roles - such as in American football - may have more variability in SRC rates among teams [10, 16, 21, 36, 37, 38, 39, 40]. The average SRC rate may be much lower or much higher than what many participants will experience. For example, linebackers have been attributed with up to 40.9% and 58.9% of all concussions suffered by defensive players in American football [36, 37]. Thus, the rates for this position and similar positions may be much higher than the average reported for American football.

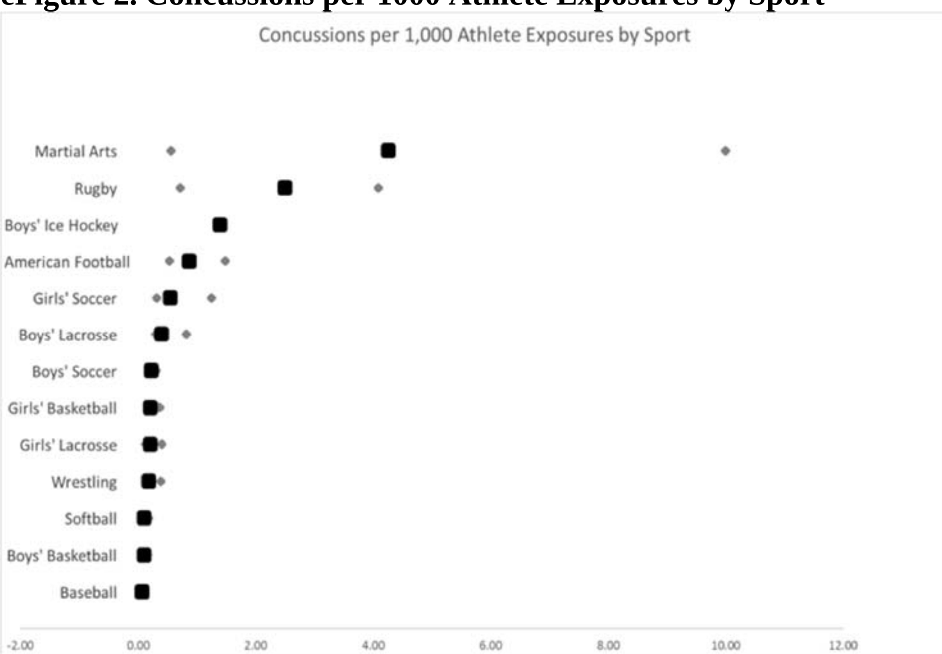
Third, we did not do an in-depth analysis of cultural factors in assessment and reporting, but studies have shown that education and beliefs about concussion may affect symptom reporting by coaches and players[11]. A relevant illustration of this may be seen with the SRC rates before and after the implementation of concussion reporting policies. For example, studies assessing SRC rates over time across multiple sports show an increase with reporting laws[41] (such as the Lystedt Law), but a study focusing solely on girls soccer did not[12]. This may be evidence that players, coaches, trainers, and others were already assessing and reporting the majority of SRCs in girls soccer while other sports were not.

Finally, gameplay differences and differences in how rates are calculated complicates comparisons among high risk sports. The majority of the papers included in our review report rates in either AE's or player-hours. AE's refer to an individual's participation in an athletic event, such as a game or a practice, but do not necessarily refer to the time individuals are actually at risk. This is important to keep in mind when comparing sports where players are only at risk for a fraction of the AE, such as football, and sports where players are at risk for essentially the full AE, such as rugby or lacrosse. AE is still the most commonly used rate likely because it is easier to compute and provide a rough comparison between sports (e.g. baseball and softball compared to soccer). Player-hours is often built on the average playing time of individuals, so it is more closely related to the time at risk. Unfortunately, few of our sports reported SRC risk in player-hours and even fewer controlled for actual playing time.

eFigure 1. Number of Rates Published on Sports-Related Concussions in Youth Since 2001



eFigure 2. Concussions per 1000 Athlete Exposures by Sport



(Note: for presentation purposes, the 75% quartile point for martial arts is set at 10 and not its actual value of 33.84)

eTable 2. Concussions per 1000 Exposures

	1,000 Athlete Exposures				1,000 Game Exposures			
Sport	**Count**	**Median**	**Upper**	**Lower**	**Count**	**Median**	**Upper**	**Lower**
Martial Arts	14	4.26	33.84	0.56	0	NA	NA	NA
Rugby	4	2.50	4.09	0.71	1	11.10	NA	NA
Boys' Ice Hockey	2	1.39	NA	NA	7	1.47	1.97	1.20
American Football	24	0.87	1.48	0.53	24	1.99	2.71	1.47
Girls' Soccer	17	0.55	1.25	0.32	7	0.97	10.00	0.85
Boys' Lacrosse	9	0.40	0.82	0.30	5	1.72	1.90	0.96
Boys' Soccer	12	0.23	0.31	0.19	6	0.58	0.73	0.54
Girls' Basketball	11	0.21	0.37	0.17	5	0.60	3.58	0.53
Girls' Lacrosse	6	0.21	0.40	0.12	2	1.02	NA	NA
Wrestling	13	0.18	0.38	0.17	5	0.48	0.77	0.35
Softball	12	0.11	0.18	0.10	5	0.29	1.12	0.09
Boys' Basketball	11	0.10	0.16	0.10	5	0.28	0.44	0.17
Baseball	12	0.07	0.11	0.05	5	0.11	0.12	0.08
Girls' Ice Hockey	0	0.00	0.00	0.00	1	1.40	NA	NA

eTable 3. Concussions per 1000 Hours

	1,000 Player Hours				1,000 Game Hours			
Sport	**Count**	**Median**	**Upper**	**Lower**	**Count**	**Median**	**Upper**	**Lower**
Rugby	10	4.60	6.75	1.71	21	8.30	12.60	6.00
Boys' Ice Hockey	18	1.22	4.77	0.77	13	0.80	3.55	0.00
Girls' Soccer	1	1.20	NA	NA	1	5.30	NA	NA
Boys' Soccer	1	0.32	NA	NA	0	0.00	NA	NA
Girls' Ice Hockey	3	0.20	0.20	0.39	2	2.80	NA	NA
Martial Arts	0	0.00	NA	NA	0	0.00	NA	NA
American Football	0	0.00	NA	NA	0	0.00	NA	NA
Boys' Lacrosse	0	0.00	NA	NA	0	0.00	NA	NA
Girls' Basketball	0	0.00	NA	NA	0	0.00	NA	NA
Girls' Lacrosse	0	0.00	NA	NA	0	0.00	NA	NA
Wrestling	0	0.00	NA	NA	0	0.00	NA	NA
Softball	0	0.00	NA	NA	0	0.00	NA	NA
Boys' Basketball	0	0.00	NA	NA	0	0.00	NA	NA
Baseball	0	0.00	NA	NA	0	0.00	NA	NA

eTable 4. Rates for Youth Under 13 Years of Age

Rates below age 13 only	1,000 Athlete Exposures				1,000 Game Exposures			
Sport	**Count**	**Median**	**Upper**	**Lower**	**Count**	**Median**	**Upper**	**Lower**
American Football	5	1.76	2.265	0.64	9	1.78	2.28	0.495
Rugby	0	-	-	-	3	20.482	30.723	11.039
Ice Hockey	1	2.84	NA	NA	3	1.47	2.89	0
Boys' Ice Hockey	0	NA	NA	NA	2	2.18	NA	NA
Girls' Soccer	1	1.3	NA	NA	1	0	NA	NA
Boys' Lacrosse	1	0.94	NA	NA	1	0.87	NA	NA
Wrestling	1	0.15	NA	NA	0	NA	NA	NA
Girls' Ice Hockey	0	0	NA	NA	0	NA	NA	NA
Soccer	2	0.683	NA	NA	0	NA	NA	NA
Boys' Soccer	0	NA	NA	NA	0	NA	NA	NA
Lacrosse	1	0.94	NA	NA	0	NA	NA	NA
Girls' Lacrosse	0	NA	NA	NA	0	NA	NA	NA
Basketball	1	0.085	NA	NA	0	NA	NA	NA
Boys' Basketball	0	NA	NA	NA	0	NA	NA	NA
Girls' Basketball	0	NA	NA	NA	0	NA	NA	NA
Baseball	0	NA	NA	NA	0	NA	NA	NA
Softball	0	NA	NA	NA	0	NA	NA	NA
Martial Arts	0	NA	NA	NA	0	NA	NA	NA

Question 2

"What is the evidence that a specific age or time in the growth and development of children is safer in terms of lower risk of concussion and lower risk of mid and long-term problems for introducing them to contact or collision sports (e.g., because the brain is less vulnerable to injury or the child is more physically mature)? What evidence exists for the developmental readiness of children to learn and perform proper contact-related techniques safely (e.g., what leg and arm strength and coordination is necessary to learn proper tackling or checking; what psychological readiness is necessary)?"

Findings

Introduction

The literature describes a complex relationship between SRC risk and age. A number of studies demonstrate an increasing risk of sustaining an SRC as youth athletes become older [4, 5, 7, 8, 9, 10, 11], and some of these authors have attributed this to youth getting stronger, larger, and faster [10, 11]. However, this relationship with age is not entirely consistent across studies and may depend upon the sport in question (showing decreases with age [42]; showing no change with age or higher rates in intermediate ages [12, 14, 15, 18, 43, 44, 45, 46]**.** While authors suggest younger athletes may be at increased risk for long-term sequelae from any SRC, our review failed to find any direct evidence of this. There exists some TBI literature suggesting younger brains are more susceptible to long-term physiological changes, but these impacts are typically more severe and a different mechanism than the SRCs which are the focus of our review.

Further, we were unable to identify specific literature investigating how youth learn and conduct proper contact techniques across age levels. We make a brief comment on how certain developmental milestones may interact with youth's ability to play more safely and suffer less severe or fewer SRCs.

Age

In most studies where age was included as an independent variable, rates of SRC appear to increase with age [4, 5, 7, 9, 10, 11, 45]. A few authors suggest this may be due to athletes becoming heavier, stronger, and faster [10, 11], which could increase impact forces**.** Importantly, two studies suggested that increased playing time (especially in games) of older and larger youth athletes may also be a contributing factor [10, 47]. However, we find no apparent difference in SRC rates when comparing the medians of all studies with youth below high school aged (<14 years of age) and those at high school ages (14-19 years of age).

American Football. SRC risk was found to increase with age in almost all studies of youth American football where age and SRC rates were specified [7, 8, 13]. This was found in studies looking at pre-high school ages (ie 8-10 years vs 11-12 years; [7]) as well as a study spanning 5-years of age to the end of high school[8]. One study found that head acceleration was lower in middle school and younger children than that found in previous studies reporting head acceleration in high school[48]. Unfortunately, there is less evidence on how age differences in high school impact SRC risk. One study found highest rates in 10th graders (15-16 years), but did not report any formal statistical comparisons[48]. When comparing our aggregate rates, pre-high school aged players appear to have higher rates per 1,000 AEs while high school players demonstrate higher rates per 1,000 game exposures (Tables 1.1-3).

Focusing on symptom recovery among American football and soccer players, one study reported that high school players exhibited a longer time to recovery than college players[49]. This is despite the college players experiencing more extreme concussions on average.

There is an increasing number of studies investigating CTE and persistent concussive symptoms among retired and former athletes with a specific focus on their age at first exposure to contact (e.g. [50, 51]; see Question 4 for a more detailed review**)**. There are some findings that former NFL players who began playing football before the age of 12 had an increased likelihood of having CTE and showed neurocognitive symptoms associated with dementia, and likely CTE, at an earlier age[50]. However, one study comparing those who were first exposed before high school and those first exposed during high school failed to replicate this finding[30]. Further, other authors have highlighted issues with the studies demonstrating associations that are likely to introduce serious bias and limit generalizability (see discussion in [52]). For example, recruiting from adult symptomatic cohorts and utilizing retrospective measures (this topic is reviewed in Question 4, as well).

Ice Hockey. In ice hockey, there is a substantial difference in SRC rate between those too young to bodycheck and ages where bodychecking is legal. One study did not report any apparent association with age once bodychecking was legalized [5], but our aggregate data shows a higher median SRC rate across studies in players aged >14 years old compared to players <14 years old (Tables 1.1-3). However, this may be due to inclusion of leagues where bodychecking is illegal (e.g. 11-12 year olds). One study of head impacts in girls ice hockey found that older and larger players had higher impact acceleration and had more playing time[47]. The authors suggest this would likely increase their risk of SRC, but they did not have sufficient statistical power for such a test.

Rugby. SRC associations with age are unclear in rugby. While two studies demonstrated that U14 and U16 players had higher rates of SRCs than U18 players (range 9-18 years and 13-18 years, respectively)[18, 38], one study failed to find a difference between Junior Cup (~13-14 years) and Senior Cup (~16-17 years) players[15]. One study of adolescent players did find that players who were older, larger, and weight trained were more likely to suffer an SRC over the course of one season[11]. Our aggregated rates show decrease in SRCs in games in individuals aged 14 years and above while also showing a decrease in SRCs with overall exposure.

Multiple Sports. Relevant studies in other sports are less common, and further complicate direct relationships between age and SRC rates. One prospective study reporting SRC rates by age in girls soccer did not demonstrate an associations between SRC rate and age[12]. Although one study found that older participants were more likely to have experienced an SRC within their lifetime[53], our aggregated rates were lower in older (>14 years old) compared to younger (<14 years old) players (Tables S1.1-3).

A study of boys lacrosse did not find significant difference with age in players aging from 9 to 15 years old[45], but our aggregate data suggest reduced SRCs per 1,000 AEs and increased SRCs in 1,000 Game exposures in boys lacrosse with older age.

In Australian Rules Football, one study reports that 14-17 year old boys had higher SRC rates than 9-13 year olds[4], and another failed to find differences in SRC rates or symptom reporting between <18 years and >18 years of age[14].

In one of the few studies with an inverse association with age, younger TaeKwonDo participants (11-13 years old) had a higher SRC rate than older participants (14-19 years old)[42]. They were also more likely to receive a blow to the head, which the authors suggested is due to lack of skill in blocking techniques.

Lastly, one study of multiple sports (using the HS RIO database) failed to find an association between age and return to play time in US high school student-athletes[54].

Developmental Preparedness

We were unable to find evidence that directly examined the ages when players were able to learn and apply proper contact techniques at different ages, and, in turn, how these differences in ability translated to SRC risk. One study found that implementing Heads Up Football coaching training together with reducing contact in practice and training on proper fit of equipment had a larger SRC reduction among 11-15 year olds compared to 8-10 year olds[55]. However, this may be due to a lack of power - the 8-10 year olds had a small number of SRCs before these interventions.

There is a literature base demonstrating that interventions teaching “proper” and “safer” contact-related techniques are associated with youth performing these techniques more often (e.g. [57]). However, we did not find age comparisons, and it’s unclear whether these techniques translate to reductions in SRC risk in youth sports participants.

For example, a few studies of SRCs in youth ice hockey found that delaying the introduction of contact sports (e.g. making body checking legal in ice hockey at a later age) does not exert a substantial effect on SRC rates[23]. That is, 13 year-old athletes were shown to have similar SRC rates whether they were newly introduced to contact or whether they were introduced two years earlier. This may suggest either that children are capable of learning to perform these techniques similarly regardless of being 11 or 13 years of age. However, considering that the most consistent modifier of SRC risk in youth is previous SRC, later introduction to collision sports may reduce the overall risk of sustaining any SRC as well as decrease the risk for sequelae arising from multiple concussions and repetitive head impacts (reviewed in Question 4). It is important to note, though, that this study also found an increased risk of sustaining an injury that took longer than 7 days to return to play.

This being said, it is worth discussing the implications from literature investigating important developmental milestones, such as vision tracking and motor coordination which may impact SRC risk.

Developmental Milestones. Lack of anticipation and preparedness for a collision or body contact leads to increased impact severity and is associated with increased SRC risk (particularly in contact sports that are non-collision). Youth generally show quickened reaction time, improved visual tracking, and motor coordination as they age, which should lessen the opportunity to be hit unexpectedly and without being able to prepare for the hit [57, 58, 59]. The Fischer and Rose model is cited throughout studies interested in SRC risk across development. It highlights nonlinear, spurt-like growth in factors that impact these functions, particularly at 7, 11, 15, and 20 years of age. Some authors suggest this growth model should be taken into account when normalizing baseline scores on neurocognitive tests for youth even if the ages are not associated with SRC risk, per se (e.g. [37]).

Thus, this theory of developmental timing posits that youth will be better able to learn and perform crucial sport-related techniques as they age, presumably leading to safer play. However, passing developmental milestones often also mean that these youth are growing larger, stronger, and faster, and become capable of exerting much greater force in collisions. This could explain why, in some youth sports, SRC rates appear to increase with age (reviewed above).

Conversely, there are relevant psychological theories that posit 'critical' or 'sensitive' periods during which individuals are best able to learn and perform skills throughout life. Trying to learn and perform these skills or tasks after these developmental windows may lead to reduced fidelity throughout life[57]. Unfortunately, our reviews here did not cite or focus on these theories while discussing potential associations between age/developmental stage and SRC risk.

Regardless, our review highlights the need to better understand SRC risk across age and developmental periods. For example, are the increased rates of SRC risk in 14-16 year old rugby players due to the combination of increased size with less technical skill than their older counterparts? Further, how is SRC risk patterned across American football players in high school where competitors range from 14-19 years of age and players differ in size and their developmental stage (using Fischer and Rose's developmental model)?

Question 3

"What evidence exists to suggest that employing modified sports rules, policies and practices (e.g., pertaining to field size, equipment, rules of play, size of balls, team size, coaching practices and other characteristics) will make "developmental sports leagues" safer for children and adolescents, especially with regard to concussions? What evidence exists that teaching contact techniques (making and taking tackles) at a younger age, improves efficacy and diminishes injury risk?"

Findings

Concussion rates in youth sports have increased over the past couple decades, which most authors attribute to improved concussion knowledge and assessment [17, 34, 35]. Accounting for these increases in reported rates, there is evidence that changes in sports rules, policies, and practices can have substantial impacts on concussion risk in youth sports. Player-to-player contact is typically the most common mechanism of SRCs in youth sports (e.g. [4, 19, 47, 45, 60, 61, 62, 63]). Accordingly, changes that substantially alter how often and in what ways players come into contact are associated with reduced SRC risk (e.g. [13, 55, 64, 65]). However, there are some open questions about how best to apply such rule changes.

Reporting and assessment rules

While a growing number of rules and legislation mandate reporting of SRCs and timelines for return-to-play have likely increased the rate of SRCs recorded in youth sports, the rates likely demonstrate a more widespread awareness and concern for the long-term impacts of SRCs among parents, players, coaches, and training staff. Coaches and teams with dedicated training staff are more likely to accurately assess such symptoms in their players[66], but not all coaches' training is effective[67]. At first glance, the increase in SRCs seem to suggest these factors increase SRC risk, but the majority of authors conclude that they are recording a more accurate prevalence of SRC. Unfortunately, this adds to the uncertainty on whether these policies reduce youth athletes' real SRC risk.

Policies limiting contact

Rules changes that reliably limit player-to-player contact throughout the full season appear to reliably reduce SRC risk risk (e.g. [13, 55, 64, 65]). Conversely, rules to limit contact within a single tournament or other limited time range appear to have limited effects[68].

Ice Hockey. The most common rule change investigated in the literature is to make body checking illegal in boys' ice hockey. Making body checking illegal in 11-12 year olds results in lower rates of concussions when compared across communities as well as when single communities are followed over time[21, 64, 69]. In one study, the Canadian policy to disallow body checking in PeeWee players is associated with a threefold reduction in concussion (IRR: 2.83; 95% CI 1.09, 7.31)[64]. It is unclear from the existing literature whether less extreme changes, such as the implementation of "Fair Play" rules, result in meaningful changes in SRC (see [68] for a full review). It is important to note that while there are comparatively few studies on SRC risk in girls ice hockey, SRC rates reported in our review are often within a similar range of boys despite the fact girls ice hockey leagues do not allow body checking.

Limiting practice contact. A growing focus of research is limiting contact during practice as a way to reduce overall exposure to contact and collisions as a way to reduce SRCs and the possible detrimental effects of repetitive head impacts in American football. Studies show that limiting full contact in practice was associated with a reduction in cumulative head impacts over a full season, especially for linemen[48, 70]. Another showed that improved including a Player Safety Coach, an integral part of the Heads Up Football coaching education program (HUF) released by USA Football, reduced head impacts without necessarily enforcing rules on limiting contact in practice[45]. However, another study only found a significant reduction in SRCs when contact limitations were put into place alongside the Heads Up Football coaching education program (HUF) released by USA Football[55]. Other evidence suggests minimizing or avoiding certain drills can drastically reduce head impact exposures, but the direct connection to SRC risk has not been made[71, 72]. Further, another study has demonstrated that younger football players experience a greater percentage of high magnitude impacts in practice whereas older players experience a greater percentage in competition[48]. Thus, limiting contact in practice may have different effects on SRC rates depending on age. Lastly, it is unclear whether limiting contact in practice has meaningful impacts in other youth sports.

Other rule changes

Although there is a strong connection between limiting player-to-player contact and reduction in SRCs, making contact illegal either may not be an option for the sport (e.g. if the sport is already non-contact) or the community at hand may not want to take such a strong approach. There is a growing literature investigating rule changes that are not directly associated with contact, but the evidence on the effectiveness of these changes is limited or nonexistent.

Soccer Heading. A growing number of youth leagues are limiting heading in soccer or making it illegal in an effort to reduce SRCs, including USA Soccer who has made heading illegal for children under 10 years of age and limited heading in ages 11 to 13. Most concussions experienced in soccer occur during headers (e.g. [17, 60, 63, 73, 74, 75]), and the most common mechanism of concussion during a header is player-to-player contact (e.g. [17, 60, 63, 73, 74, 75]). Conversely, two recent meta-analyses and reviews say there is no conclusive evidence that heading in soccer is associated with adverse outcomes in youth[73, 74]. While the physical act of a purposeful header may not be the most dangerous part of a header, the goal of limiting headers is to reduce both the ball-head impact and the player-to-player impacts that occur because of the situation. Unfortunately, a direct test of this was not found in the literature.

Fair Play and no tolerance. “Fair Play” and “Zero Tolerance for Head Contact” and similar programs reward teams and players for not receiving penalties and enact stricter rules for illegal contact[76, 77]. The larger goal being to encourage participants to engage in less aggressive and less dangerous play. A number of leagues have begun instituting some form of these programs in hopes it will reduce SRCs and other injuries. While there is some evidence of it reducing overall injuries[78], and newer work suggests they may be able to reduce SRCs[79].

There are more rule changes that have been instituted or are under discussion in youth sports leagues, such as the effect of moving kickoff positions in American football, but our review was unable to find direct tests of these proposed changes.

Playing Area

Increasing the playing area may reduce concussion risk, likely from decreasing the likelihood of impact between players. For example, Olympic size ice rinks result in fewer player-player impacts and reduced risk of concussion in ice hockey [65, 80, 81]. It is unclear if such an effect is seen in other sports, probably because playing size is more uniform. However, a few studies indicate that playing strategy is different in soccer when the field size and number of players is reduced, but this was not directly connected to SRC (e.g. [82]).

Playing Surface

Contact with the ground is another common cause of SRC in contact sports and is often the leading cause for non-contact sports, such as cheerleading and volleyball[37, 83]. Multiple lines of evidence suggest that softer floors should help reduce concussions in gymnastics and cheerleading (the majority of injuries are from falls)[84]. Further, artificial turf appears to be associated with an increased risk of blackout with concussion in American football[24]. The current literature review did not pull enough information to comment on other youth sports.

Equipment

There has been a substantial amount of research into the effects of headgear on concussion risk, but less so on other forms of equipment. This line of research is discussed in detail in Question 6.

Contact techniques

Our review has pulled up limited evidence pertaining to the second portion of this question. It is unclear whether teaching proper contact techniques at earlier ages will result in safer play or reduced injury in youth sports participants, and Question 2 deals with evidence addressing several related questions. This being said, one study found that Heads Up Football coach training (as proscribed by USA Football) is associated with a reduced number of concussions in youth football players aged 11-15 years old when teams also restricted contact in practices[55]. The SRC risk with combination of both strategies was significantly less than only instituting “Heads Up” which was not significantly different than teams that did not institute either strategy for reducing concussions and injuries. A newer study on high school athletes also found that “Heads Up” Training reduced concussions[85].

We also came across a body of evidence addressing contact techniques and concussion incidence in rugby. Many of these articles were focused on adults and were thus out of the range of our review. However, the main takeaways from these discussions are that concussions are more likely from hits where the tackler is upright (i.e. impacting high on each players’ body), running at high speeds, and active shoulder tackles. These patterns may be relevant for youth athletes as well, but more evidence is needed.

Exercise and conditioning

A recent study suggests that functional movement exercise and conditioning aimed at reducing concussion rates in youth rugby players may be effective[86]. However, it is important to note that while the authors claim their effects had practical significance, they are not statistically significant and other researchers have published concerns about the study’s methods[87].

Question 4

“What evidence exists to suggest that (a) repetitive head impact exposure or (b) multiple documented concussions incurred during youth participation in collision and contact sports results in long-term cognitive and neurological harm (e.g., prolonged recovery from concussion, cognitive impairment, mental health problems including depression and anxiety, chronic headaches, and chronic degenerative neurological diseases seen on imaging or at autopsy such as chronic traumatic encephalopathy)?”

Introduction

The techniques used to investigate this question have grown quickly over the past decade, and the majority of our sources have been published in the last five years. Neuroimaging and neuropsychological tests are both being used more frequently to examine both short- and long-term impacts of participation in contact sports.

In youth, there has been concern about repetitive head impact exposure and subsequent possible brain and cognitive changes. However, while studies have found short-term neurological and functional changes (e.g. [88, 89, 90]), the preponderance of the highest quality evidence suggest there are no long-term neurological effects of repetitive head impact exposure sustained during contact or collision sports (e.g. [55]; see [91] for another review of the central papers included here).

Findings

Repetitive head impact exposure

Repetitive head impact exposure is typically defined as hits to the head that transfer mechanical energy to the brain at enough force to injure various aspects of neuronal integrity, but not be expressed in clinical symptoms. Our review suggests that repetitive head impact exposure may be associated with short-term changes in the brain and neurocognitive functioning [88, 89, 90, 92, 93, 94, 95, 96, 97], but not all studies demonstrate consistent associations and others fail to demonstrate any associations [30, 52, 98, 99].

Neuroimaging. The majority of neuroimaging studies found in our review support an association between increased repetitive head impact exposure and physiological changes in the brain as measured in neuroimaging[50, 88, 89, 90, 93, 95, 96, 100, 101, 102, 103, 104]. Prospective studies in youth have focused largely around American football players with telemetry measures of impact exposure (via equipping of helmets with Head Impact Telemetry (HIT) System) where longitudinal changes and/or comparisons against a control group were measured [90, 93, 95, 96]. Impact exposure has been associated with changes in white matter diffusivity[95], default mode network connections[88], metabolism (as measured by MRS)[101], and functional activation[90, 93]. The timeline of these studies showed changes within a week of repetitive impact or within months of the end of a season (if they were assessed pre- and post-season). However, these changes are not always in the same direction across studies and in some studies they correlate with symptoms at one time point but not at another (e.g. [89]). In a few instances, exposure was also associated with changes in neurocognitive scores (e.g. [90]). Importantly, the cumulative number and strength of hits did not always predict changes - players with low number and amplitude hits showed changes as well[90, 95]. Cross-sectional study of cortical thinning in youth ice hockey players was associated with changes in scores on computerized neurocognitive assessments[102].

With these findings in mind, it is important to note some very important potential caveats. The reported changes due to repetitive head impact exposure are highly non-specific and have been found in other conditions/populations without exposure. Many studies have not included proper controls, i.e. exposed and non-exposed athletes matched on exercise level [89, 90, 93, 96, 102] and other important demographic and neurobiological variables. Metrics of exposure are also imperfect.

Many of the prospective neuroimaging studies are small (N<40) and come from the same (or related) cohort of youth football players (e.g. [89, 90, 96]). The brain changes across studies are not always the same, potentially due to players receiving hits at different locations. The long-term stability of the changes in prospective findings is unclear since they do not match well with the retrospective studies of retired football players. The association between these changes and behavioral and cognitive profiles are not clear in most of these studies. In addition, many such studies presume that changes over the course of a season are due to repetitive head impact exposure as opposed to other factors that change over the course of an athletic season.

Neurocognitive. Studies focusing on neurocognitive factors are more heterogeneous. About half of our non-prospective studies demonstrated an association between a measure of repetitive head impact exposure and neurocognitive profiles [92, 94]. Two studies of AFE for football players showed detrimental impacts in adulthood for players starting before 12 years of age[50, 51]. However, both studies started from an adult symptomatic cohort and then used retrospective recall to determine AFE. One study[50] was former NFL players which is clearly not the same population as high school or younger athletes (i.e. not generalizable, ascertainment bias) and the experimental variable may be inaccurate (i.e. recall bias). Relatedly, another study failed to replicate this finding focusing on AFE pre-high school vs high school (AFE reviewed more below)[30]. Further, two retrospective community-based studies of medical record data from high school players in Rochester, MN (together spanning 1946-1970) failed to find associations between men who had played American football in high school and increased risk of neurodegenerative disease in later life[98, 99].

Our review included two prospective, longitudinal studies focusing on neurocognitive associations with repetitive head impact exposure[92, 94]. One showed changes in visual motor speed only, but the authors suggest it is not conclusively from head impact exposure[92]. The other study, utilizing helmet telemetry, found that impact exposure was associated with worsened neurocognitive functioning, and this was independent of concussion symptoms or diagnosis[94]. This group also showed changes in the brain (reviewed above). Relatedly, a study of girl soccer players found decreases in several neurocognitive measures immediately following a practice in which they headed the ball[97].

A study conducted with a large population-based cohort with prospectively collected data from Wisconsin high school graduates in 1957 failed to find an association between high school football participation and cognitive decline or depression at 54, 65, or 72 years of age[52]. The authors note that they do not have data on pre-high school participation, but they performed multiple strategies of matching and controlling for confounding (e.g. physical activity levels at age 35, parental income) and they pre-registered their analyses *a priori*. Thus, this study is likely the strongest level of evidence against long-term impacts of high school football participation.

Moving forward, studies using multiple neurocognitive factors should be sure to correct for multiple comparisons and avoid *post hoc* choice of findings from a panel of tests. Studies using a large sample also need to consider the clinical significance of changes, not simply statistical significance. Lastly, while direct impact in the past may have had less force compared to modern play, head protection was less protective against forces and sports rules and policies were less restrictive. Generally, many authors suggest that further studies of longitudinal cohorts will provide better understanding of how these secular changes may affect neurocognitive associations in current youth (e.g. [52]; see [91] for another review of the limitations of this body of work).

Multiple documented concussions

Studies investigating associations of the brain and neurocognitive factors with multiple concussions are inconsistent. The prospective study included in our review found that athletes with multiple concussions reported more symptoms at baseline and suffered larger memory reductions when experiencing a new concussion[94]. Cross-sectionally, multiple concussions was associated with increased time to recovery[105]. Youth who had multiple SRCs and were symptom-free also scored worse on attention and concentration assessments [106, 107]. Further, they often scored similarly to athletes with a recent concussion on neurocognitive tests (both were worse than no recent concussions). Multiple SRCS have been associated with worse GPAs in high school[107]. Lastly, former collegiate athletes reporting more concussions (including high school and college) were at greater risk for severe depression and reduced impulse control scores[108].

However, one study only found an association with multiple SRCs and verbal memory and found that gender, history of headaches/migraines, psychiatric history, and learning problems also strongly influenced these scores[109]. Since concussion risk is associated with these factors bi-directionally, it's difficult to ascertain direction of causality in these and other non-prospective analyses.

There are at least a few examples of studies failing to find an association. A study of American football players in Maine failed to find an association between cognitive test performances and concussion history[110]. A large study failed to find an impact of one or two previous concussions on test performance or symptom reporting[111]. One study failed to find associations with neurocognitive tests, but did report symptom differences in athletes with 3 or more concussions[112]. A study of adults who received concussions as youth athletes failed to show differences across a range of tasks[113]. One study of youth ice hockey players failed to find associations[114]. Another study of youth ice hockey players failed to find differences measured with several robotic tests of sensory, motor, and cognitive functioning[115].

Age at first exposure

Recent studies of former NFL players indicates increased brain pathology and neurological changes in individuals who started playing before age 12[50, 103, 116]. A study of brains with CTE found that earlier age at first exposure (AFE) was associated with earlier behavioral symptoms, particularly with AFE before 12[51]. Cross-sectional *in vivo* neuroimaging studies of former NFL players have shown reductions in thalamic volume and white matter integrity with an AFE younger than 12 years[103]. Studies of former American football players broadly (including those who played up to high school, college, or NFL) found that AFE <12 was associated with impairment on self-reported and lab assessed neurocognitive function[51]. Further, one study developed a measure of cumulative head impact, which was associated with reduced functioning in these individuals[117].

There was one study of former NFL players where they were recruited randomly from lists of retired players which did not find differences in cognitive functioning or wellbeing based on when they started playing football[30]. It is important to note, though, that this study compared individuals who began before high school to those who started in high school. Therefore, the "early exposure" group was actually 2 years older than the other studies describing findings. Lastly, studies demonstrating associations were larger than those not.

However, there are important limitation and methodological issues to note with these studies of AFE. First, much of their samples are recruited from adult symptomatic cohorts, so they may be biased towards individuals with neurobiological changes. Second, AFE as well as lifestyle and childhood characteristics (e.g. alcohol use and childhood environment) that may impact later brain health are retrospectively measured, making them sensitive to recall bias. Lastly, very few individuals playing football before and during high school ever compete at the college or NFL level. These smaller populations may be self-selecting and unrepresentative of the high school football population more broadly.

(AFE is discussed in Question 2, as well)

Post-mortem studies

Two studies of *post mortem* brains (not included in AFE analysis) were relevant to this question. One study found 'incipient' CTE in one out of three high schools with exposure to collision sports before an unexpected death[118]. Another study found CTE-related changes in the brains of recently deceased 17-22 year olds exposed to closed head injury compared to those who had no such exposure[119], but there are substantial concerns over whether these changes can be directly connected to the head injuries in this study.

Question 5

"What is the evidence that equipment can reduce the risk of concussion in youth athletes?"

Findings

Our review found two strategies of reducing SRCs with equipment in youth athletes. Protecting the head from direct trauma with padded headgear or full helmets is more studied, but we also found some studies investigating mouthguard use. In general, authors are concerned with poor adherence to study protocol and that athletes may play more dangerously when they wear more protective equipment.

American football

The use of modern helmets has dramatically reduced the rate of concussions and deadly injury in American football, but differences between modern helmets in SRC risk is not consistent[120, 121, 122]. While one study demonstrates reduced SRC risk with a newly designed helmet (Riddell Revolution) when compared to "standard" helmets[120], two other studies failed to show differences in helmet brand or between new and reconditioned helmets[121, 122]. One study suggests that athletes suffering a SRC may have a larger proportion of symptoms that do not completely resolve within one day if they were wearing an old, non-reconditioned helmet[121]. However, this same study did not demonstrate a difference in SRC risk in old helmets.

Rugby

Studies of headgear in rugby have also failed to demonstrate they are protective against concussions[11, 123, 124]. However, they are effective against lacerations and abrasive injury. Importantly, authors suspect poor study adherence among many of the teams and participants[124], so the effects are perhaps not well tested.

Football (soccer)

Our review only found one study of headgear use in youth soccer, which demonstrated a reduction in SRC risk in players wearing protective headgear[125]. However, it is important to note that these players self-selected into groups and data on symptoms was collected via retrospective self-report.

Mouthguards

Mouth guards are another common piece of equipment used, at least in part, to prevent concussions. They certainly protect against dental injuries, but our review only found a handful of studies investigating mouthguard protection against SRC in youth athletes[11, 122, 126]. There is evidence from at least one study that they were associated with reduced number of all injuries to the head/face region[11], but the other studies compare mouthguard types as opposed to their direct effects on SRCs[122, 126]. It is unclear whether customized or preformed mouthguards provide improved protection against SRCs.

Equipment concerns

There is a common sentiment among authors, but it is unclear whether there is any supporting data, that more protective equipment may increase risk of concussion or other injuries by leading to a false sense of security within the athletes (e.g. [124]). This sense of being protected may lead to more dangerous behavior that cancels out any real protective effects of equipment. For example, wearing a newer model of helmet may lead a young football player to be less considerate of using correct form when tackling. Unfortunately, our review did not find any direct tests of this concern.

Question 6

"What proportion of contact/collision sport athletes go on to participate in non-contact sports after contact/collision options are removed?"

Findings

Our review did not find any peer-reviewed analyses or resources that directly addressed this question. It is unclear whether the removal of contact/collision sports will lead to reduced activity levels for youth or whether they will go on to participate in non-contact or non-collision sports. This being said, the Sports and Fitness Industry Association (SFIA), the Aspen Institute, and the National Federation of High Schools (NFHS) have reported trends in flag football participation in the US that are relevant to this discussion [127, 128, 129, 130, 131, 132, 133].

Flag football is a non-collision version of American football where players typically do not wear pads or helmets and remove "flags" that are attached to their uniforms instead of tackling them. While participation in American tackle football has declined in US youth over the past decade (and for team sports overall), youth participation in flag football has increased - it is currently more popular for 6-12 year olds than tackle football[127]. Thus, while there are no direct tests of how youths respond to the removal of collision or contact sports, these data demonstrate that youth are interested and willing to participate in non-collision team sports. It is unknown if removing collision or contact options will reduce youth participation in team sports when non-collision/non-contact options are available.

Further, recent surveys indicate that parents and families are concerned for children's safety in collision sports such as American football[128]. These concerns may be driving participation away from these sports regardless of whether schools and clubs still offer them. Thus, offering flag football and other non-collision/non-contact options may be necessary to ensure that youth are able to gain the benefits of participating in organized team sports.

Question 7

"What is the evidence to recommend youth player retirement (or redirection to other sports) in the setting of multiple concussions?"

Introduction

Most of the literature found in our review is focused on communicating expert guidelines [134, 135, 136, 137, 138] and reviews[139, 140, 141, 142] that provided recommendations as opposed to analyzing decision-making algorithms regarding sports retirement or redirection to other sports after multiple concussions. There is no clear evidence regarding a specific cut-off for multiple concussions (i.e. how many concussions should lead a player to retire?). This being said, these expert and position statements agree that children and adolescents should begin to consider retiring from contact or collision sports after multiple concussions. The final decision on whether or not to retire should be based on a combination of accumulated neurological and/or neuropsychological symptoms induced by head trauma, time intervals between concussions, and the individual's relationship to the sport. Redirection to other sports should take into account the demonstrated SRC risks in the "new" sport.

Our review found that experts offer a fairly consistent list of scenarios and factors thought to increase risk for youths returning to play contact or collision sports, but there is limited evidence for how retiring or not retiring in these scenarios will impact long-term brain health. This lack of clarity results in part to our findings in Question 4 in that it is unclear whether multiple concussions and repetitive head impacts experienced in youth sports connect to long-term neurological and neuropsychological deficits. It also results from the complications inherent in testing if a player should retire or be redirected to other sports after multiple concussions.

Findings

Future Health and Wellbeing

Overall, authors agree that protecting youths' future health and wellbeing (neurological, mental, and physical) is the most important factor when deciding whether an athlete should retire or be redirected due to multiple SRCs. The various scenarios and risk factors against continuing to play contact or collision sports discussed below are made with this point in mind. However, experts also stress the need to balance a child's career goals (eg college scholarship), mental health (eg depression is a risk when retiring from youth sports), overall physical health (including cardiovascular and endocrine health as opposed to only neurological), self-identity, and peer group interactions with the risks of returning to play. There are many positive aspects to wellbeing and health that can be gained from playing sports[143] and the removal of these options should not be done without due consideration of these factors.

Scenarios and Risk Factors

Expert guidelines and position statements recommend that the following scenarios and risk factors lead to discussions with the youth and family about retiring or taking time off from contact/collision sports: multiple concussions (without residual symptoms), multiple concussions within a single season (particularly within several months), prolonged PCS, worsening PCS with subsequent concussions, diminished academic performance, increasing susceptibility to SRC with decreasing impacts (ie lowering threshold for concussion), and Chiari malformation [134, 135, 140, 142]. These patterns should be considered alongside the expected psychosocial effects of retiring or being redirected from a sport for the child in question. While we are lacking the highest level evidence that returning to play a sport in these scenarios or despite these risk factors is connected to long-term irreversible damage, many of the authors consider it likely. Further, there is little downside to using this discussion as an opportunity to educate the athlete and family.

These same sources offer other scenarios and risk factors for which they strongly recommend retirement from contact/collision sports. These typically include trauma-induced structural brain abnormalities and permanent neurological injury as well as disabling PCS symptoms and CTE symptoms. These scenarios are held consistently across these guidelines and position statements, but it is important to make at least a few notes. First, these scenarios must be related to trauma - some of these risk factors (eg brain abnormalities) may be benign or found in certain disabilities where they are not thought to increase risk of long-term damage from head impacts. Second, it is difficult to define certain brain matter abnormalities (eg white matter abnormalities) on an individual basis because they require normed control groups. These differences may be useful in a research setting but less so in building individualized recommendations. Third, these recommendations are made less from evidence based in youth sports and more from the TBI literature and neurosurgery literature more broadly.

Complications in building evidence

High-level evidence for recommending retirement or redirection from a sport after multiple concussions and signs and symptoms is difficult to define for at least several reasons. First, concussions can differ substantially in their severity, impact on an individual's quality of life, and neurological integrity. As the literature is still describing associations with concussions and head impacts broadly (reviewed in other questions in this review), it is not yet clear how concussive symptoms and assessment map onto neurological and psychological outcomes. There is little evidence regarding how to compare one very substantial concussion to multiple less-severe concussions regarding their risk to long-term health and well-being. While data on concussion symptom severity is often connected with diagnoses, it is not always input into epidemiological or large-scale studies. Since the importance of different symptoms is unclear, *a priori* analyses of their connections to concussions and outcomes is limited, and understanding on the long-term impacts of SRCs in youth is also limited (as per the discussion in Question 4). Further, concussion symptoms are non-specific, so it is unclear whether long-lasting symptoms are attributable to incomplete recovery or other etiologies (e.g. ADHD or MDD), especially in prolonged recoveries.

Second, clinical and practical guidelines existed before many of the measures commonly used were in widespread use. The Cantu algorithm had been widespread in practice since the 1990's[144], while many computerized neuropsychological tests and neuroimaging paradigms weren't widely used until the past decade. Therefore, to know if youth athletes suffered from not retiring when the Cantu algorithm (or other expert guideline) recommended it, athletic trainers and players would need to knowingly go against expert recommendations and report they were doing so. This is a potential problem for reporting accuracy.

Third, the literature demonstrates that assessment and reporting of concussions is not uniform across individuals, teams, coaches, and athletic programs (e.g. [145]). Many youth teams and sports often have cultures of not reporting concussive symptoms. Youth will also differ substantially in their knowledge of concussions, which may affect what they report to coaches and trainers. Further, access to concussion training for coaches and athletic support staff is associated with concussion rates[66], so youth athletes from less affluent areas are more likely to go undiagnosed. This may add noise or even bias SRC-related outcomes in larger epidemiological studies and reporting databases, which could either weaken actual associations or lead to spurious associations. However, even if concussion diagnosis was perfectly similar, it is unclear how important repetitive head impacts (without concussion diagnosis) may be on long-term health (reviewed in previous questions).

Lastly, and importantly, symptom threshold can vary widely between individuals and can be distinct from injury threshold, and individuals may differ in their susceptibility to post-concussive symptoms (e.g. [135]). This compounds the other difficulties in comparing outcomes of individuals with different exposures and SRC histories. Individuals may need different specific cutoffs depending on difficult to assess traits, such as genotype or learning disorder.

eReferences

[1] Dick, R. W. (2009). Is there a gender difference in concussion incidence and outcomes? *British Journal of Sports Medicine*, *43 Suppl 1*(Suppl 1), i46-50. https://doi.org/10.1136/bjsm.2009.058172

[2] Miyashita, T. L., Diakogeorgiou, E., & VanderVegt, C. (2016). Gender Differences in Concussion Reporting Among High School Athletes. *Sports Health: A Multidisciplinary Approach*, *8*(4), 359–363. https://doi.org/10.1177/1941738116651856

[3] Black, A., Palacios-Derflingher, L., Schneider, K. J., Hagel, B. E., & Emery, C. A. (2017). The effect of a national body checking policy change on concussion risk in youth ice hockey players. *British Journal of Sports Medicine*, *51*(11), A70.3-A71. https://doi.org/10.1136/bjsports-2016-097270.183

[4] Hecimovich, M. D., & King, D. (2017). Prevalence of head injury and medically diagnosed concussion in junior-level community-based Australian Rules Football. *Journal of Paediatrics and Child Health*, *53*(3), 246–251. https://doi.org/10.1111/jpc.13405

[5] Emery, C. A., & Meeuwisse, W. H. (2006). Injury Rates, Risk Factors, and Mechanisms of Injury in Minor Hockey. *The American Journal of Sports Medicine*, *34*(12), 1960–1969. https://doi.org/10.1177/0363546506290061

[6] Kontos, Z. Y., Marshall, S. W., Simon, J. E., Hayden, R., Snook, E. M., Dodge, T., … Parsons, J. T. (2015). Injury Rates in Age-Only Versus Age-and-Weight Playing Standard Conditions in American Youth Football. *Orthopaedic Journal of Sports Medicine*, *3*(9), 232596711560397. https://doi.org/10.1177/2325967115603979

[7] Kontos, A. P., Elbin, R. J., Newcomer Appaneal, R., Covassin, T., & Collins, M. W. (2013). A comparison of coping responses among high school and college athletes with concussion, orthopedic injuries, and healthy controls. *Research in Sports Medicine (Print)*, *21*(4), 367–379. https://doi.org/10.1080/15438627.2013.825801

[8] Dompier, T. P., Kerr, Z. Y., Marshall, S. W., Hainline, B., Snook, E. M., Hayden, R., & Simon, J. E. (2015). Incidence of Concussion During Practice and Games in Youth, High School, and Collegiate American Football Players. *JAMA Pediatrics*, *169*(7), 659. https://doi.org/10.1001/jamapediatrics.2015.0210

[9] DePadilla, L., Miller, G. F., Jones, S. E., Peterson, A. B., & Breiding, M. J. (2018). Self-Reported Concussions from Playing a Sport or Being Physically Active Among High School Students — United States, 2017. *MMWR. Morbidity and Mortality Weekly Report*, *67*(24), 682–685. https://doi.org/10.15585/mmwr.mm6724a3

[10] Tsushima, W. T., Siu, A. M., Ahn, H. J., Chang, B. L., & Murata, N. M. (2018). Incidence and Risk of Concussions in Youth Athletes: Comparisons of Age, Sex, Concussion History, Sport, and Football Position. *Archives of Clinical Neuropsychology*. https://doi.org/10.1093/arclin/acy019

[11] Archbold, H. A. P., Rankin, A. T., Webb, M., Nicholas, R., Eames, N. W. A., Wilson, R. K., … Bleakley, C. M. (2017). RISUS study: Rugby Injury Surveillance in Ulster Schools. *British Journal of Sports Medicine*, *51*(7), 600–606. https://doi.org/10.1136/bjsports-2015-095491

[12] O'Kane, J. W., Levy, M. R., Neradilek, M., Polissar, N. L., & Schiff, M. A. (2014). Evaluation of the Zachery Lystedt Law Among Female Youth Soccer Players. *The Physician and Sportsmedicine*, *42*(3), 39–44. https://doi.org/10.3810/psm.2014.09.2074

[13] Kerr, Z. Y., Zuckerman, S. L., Wasserman, E. B., Covassin, T., Djoko, A., & Dompier, T. P. (2016). Concussion Symptoms and Return to Play Time in Youth, High School, and College American Football Athletes. *JAMA Pediatrics*, *170*(7), 647. https://doi.org/10.1001/jamapediatrics.2016.0073

[14] Makdissi, M., Darby, D., Maruff, P., Ugoni, A., Brukner, P., & McCrory, P. R. (2010). Natural History of Concussion in Sport. *The American Journal of Sports Medicine*, *38*(3), 464–471. https://doi.org/10.1177/0363546509349491

[15] Delahunty, S. E., Delahunt, E., Condon, B., Toomey, D., & Blake, C. (2015). Prevalence of and Attitudes About Concussion in Irish Schools' Rugby Union Players. *Journal of School Health*, *85*(1), 17–26. https://doi.org/10.1111/josh.12219

[16] Reed, N., Taha, T., Keightley, M., Duggan, C., McAuliffe, J., Cubos, J., … Montelpare, W. (2010). Measurement of Head Impacts in Youth Ice Hockey Players. Int J Sports Med, 31(11), 826–833. https://doi.org/10.1055/s-0030-1263103

[17] Khodaee, M., Currie, D. W., Asif, I. M., & Comstock, R. D. (2017). Nine-year study of US high school soccer injuries: data from a national sports injury surveillance programme. *British Journal of Sports Medicine*, *51*(3), 185–193. https://doi.org/10.1136/bjsports-2015-095946

[18] Leung, F. T., Franettovich Smith, M. M., Brown, M., Rahmann, A., Mendis, M. D., & Hides, J. A. (2017). Epidemiology of injuries in Australian school level rugby union. *Journal of Science and Medicine in Sport*, *20*(8), 740–744. https://doi.org/10.1016/j.jsams.2017.03.006

[19] Castile, L., Collins, C. L., McIlvain, N. M., & Comstock, R. D. (2012). The epidemiology of new versus recurrent sports concussions among high school athletes, 2005–2010. *British Journal of Sports Medicine*, *46*(8), 603–610. https://doi.org/10.1136/bjsports-2011-090115

[20] Pieter, W. (2005). Martial arts injuries. *Medicine and Sport Science*, *48*, 59–73. https://doi.org/10.1159/000084283

[21] Emery, C. A., Hagel, B., Decloe, M., & Carly, M. (2010). Risk factors for injury and severe injury in youth ice hockey: a systematic review of the literature. *Injury Prevention : Journal of the International Society for Child and Adolescent Injury Prevention*, *16*(2), 113–118. https://doi.org/10.1136/ip.2009.022764

[22] Emery, C. A., Kang, J., Schneider, K. J., & Meeuwisse, W. H. (2011). Risk of injury and concussion associated with team performance and penalty minutes in competitive youth ice hockey. *British Journal of Sports Medicine*, *45*(16), 1289–1293. https://doi.org/10.1136/bjsports-2011-090538

[23] Emery, C., Kang, J., Shrier, I., Goulet, C., Hagel, B., Benson, B., … Meeuwisse, W. (2011). Risk of injury associated with bodychecking experience among youth hockey players. *CMAJ : Canadian Medical Association Journal = Journal de l'Association Medicale Canadienne*, *183*(11), 1249–1256. https://doi.org/10.1503/cmaj.101540

[24] Guskiewicz, K. M., Weaver, N. L., Padua, D. A., & Garrett, W. E. (2000). Epidemiology of Concussion in Collegiate and High School Football Players. *The American Journal of Sports Medicine*, *28*(5), 643–650. https://doi.org/10.1177/03635465000280050401

[25] Zemper, E. D. (2003). A Two-Year Prospective Study of Cerebral Concussion in American Football. *Research in Sports Medicine*, *11*(3), 157–172. https://doi.org/10.1080/15438620390231175

[26] Hollis, S. J., Stevenson, M. R., McIntosh, A. S., Shores, E. A., Collins, M. W., & Taylor, C. B. (2009). Incidence, Risk, and Protective Factors of Mild Traumatic Brain Injury in a Cohort of Australian Nonprofessional Male Rugby Players. *The American Journal of Sports Medicine*, *37*(12), 2328–2333. https://doi.org/10.1177/0363546509341032

[27] Schneider, K. J., Leddy, J. J., Guskiewicz, K. M., Seifert, T., McCrea, M., Silverberg, N. D., … Makdissi, M. (2017). Rest and treatment/rehabilitation following sport-related concussion: a systematic review. *British Journal of Sports Medicine*, *51*(12), 930–934. https://doi.org/10.1136/bjsports-2016-097475

[28] Kontos, A. P., Elbin, R. J., Fazio-Sumrock, V. C., Burkhart, S., Swindell, H., Maroon, J., & Collins, M. W. (2013). Incidence of Sports-Related Concussion among Youth Football Players Aged 8-12 Years. *The Journal of Pediatrics*, *163*(3), 717–720. https://doi.org/10.1016/j.jpeds.2013.04.011

[29] Sarac, N., Sarac, B., Pedroza, A., & Borchers, J. (2018). Epidemiology of mental health conditions in incoming division I collegiate athletes. *The Physician and sportsmedicine*, *46*(2), 242-248.

[30] Solomon, G. S., Kuhn, A. W., & Zuckerman, S. L. (2016). Depression as a Modifying Factor in Sport-Related Concussion: A Critical Review of the Literature. *The Physician and Sportsmedicine*, *44*(1), 14–19. https://doi.org/10.1080/00913847.2016.1121091

[31] Iverson, G. L., Wojtowicz, M., Brooks, B. L., Maxwell, B. A., Atkins, J. E., Zafonte, R., & Berkner, P. D. (2016). High School Athletes With ADHD and Learning Difficulties Have a Greater Lifetime Concussion History. *Journal of Attention Disorders*, 108705471665741. https://doi.org/10.1177/1087054716657410

[32] Nelson, L. D., Guskiewicz, K. M., Marshall, S. W., Hammeke, T., Barr, W., Randolph, C., & McCrea, M. A. (2016). Multiple Self-Reported Concussions Are More Prevalent in Athletes With ADHD and Learning Disability. *Clinical Journal of Sport Medicine*, *26*(2), 120–127. https://doi.org/10.1097/JSM.0000000000000207

[33] Weber, M. L., Dean, J.-H. L., Hoffman, N. L., Broglio, S. P., McCrea, M., McAllister, T. W., … Dykhuizen, B. H. (2018). Influences of Mental Illness, Current Psychological State, and Concussion History on Baseline Concussion Assessment Performance. *The American Journal of Sports Medicine*, *46*(7), 1742–1751. https://doi.org/10.1177/0363546518765145

[34] Lincoln, A. E., Caswell, S. V., Almquist, J. L., Dunn, R. E., Norris, J. B., & Hinton, R. Y. (2011). Trends in Concussion Incidence in High School Sports. *The American Journal of Sports Medicine*, *39*(5), 958–963. https://doi.org/10.1177/0363546510392326

[35] Schallmo, M. S., Weiner, J. A., & Hsu, W. K. (2017). Sport and Sex-Specific Reporting Trends in the Epidemiology of Concussions Sustained by High School Athletes. *The Journal of Bone and Joint Surgery*, *99*(15), 1314–1320. https://doi.org/10.2106/JBJS.16.01573

[36] Gessel, L. M., Fields, S. K., Collins, C. L., Dick, R. W., & Comstock, R. D. (n.d.). Concussions among United States high school and collegiate athletes. *Journal of Athletic Training*, *42*(4), 495–503. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18174937

[37] Marar, M., McIlvain, N. M., Fields, S. K., & Comstock, R. D. (2012). Epidemiology of Concussions Among United States High School Athletes in 20 Sports. *The American Journal of Sports Medicine*, *40*(4), 747–755. https://doi.org/10.1177/0363546511435626

[38] Mc Fie, S., Brown, J., Hendricks, S., Posthumus, M., Readhead, C., Lambert, M., … Viljoen, W. (2016). Incidence and Factors Associated With Concussion Injuries at the 2011 to 2014 South African Rugby Union

Youth Week Tournaments. *Clinical Journal of Sport Medicine*, *26*(5), 398–404. https://doi.org/10.1097/JSM.0000000000000276

[39] Blumenfeld, R. S., Winsell, J. C., Hicks, J. W., & Small, S. L. (2016). The Epidemiology of Sports-Related Head Injury and Concussion in Water Polo. *Frontiers in Neurology*, *7*, 98. https://doi.org/10.3389/fneur.2016.00098

[40] Sarac, N., Haynes, W., Pedroza, A., Kaeding, C., & Borchers, J. (2017). Lifetime prevalence of injuries in incoming division I collegiate football players. The Physician and sportsmedicine, 45(4), 458-462.

[41] Yang, J., Comstock, R. D., Yi, H., Harvey, H. H., & Xun, P. (2017). New and Recurrent Concussions in High-School Athletes Before and After Traumatic Brain Injury Laws, 2005-2016. *American Journal of Public Health*, *107*(12), 1916–1922. https://doi.org/10.2105/AJPH.2017.304056

[42] Koh, J. O., & Cassidy, J. D. (2004). Incidence Study of Head Blows and Concussions in Competition Taekwondo. *Clinical Journal of Sport Medicine*, *14*(2).

[43] Dugan, S., Seymour, L., Roesler, J., Glover, L., & Kinde, M. (2014). This is your brain on sports. Measuring concussions in high school athletes in the Twin Cities metropolitan area. *Minnesota Medicine*, *97*(9), 43–46. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/25282771

[44] Mc Fie, S., Brown, J., Hendricks, S., Posthumus, M., Readhead, C., Lambert, M., … Viljoen, W. (2016). Incidence and Factors Associated With Concussion Injuries at the 2011 to 2014 South African Rugby Union Youth Week Tournaments. *Clinical Journal of Sport Medicine*, *26*(5), 398–404. https://doi.org/10.1097/JSM.0000000000000276

[45] Kerr, Z. Y., Caswell, S. V., Lincoln, A. E., Djoko, A., & Dompier, T. P. (2016). The epidemiology of boys' youth lacrosse injuries in the 2015 season. *Injury Epidemiology*, *3*(1), 3. https://doi.org/10.1186/s40621-016-0068-5

[46] O'Kane, J. W., Spieker, A., Levy, M. R., Neradilek, M., Polissar, N. L., & Schiff, M. A. (2014). Concussion among female middle-school soccer players. JAMA pediatrics, 168(3), 258-264.

[47] Reed, N., Taha, T., Greenwald, R., & Keightley, M. (2017). Player and Game Characteristics and Head Impacts in Female Youth Ice Hockey Players. *Journal of Athletic Training*, *52*(8), 771–775. https://doi.org/10.4085/1062-6050-52.5.04

[48] Cobb, B. R., Urban, J. E., Davenport, E. M., Rowson, S., Duma, S. M., Maldjian, J. A., … Stitzel, J. D. (2013). Head Impact Exposure in Youth Football: Elementary School Ages 9–12 Years and the Effect of Practice Structure. *Annals of Biomedical Engineering*, *41*(12), 2463–2473. https://doi.org/10.1007/s10439-013-0867-6

[49] Field, M., Collins, M. W., Lovell, M. R., & Maroon, J. (2003). Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *The Journal of Pediatrics*, *142*(5), 546–553. https://doi.org/10.1067/MPD.2003.190

[50] Stamm, J. M., Bourlas, A. P., Baugh, C. M., Fritts, N. G., Daneshvar, D. H., Martin, B. M., … Stern, R. A. (2015). Age of first exposure to football and later-life cognitive impairment in former NFL players. *Neurology*, *84*(11), 1114. Retrieved from http://n.neurology.org/content/84/11/1114.abstract

[51] Alosco, M. L., Mez, J., Tripodis, Y., Kiernan, P. T., Abdolmohammadi, B., Murphy, L., … McKee, A. C. (2018). Age of first exposure to tackle football and chronic traumatic encephalopathy. *Annals of Neurology*, *83*(5), 886–901. https://doi.org/10.1002/ana.25245

[52] Deshpande, S. K., Hasegawa, R. B., Rabinowitz, A. R., Whyte, J., Roan, C. L., Tabatabaei, A., … Small, D. S. (2017). Association of Playing High School Football With Cognition and Mental Health Later in Life. *JAMA Neurology*, *74*(8), 909. https://doi.org/10.1001/jamaneurol.2017.1317

[53] Chiang Colvin, A., Mullen, J., Lovell, M. R., Vereeke West, R., Collins, M. W., & Groh, M. (2009). The Role of Concussion History and Gender in Recovery from Soccer-Related Concussion. *The American Journal of Sports Medicine*, *37*(9), 1699–1704. https://doi.org/10.1177/0363546509332497

[54] Meehan, W. P., d'Hemecourt, P., & Dawn Comstock, R. (2010). High School Concussions in the 2008-2009 Academic Year. *The American Journal of Sports Medicine*, *38*(12), 2405–2409. https://doi.org/10.1177/0363546510376737

[55] Kerr, Z. Y., Dalton, S. L., Roos, K. G., Djoko, A., Phelps, J., & Dompier, T. P. (2016). Comparison of Indiana high school football injury rates by inclusion of the USA Football "Heads Up Football" Player Safety Coach. Orthopaedic journal of sports medicine, 4(5), 2325967116648441.

[56] Tai, S. S. M., & Miltenberger, R. G. (2017). Evaluating behavioral skills training to teach safe tackling skills to youth football players. *Journal of Applied Behavior Analysis*, *50*(4), 849–855. https://doi.org/10.1002/jaba.412

[57] Quatman-Yates, C. C., Quatman, C. E., Meszaros, A. J., Paterno, M. V, & Hewett, T. E. (2012). A systematic review of sensorimotor function during adolescence: a developmental stage of increased motor awkwardness? *British Journal of Sports Medicine*, *46*(9), 649–655. https://doi.org/10.1136/bjsm.2010.079616

[58] Bergeron, M. F., Mountjoy, M., Armstrong, N., Chia, M., Côté, J., Emery, C. A., … Engebretsen, L. (2015). International Olympic Committee consensus statement on youth athletic development. *British Journal of Sports Medicine*, *49*(13), 843–851. https://doi.org/10.1136/bjsports-2015-094962

[59] Cattuzzo, M. T., dos Santos Henrique, R., Ré, A. H. N., de Oliveira, I. S., Melo, B. M., de Sousa Moura, M., … Stodden, D. (2016). Motor competence and health related physical fitness in youth: A systematic review. *Journal of Science and Medicine in Sport*, *19*(2), 123–129. https://doi.org/10.1016/J.JSAMS.2014.12.004

[60] O'Connor, K. L., Baker, M. M., Dalton, S. L., Dompier, T. P., Broglio, S. P., & Kerr, Z. Y. (2017). Epidemiology of Sport-Related Concussions in High School Athletes: National Athletic Treatment, Injury and Outcomes Network (NATION), 2011–2012 Through 2013–2014. *Journal of Athletic Training*, *52*(3), 175–185. https://doi.org/10.4085/1062-6050-52.1.15

[61] Powell, J. W., & Barber-Foss, K. D. (1999). Traumatic Brain Injury in High School Athletes. *JAMA*, *282*(10), 958. https://doi.org/10.1001/jama.282.10.958

[62] Lincoln, A. E., Hinton, R. Y., Almquist, J. L., Lager, S. L., & Dick, R. W. (2007). Head, face, and eye injuries in scholastic and collegiate lacrosse: a 4-year prospective study. The American journal of sports medicine, 35(2), 207-215.

[63] Comstock, R. D., Currie, D. W., Pierpoint, L. A., Grubenhoff, J. A., & Fields, S. K. (2015). An evidence-based discussion of heading the ball and concussions in high school soccer. JAMA pediatrics, 169(9), 830-837.

[64] Black, A. M., Macpherson, A. K., Hagel, B. E., Romiti, M. A., Palacios-Derflingher, L., Kang, J., … Emery, C. A. (2016). Policy change eliminating body checking in non-elite ice hockey leads to a threefold reduction in injury and concussion risk in 11- and 12-year-old players. *British Journal of Sports Medicine*, *50*(1), 55–61. https://doi.org/10.1136/bjsports-2015-095103

[65] Williamson, I., & Goodman, D. (2009). Concussion in Youth Hockey: Prevalence, Risk Factors, and Management across Observation Strategies. In *Concussion in Youth Hockey: Prevalence, Risk Factors, and Management across Observation Strategies*.

[66] Kroshus, E., Kerr, Z. Y., & Lee, J. G. L. (2017). Community-Level Inequalities in Concussion Education of Youth Football Coaches. *American Journal of Preventive Medicine*, *52*(4), 476–482. https://doi.org/10.1016/j.amepre.2016.12.021

[67] Rivara, F. P., Schiff, M. A., Chrisman, S. P., Chung, S. K., Ellenbogen, R. G., & Herring, S. A. (2014). The Effect of Coach Education on Reporting of Concussions Among High School Athletes After Passage of a Concussion Law. *The American Journal of Sports Medicine*, *42*(5), 1197–1203. https://doi.org/10.1177/0363546514521774

[68] Emery, C. A., Black, A. M., Kolstad, A., Martinez, G., Nettel-Aguirre, A., Engebretsen, L., … Schneider, K. (2017). What strategies can be used to effectively reduce the risk of concussion in sport? A systematic review. *British Journal of Sports Medicine*, *51*(12), 978–984. https://doi.org/10.1136/bjsports-2016-097452

[69] Black, A., Palacios-Derflingher, L., Schneider, K. J., Hagel, B. E., & Emery, C. A. (2017). The effect of a national body checking policy change on concussion risk in youth ice hockey players. *British Journal of Sports Medicine*, *51*(11), A70.3-A71. https://doi.org/10.1136/bjsports-2016-097270.183

[70] Broglio, S. P., Williams, R. M., O'Connor, K. L., & Goldstick, J. (2016). Football players' head-impact exposure after limiting of full-contact practices. Journal of athletic training, 51(7), 511-518.

[71] Campolettano, E. T., Rowson, S., & Duma, S. M. (2016). Drill-specific head impact exposure in youth football practice. *Journal of Neurosurgery: Pediatrics*, *18*(5), 536–541. https://doi.org/10.3171/2016.5.PEDS1696

[72] Kelley, M. E., Kane, J. M., Espeland, M. A., Miller, L. E., Powers, A. K., Stitzel, J. D., & Urban, J. E. (2017). Head impact exposure measured in a single youth football team during practice drills. *Journal of Neurosurgery: Pediatrics*, *20*(5), 489–497. https://doi.org/10.3171/2017.5.PEDS16627

[73] Maher, M. E., Hutchison, M., Cusimano, M., Comper, P., & Schweizer, T. A. (2014). Concussions and heading in soccer: A review of the evidence of incidence, mechanisms, biomarkers and neurocognitive outcomes. *Brain Injury*, *28*(3), 271–285. https://doi.org/10.3109/02699052.2013.865269

[74] Kontos, A. P., Braithwaite, R., Chrisman, S. P., McAllister-Deitrick, J., Symington, L., Reeves, V. L., & Collins, M. W. (2017). Systematic review and meta-analysis of the effects of football heading. Br J Sports Med, 51(15), 1118-1124.

[75] Faude, O., Rössler, R., Junge, A., Aus der Fünten, K., Chomiak, J., Verhagen, E., ... & Feddermann-Demont, N. (2017). Head injuries in children′ s football—results from two prospective cohort studies in four European countries. Scandinavian journal of medicine & science in sports, 27(12), 1986-1992.

[76] Krolikowski, M. (2014). Did Implementation of the Zero-Tolerance for Head Contact Rule Change the Risk of Concussion and Injury in Youth Hockey Players in Alberta? *Journal of Undergraduate Research in Alberta*, *4*(0), 6–7. Retrieved from https://journalhosting.ucalgary.ca/index.php/jura/article/view/30182

[77] Krolikowski, M. P., Black, A. M., Palacios-Derflingher, L., Blake, T. A., Schneider, K. J., & Emery, C. A. (2017). The Effect of the "Zero Tolerance for Head Contact" Rule Change on the Risk of Concussions in Youth Ice Hockey Players. *The American Journal of Sports Medicine*, *45*(2), 468–473. https://doi.org/10.1177/0363546516669701

[78] Roberts, W. O., Brust, J. D., Leonard, B., & Hebert, B. J. (1996). Fair-Play Rules and Injury Reduction in Ice Hockey. *Archives of Pediatrics & Adolescent Medicine*, *150*(2), 140. https://doi.org/10.1001/archpedi.1996.02170270022003

[79] Kriz, P. K., Staffa, S. J., Zurakowski, D., MacAskill, M., Kirchberg, T., Robert, K., … Lockhart, G. (2019). Effect of Penalty Minute Rule Change on Injuries and Game Disqualification Penalties in High School Ice Hockey. *The American Journal of Sports Medicine*, *47*(2), 438–443. https://doi.org/10.1177/0363546518815886

[80] Wennberg, R. (2004). Collision Frequency in Elite Hockey on North American versus International Size Rinks. *The Canadian Journal of Neurological Sciences*, *31*(03), 373–377. https://doi.org/10.1017/S0317167100003474

[81] Wennberg, R. (2005). Effect of Ice Surface Size on Collision Rates and Head Impacts at the World Junior Hockey Championships, 2002 to 2004. *Clinical Journal of Sport Medicine*, *15*(2). Retrieved from https://journals.lww.com/cjsportsmed/Fulltext/2005/03000/Effect_of_Ice_Surface_Size_on_Collision_Rates_and.6.aspx

[82] Silva, B., Garganta, J., Santos, R., & Teoldo, I. (2014). Comparing Tactical Behaviour of Soccer Players in 3 vs. 3 and 6 vs. 6 Small-Sided Games. *Journal of Human Kinetics*, *41*(1), 191–202. https://doi.org/10.2478/hukin-2014-0047

[83] Shields, B. J., & Smith, G. A. (2009). Cheerleading-Related Injuries in the United States: A Prospective Surveillance Study. *Journal of Athletic Training*, *44*(6), 567–577. https://doi.org/10.4085/1062-6050-44.6.567

[84] Shields, B. J., & Smith, G. A. (2009). The Potential for Brain Injury on Selected Surfaces Used by Cheerleaders. *Journal of Athletic Training*, *44*(6), 595–602. https://doi.org/10.4085/1062-6050-44.6.595

[85] Tokish, J. M., Shanley, E., Kissenberth, M. J., Brooks, J., Nance, D., Gilliland, R. G., & Thorpe, J. (2017). Heads Up Football Training Decreases Concussion Rates in High School Football Players. *Orthopaedic Journal of Sports Medicine*, *5*(3_suppl3), 2325967117S0013. https://doi.org/10.1177/2325967117S00131

[86] Hislop, M. D., Stokes, K. A., Williams, S., McKay, C. D., England, M. E., Kemp, S. P. T., & Trewartha, G. (2017). Reducing musculoskeletal injury and concussion risk in schoolboy rugby players with a pre-activity movement control exercise programme: a cluster randomised controlled trial. *British Journal of Sports Medicine*, *51*(15), 1140–1146. https://doi.org/10.1136/bjsports-2016-097434

[87] White, A. J., Batten, J., Kirkwood, G., Anderson, E., & Pollock, A. M. (2018). "Pre-activity movement control exercise programme to prevent injuries in youth rugby": some concerns. *British Journal of Sports Medicine*, bjsports-2018-099051. https://doi.org/10.1136/bjsports-2018-099051

[88] Abbas, K., Shenk, T. E., Poole, V. N., Breedlove, E. L., Leverenz, L. J., Nauman, E. A., … Robinson, M. E. (2014). Alteration of Default Mode Network in High School Football Athletes Due to Repetitive Subconcussive Mild Traumatic Brain Injury: A Resting-State Functional Magnetic Resonance Imaging Study. *Brain Connectivity*, *5*(2), 91–101. https://doi.org/10.1089/brain.2014.0279

[89] Abbas, K., Shenk, T. E., Poole, V. N., Robinson, M. E., Leverenz, L. J., Nauman, E. A., & Talavage, T. M. (2015). Effects of Repetitive Sub-Concussive Brain Injury on the Functional Connectivity of Default Mode Network in High School Football Athletes. *Developmental Neuropsychology*, *40*(1), 51–56. https://doi.org/10.1080/87565641.2014.990455

[90] Breedlove, K. M., Breedlove, E. L., Robinson, M., Poole, V. N., King, J. R., Rosenberger, P., … Nauman, E. A. (2014). Detecting Neurocognitive and Neurophysiological Changes as a Result of Subconcussive Blows

Among High School Football Athletes. *Athletic Training & Sports Health Care*, *6*(3), 119–127. https://doi.org/10.3928/19425864-20140507-02

[91] Alosco, M. L., & Stern, R. A. (2019, March). Youth Exposure to Repetitive Head Impacts From Tackle Football and Long-term Neurologic Outcomes: A Review of the Literature, Knowledge Gaps and Future Directions, and Societal and Clinical Implications. In Seminars in Pediatric Neurology. WB Saunders.

[92] Brett, B. L., & Solomon, G. S. (2017). Comparison of Neurocognitive Performance in Contact and Noncontact Nonconcussed High School Athletes Across a Two-Year Interval. *Developmental Neuropsychology*, *42*(2), 70–82. https://doi.org/10.1080/87565641.2016.1243114

[93] Talavage, T. M., Nauman, E. A., Breedlove, E. L., Yoruk, U., Dye, A. E., Morigaki, K. E., … Leverenz, L. J. (2010). Functionally-Detected Cognitive Impairment in High School Football Players without Clinically-Diagnosed Concussion. *Journal of Neurotrauma*, *31*(4), 327–338. https://doi.org/10.1089/neu.2010.1512

[94] Breedlove, E. L., Robinson, M., Talavage, T. M., Morigaki, K. E., Yoruk, U., O'Keefe, K., … Nauman, E. A. (2012). Biomechanical correlates of symptomatic and asymptomatic neurophysiological impairment in high school football. *Journal of Biomechanics*, *45*(7), 1265–1272. https://doi.org/10.1016/J.JBIOMECH.2012.01.034

[95] Davenport, E. M., Urban, J. E., Mokhtari, F., Lowther, E. L., Van Horn, J. D., Vaughan, C. G., … Maldjian, J. A. (2016). Subconcussive impacts and imaging findings over a season of contact sports. *Concussion*, *1*(4), CNC19. https://doi.org/10.2217/cnc-2016-0003

[96] Davenport, E. M., Apkarian, K., Whitlow, C. T., Urban, J. E., Jensen, J. H., Szuch, E., … Maldjian, J. A. (2016). Abnormalities in Diffusional Kurtosis Metrics Related to Head Impact Exposure in a Season of High School Varsity Football. *Journal of Neurotrauma*, *33*(23), 2133–2146. https://doi.org/10.1089/neu.2015.4267

[97] Zhang, M. R., Red, S. D., Lin, A. H., Patel, S. S., & Sereno, A. B. (2013). Evidence of Cognitive Dysfunction after Soccer Playing with Ball Heading Using a Novel Tablet-Based Approach. *PLoS ONE*, *8*(2), e57364. https://doi.org/10.1371/journal.pone.0057364

[98] Savica, R., Parisi, J. E., Wold, L. E., Josephs, K. A., & Ahlskog, J. E. (2012). High School Football and Risk of Neurodegeneration: A Community-Based Study. *Mayo Clinic Proceedings*, *87*(4), 335–340. https://doi.org/10.1016/J.MAYOCP.2011.12.016

[99] Janssen, P. H. H., Mandrekar, J., Mielke, M. M., Ahlskog, J. E., Boeve, B. F., Josephs, K., & Savica, R. (2017). High School Football and Late-Life Risk of Neurodegenerative Syndromes, 1956-1970. *Mayo Clinic Proceedings*, *92*(1), 66–71. https://doi.org/10.1016/J.MAYOCP.2016.09.004

[100] Bazarian, J. J., Zhu, T., Blyth, B., Borrino, A., & Zhong, J. (2012). Subject-specific changes in brain white matter on diffusion tensor imaging after sports-related concussion. *Magnetic Resonance Imaging*, *30*(2), 171–180. https://doi.org/10.1016/J.MRI.2011.10.001

[101] Poole, V. N., Abbas, K., Shenk, T. E., Breedlove, E. L., Breedlove, K. M., Robinson, M. E., … Dydak, U. (2014). MR Spectroscopic Evidence of Brain Injury in the Non-Diagnosed Collision Sport Athlete. *Developmental Neuropsychology*, *39*(6), 459–473. https://doi.org/10.1080/87565641.2014.940619

[102] Albaugh, M. D., Orr, C., Nickerson, J. P., Zweber, C., Slauterbeck, J. R., Hipko, S., … Hudziak, J. J. (2015). Postconcussion Symptoms Are Associated with Cerebral Cortical Thickness in Healthy Collegiate and Preparatory School Ice Hockey Players. *The Journal of Pediatrics*, *166*(2), 394-400.e1. https://doi.org/10.1016/J.JPEDS.2014.10.016

[103] Schultz, V., Stern, R. A., Tripodis, Y., Stamm, J., Wrobel, P., Lepage, C., … Koerte, I. K. (2017). Age at First Exposure to Repetitive Head Impacts Is Associated with Smaller Thalamic Volumes in Former Professional American Football Players. *Journal of Neurotrauma*, *35*(2), 278–285. https://doi.org/10.1089/neu.2017.5145

[104] Wilde, E. A., Hunter, J. V., Li, X., Amador, C., Hanten, G., Newsome, M. R., … Levin, H. S. (2016). Chronic Effects of Boxing: Diffusion Tensor Imaging and Cognitive Findings. *Journal of Neurotrauma*, *33*(7), 672–680. https://doi.org/10.1089/neu.2015.4035

[105] Morgan, C. D., Zuckerman, S. L., Lee, Y. M., King, L., Beaird, S., Sills, A. K., & Solomon, G. S. (2015). Predictors of postconcussion syndrome after sports-related concussion in young athletes: a matched case-control study. *Journal of Neurosurgery: Pediatrics*, *15*(6), 589–598. https://doi.org/10.3171/2014.10.PEDS14356

[106] Moser, R. S., & Schatz, P. (2002). Enduring effects of concussion in youth athletes. *Archives of Clinical Neuropsychology*, *17*(1), 91–100. Retrieved from http://dx.doi.org/10.1093/arclin/17.1.91

[107] Moser, R. S., Schatz, P., & Jordan, B. D. (2005). Prolonged Effects of Concussion in High School Athletes. *Neurosurgery*, *57*(2), 300–306. https://doi.org/10.1227/01.NEU.0000166663.98616.E4

[108] Kerr, Z. Y., Evenson, K. R., Rosamond, W. D., Mihalik, J. P., Guskiewicz, K. M., & Marshall, S. W. (2014). Association between concussion and mental health in former collegiate athletes. *Injury Epidemiology*, *1*(1), 28. https://doi.org/10.1186/s40621-014-0028-x

[109] Mannix, R., Iverson, G. L., Maxwell, B., Atkins, J. E., Zafonte, R., & Berkner, P. D. (2014). Multiple prior concussions are associated with symptoms in high school athletes. *Annals of Clinical and Translational Neurology*, *1*(6), 433–438. https://doi.org/10.1002/acn3.70

[110] Brooks, B. L., Mannix, R., Maxwell, B., Zafonte, R., Berkner, P. D., & Iverson, G. L. (2016). Multiple Past Concussions in High School Football Players: Are There Differences in Cognitive Functioning and Symptom Reporting? *The American Journal of Sports Medicine*, *44*(12), 3243–3251. https://doi.org/10.1177/0363546516655095

[111] Iverson, G. L., Brooks, B. L., Lovell, M. R., & Collins, M. W. (2006). No cumulative effects for one or two previous concussions. *British Journal of Sports Medicine*, *40*(1), 72. Retrieved from http://bjsm.bmj.com/content/40/1/72.abstract

[112] Iverson, G. L., Echemendia, R. J., LaMarre, A. K., Brooks, B. L., & Gaetz, M. B. (2012). Possible lingering effects of multiple past concussions. Rehabilitation research and practice, 2012.

[113] Martini, D. N., Eckner, J. T., Meehan, S. K., & Broglio, S. P. (2017). Long-term Effects of Adolescent Sport Concussion Across the Age Spectrum. *The American Journal of Sports Medicine*, *45*(6), 1420–1428. https://doi.org/10.1177/0363546516686785

[114] Brooks, B. L., McKay, C. D., Mrazik, M., Barlow, K. M., Meeuwisse, W. H., & Emery, C. A. (2013). Subjective, but not Objective, Lingering Effects of Multiple Past Concussions in Adolescents. *Journal of Neurotrauma*, *30*(17), 1469–1475. https://doi.org/10.1089/neu.2012.2720

[115] Little, C. E., Emery, C., Scott, S. H., Meeuwisse, W., Palacios-Derflingher, L., & Dukelow, S. P. (2016). Do children and adolescent ice hockey players with and without a history of concussion differ in robotic testing of sensory, motor and cognitive function? *Journal of NeuroEngineering and Rehabilitation*, *13*(1), 89. https://doi.org/10.1186/s12984-016-0195-9

[116] Stamm, J. M., Koerte, I. K., Muehlmann, M., Pasternak, O., Bourlas, A. P., Baugh, C. M., … Shenton, M. E. (2015). Age at First Exposure to Football Is Associated with Altered Corpus Callosum White Matter Microstructure in Former Professional Football Players. *Journal of Neurotrauma*, *32*(22), 1768–1776. https://doi.org/10.1089/neu.2014.3822

[117] Montenigro, P. H., Alosco, M. L., Martin, B. M., Daneshvar, D. H., Mez, J., Chaisson, C. E., … Tripodis, Y. (2016). Cumulative Head Impact Exposure Predicts Later-Life Depression, Apathy, Executive Dysfunction, and Cognitive Impairment in Former High School and College Football Players. *Journal of Neurotrauma*, *34*(2), 328–340. https://doi.org/10.1089/neu.2016.4413

[118] Omalu, B., Bailes, J., Hamilton, R. L., Kamboh, M. I., Hammers, J., Case, M., & Fitzsimmons, R. (2011). Emerging Histomorphologic Phenotypes of Chronic Traumatic Encephalopathy in American Athletes. *Neurosurgery*, *69*(1), 173–183. https://doi.org/10.1227/NEU.0b013e318212bc7b

[119] Tagge, C. A., Fisher, A. M., Minaeva, O. V, Gaudreau-Balderrama, A., Moncaster, J. A., Zhang, X.-L., … Goldstein, L. E. (2018). Concussion, microvascular injury, and early tauopathy in young athletes after impact head injury and an impact concussion mouse model. *Brain*, *141*(2), 422–458. Retrieved from http://dx.doi.org/10.1093/brain/awx350

[120] Collins, C. L., McKenzie, L. B., Ferketich, A. K., Andridge, R., Xiang, H., & Comstock, R. D. (2016). Concussion Characteristics in High School Football by Helmet Age/Recondition Status, Manufacturer, and Model. *The American Journal of Sports Medicine*, *44*(6), 1382–1390. https://doi.org/10.1177/0363546516629626

[121] Collins, M., Lovell, M. R., Iverson, G. L., Ide, T., & Maroon, J. (2006). Examining Concussion Rates and Return to Play in High School Football Players Wearing Newer Helmet Technology: A Three-Year Prospective Cohort Study. *Neurosurgery*, *58*(2), 275–286. https://doi.org/10.1227/01.NEU.0000200441.92742.46

[122] McGuine, T. A., Hetzel, S., McCrea, M., & Brooks, M. A. (2014). Protective Equipment and Player Characteristics Associated With the Incidence of Sport-Related Concussion in High School Football Players. *The American Journal of Sports Medicine*, *42*(10), 2470–2478. https://doi.org/10.1177/0363546514541926

[123] McIntosh, A. S., & McCrory, P. (2001). Effectiveness of headgear in a pilot study of under 15 rugby union football. *British Journal of Sports Medicine*, *35*(3), 167–169. https://doi.org/10.1136/BJSM.35.3.167

[124] Mcintosh, A., McCrory, P., Finch, C., Best, J., Chalmers, D., & Wolfe, R. (2009). Does padded headgear prevent head injury in rugby union football?. Medicine+ Science in Sports+ Exercise, 41(2), 306.

[125] Delaney, J. S., Al-Kashmiri, A., Drummond, R., & Correa, J. A. (2007). The effect of protective headgear on head injuries and concussions in adolescent football (soccer) players. *British Journal of Sports Medicine*, *42*(2), 110–115. https://doi.org/10.1136/bjsm.2007.037689

[126] Winters, J., & DeMont, R. (2014). Role of mouthguards in reducing mild traumatic brain injury/concussion incidence in high school football athletes. *General Dentistry*, *62*(3), 34–38. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/24784512

[127] Sports and Fitness Industry Association. (2018). *SFIA Single Sport Activity Report on Tackle Football*. Silver Spring, MD.

[128] Aspen Institute: Project Play. (2018). *State of Play 2018: Trends and Developments*. Washington, DC.

[129] 2018 Physical Activity Guidelines Advisory Committee. (2018). *2018 Physical Activity Guidelines Advisory Committee Scientific Report*. Washington, D.C.

[130] An Aspen Institute Sports & Society Program. (2018). *What if …flag becomes the standard way of playing football until high school?* Washington, DC.

[131] National Federation of State High School Associations. (2018). NFHS Participation Statistics. Retrieved October 10, 2018, from https://members.nfhs.org/participation_statistics

[132] Solomon, J. (2015). 7 Charts that Show the State of Youth Sports in the US and Why it Matters. Retrieved October 15, 2018, from https://www.aspeninstitute.org/blog-posts/7-charts-show-fix-youth-sports/

[133] The National Federation of State High School Associations. (n.d.). *2017-18 High School Athletics Participation Survey*. Indianapolis, IN.

[134] Cantu, R. C., & Register-Mihalik, J. K. (2011). Considerations for Return-to-Play and Retirement Decisions After Concussion. *PM&R*, *3*(10), S440–S444. https://doi.org/10.1016/j.pmrj.2011.07.013

[135] Ellis, M. J., McDonald, P. J., Cordingley, D., Mansouri, B., Essig, M., & Ritchie, L. (2016). Retirement-from-sport considerations following pediatric sports-related concussion: case illustrations and institutional approach. *Neurosurgical Focus*, *40*(4), E8. https://doi.org/10.3171/2016.1.FOCUS15600

[136] Cantu, R. C. (2003). Recurrent athletic head injury: risks and when to retire. *Clinics in Sports Medicine*, *22*(3), 593–603, x. https://doi.org/10.1016/S0278-5919(02)00095-9

[137] DeMatteo, C., Stazyk, K., Singh, S. K., Giglia, L., Hollenberg, R., Malcolmson, C. H., … McCauley, D. (2015). Development of a Conservative Protocol to Return Children and Youth to Activity Following Concussive Injury. *Clinical Pediatrics*, *54*(2), 152–163. https://doi.org/10.1177/0009922814558256

[138] Laker, S. R., Meron, A., Greher, M. R., & Wilson, J. (2016). Retirement and Activity Restrictions Following Concussion. *Physical Medicine and Rehabilitation Clinics of North America*, *27*(2), 487–501. https://doi.org/10.1016/j.pmr.2016.01.001

[139] Davis-Hayes, C., Baker, D. R., Bottiglieri, T. S., Levine, W. N., Desai, N., Gossett, J. D., & Noble, J. M. (2018). Medical retirement from sport after concussions. *Neurology: Clinical Practice*, *8*(1), 40–47. https://doi.org/10.1212/CPJ.0000000000000424

[140] Concannon, L. G., Kaufman, M. S., & Herring, S. A. (2014). The Million Dollar Question. *Current Sports Medicine Reports*, *13*(6), 365–369. https://doi.org/10.1249/JSR.0000000000000098

[141] Moore, R. D., Kay, J. J., & Ellemberg, D. (2018). The long-term outcomes of sport-related concussion in pediatric populations. International Journal of Psychophysiology, 132, 14-24.

[142] Sedney, C. L., Orphanos, J., & Bailes, J. E. (2011). When to consider retiring an athlete after sports-related concussion. *Clinics in Sports Medicine*, *30*(1), 189–200, xi. https://doi.org/10.1016/j.csm.2010.08.005

[143] 2018 Physical Activity Guidelines Advisory Committee. (2018). *2018 Physical Activity Guidelines Committee Scientific Report*. Washington, D.C.

[144] Cantu, R. C. (1996). Head injuries in sport. *British Journal of Sports Medicine*, *30*(4), 289–296. https://doi.org/10.1136/bjsm.30.4.289

[145] Kroshus, E., Garnett, B., Hawrilenko, M., Baugh, C. M., & Calzo, J. P. (2015). Concussion under-reporting and pressure from coaches, teammates, fans, and parents. *Social Science & Medicine*, *134*, 66–75. https://doi.org/10.1016/J.SOCSCIMED.2015.04.011