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The Age Variable in Childhood Concussion Management: A Systematic Review

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Abstract

Background: Sports-related concussion in young children has become a significant international public health issue. This paper reviews the research literature in an effort to shed light on the question, "At what age should young children be managed differently than adults or older adolescents?"
Method: A systematic review, registered with PROSPERO and using PRISMA guidelines, was conducted rendering 37 sports concussion original research studies that examined age as a variable (5–18 years), and which met specific inclusion/exclusion criteria.
Findings: There are no defined, evidence-based age groups for childhood concussion to substantiate differential management across the childhood and adolescent age span. There is evidence to support: (1) concussion may present differently across developmental stages; (2) with increasing age, adolescents may exhibit more symptoms from concussion; (3) the age range of 12–13 is the most frequently used cutoff point between younger and older children; (4) sports concussion research has classified the age variable in children in a number of manners: educational, developmental, sport level, or as a continuous variable, or matter of sample convenience; and (5) four general groupings of young versus pre-puberty child and early versus late adolescent are often utilized.
Conclusions: Due to limited measures and challenges of assessing younger children, current research presents a limited understanding of childhood concussion. Studies in children often lack explained rationales or theories behind age groupings or cutoffs. There is a need for studies dedicated to the question of how concussion varies developmentally from preschool through late adolescence to guide diagnosis and management.

Keywords: Concussion; Age; Youth; Child; Adolescent; Pediatric; Mild traumatic brain injury

Introduction

Sports-related concussion in children has become a significant international public health issue. Although the exact incidence is not known, it is estimated that annually 4 million children are seen worldwide in emergency departments (EDs) for concussion (Crowe, Babl, Anderson, & Catroppa, 2009; Lyttle, Crowe, Oakley, Dunning, & Babl, 2012; Peden, UNICEF, WHO, & 2008). Furthermore, those medically evaluated may only account for approximately 10% of the total number of children who sustain a concussion each year (Arbogast *et al.*, 2016).

The problem of concussion, especially in sports, was brought to light in the adult and college population with the early studies of Barth and colleagues in the 1980s (Barth *et al.*, 1989) and subsequent research that focused on professional sports (Aubry *et al.*, 2002). The repercussions of concussion in youth came later to the forefront in the study of sports in adolescent populations that revealed possible enduring effects of concussion (Moser, Schatz, & Jordan, 2005; Schatz, Moser, Covassin, & Karpf, 2011). Growing concern resulted in numerous studies focusing on high school level adolescent populations, and the

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International Concussion in Sport Group (CISG) meeting in Prague 2004 rendered landmark recommendations for the pediatric population: “Because of the different physiological response during childhood to head trauma, a conservative return to play approach is recommended. It may be appropriate to extend the amount of time of asymptomatic rest and/or the length of the graded exertion in children and adolescents. Future research is needed in this area” (McCrory *et al*., 2005). Subsequent meetings of the CISG resulted in further recognition of a need for differential treatment of the child versus adolescent athlete, with the development of an assessment tool for those aged 5–12 years, the Child Sport Concussion Assessment Tool 3 (McCrory *et al*., 2013).

It is recognized that brain development varies across the 0–18 year age span based on changes in neuroanatomy and cognitive development that have been well documented (Casey, Jones, Hare, 2008; Piaget & Inhelder, 1969). However, the specific developmental stages or age cutoff points where there are changes in brain maturation that affect the clinical course of concussion have not been well-researched. Such knowledge would affect the diagnosis, investigation and management of concussion across different developmental age groups.

Although there is recognition of a need for separate guidelines for childhood concussion management, many questions remain unanswered and there is a dearth of research to guide clinicians in the diagnosis, investigation, and management of childhood concussion. Although the corpus of research on adolescent concussion has grown, research on younger children is lacking. Furthermore, although it may be assumed that different age levels or developmental levels may require different management, evidence is needed to support differential age guidelines. Thus, the present paper sought to review the existing research on youth concussion to help determine what evidence if any may be available at this time to help guide the treatment of childhood concussion.

This review was conducted to inform the 5th International Consensus Conference on Concussion in Sport in Berlin 2016 on the published evidence on age as a variable in the management of sports concussion in children.

Method

A systematic research literature review was conducted. Studies that were original peer reviewed research in the area of sports concussion that included children aged 5–18 years, published in English between 1985 and May 2016, were included. Review articles, case reports, opinion articles, and letters to the editor were excluded. Also excluded were articles that included moderate or severe traumatic brain injury and participants with Glasgow Coma Scale score <13, open head injury, positive neuroimaging, intracranial hemorrhage, skull fracture, operative neurosurgery, intensive care, or non-accidental injury. Studies which reported mixed age cohorts, wherein the age 5–18 participants were not separately studied, were excluded.

PRISMA guidelines were followed and the search strategy was registered with PROSPERO International prospective register of systematic reviews. Search terms included: brain concussion, concussion, mild/minor/minimal traumatic brain injury, child/adolescent, childhood/adolescence, minor/minors, boy/s, girl/s, kid/s, child/children, school child, juvenile, youth, teen, pediatric, pubescent, human, English, 1985–present, age, age factor, age discrimination, age difference, and chronological age.

The following databases were reviewed: Ovid MEDLINE, Ovid Embase, and PsychInfo. Also, reference lists from articles were reviewed for additional original research. At least two independent reviewers reviewed the articles for inclusion. Initially 2695 records were identified through the database searches and an additional 37 records through other sources. After duplicate abstracts were removed, the remaining records were screened, and 87 full text articles were assessed for eligibility. Of those full text articles, 50 did not meet inclusion criteria, resulting in 37 articles that were included for final review. These 37 articles are summarized in Table 1. To assess the risk of bias, the Newcastle-Ottawa Scale was employed (Wells *et al.*). For each study the level of evidence was assessed using The Oxford 2011 Levels of Evidence (OCEBM, 2011). Data were synthesized through a qualitative analysis in a descriptive manner. Overall level of evidence was at Levels 3 and 4.

Findings

This systematic review rendered 37 papers (see Table 1) that examined age as a variable, and which for the most part, considered age in one or more of four manners: (1) “developmentally”; (2) “educationally”; (3) based on “sport-level”; and or (4) using age as a “continuous variable”. Very often, these studies were conducted with available samples or samples of convenience. When age was considered developmentally, for example by using categories of 5–7 years versus 8–9 years versus. 10–12 years, etc., there was often no clear rationale or theory described in the study for adopting the specific age cutoffs. Some studies preferred the 10–12 year age grouping instead of a 9–11 years age grouping. In contrast, educational groupings were defined by school level, for example, high school versus middle school (in North America, middle school is approximately for children ages 10–13 or school years 5th–8th grades). Sport-level groupings were defined similarly, such as bantam

Table 1. Summary of results of systematic review for age as a variable in youth concussion

Authors, year	Study type	Sample size	Age groups	Age classification type	Age-related findings
Anderson, Catroppa, Morse, Haritou and Rosenfeld (2000)	Prospective-longitudinal study	124	Young 3–7 years, old 8–12 years	Developmental	"Age at injury was not predictive of outcome for children with mild/moderate TBI"
Anderson, Catroppa, Morse, Haritou and Rosenfeld (2005)	Prospective-longitudinal study	122	Young 3–7 years, old 8–12 years	Developmental	"Age at injury was not predictive of outcome for children with mild/moderate TBI"
Babcock and colleagues (2013)	Retrospective analysis of a prospective observational study	406	5–10 years, 11–18 years	Developmental	Adolescent age was one predictor of Post Concussion Syndrome (headache predictor)
Baillargeon, Lassonde, Leclerc and Ellemberg (2012)	Cross-sectional study	96	9–12 years,13–16 years, adults	Developmental	Neurophysiological and Working Memory measures indicated "adolescents are more sensitive to the consequences of concussions than are children or adults"
Bakhos, Lockhart, Myers and Linakis (2010)	Retrospective review; epidemiological, stratifed probability sample	502,784	Pre-high school 8–13, high school 14–19 years	Educational	ED visits for concussion in older group (65%) vs. younger group (35%)
Barlow and colleagues (2010)	Prospective, consecutive controlled-cohort study	670	School age vs. non-school age 0–18 years, under 6 years vs. over 6 years	Educational	Asymptomatic mTBI group was younger than symptomatic group: "Children older than 6 years more likely to remain symptomatic…" Mediated by severity: School-aged children with mTBI and LOC may have longer recovery
Blume and colleagues (2012)	Prospective-cohort study	Three samples examined: 402, 60, 122	5–12 years, 13–17 years	Developmental	Headache associated with greater age. Girls and adolescents at greater risk for headache after TBI
Browne and Lam (2006)	Retrospective case series	592	0–4 years, 5–9 years, 10–16 years	Developmental	Children and adolescents who suffered a concussive head injury while playing organized sports (compared to other leisure activities) were likely male and older than 10 years. The most severe were also in that group
Corwin and colleagues (2014)	Retrospective, exploratory cohort	247	5–12 years, 13–14 years, 15–16 years	Developmental	Oldest group took a longer time to return to school full-time and youngest group took longest to recover
Covassin, Elbin, Harris, Parker and Kontos (2012)	Cohort study	296	High school vs. college	Educational	HS athletes worse on visual/verbal memory; BESS results had age–sex interaction. Male HS athletes worse on BESS than college athletes; opposite findings for female
Eisenberg, Andrea, Meehan and Mannix (2013)	Prospective cohort study	280	11–12 years, 13–22 years	Developmental	Those 13 years and above=predictor of prolonged recovery
Field, Collins, Lovell and Maroon (2003)	Prospective cohort study	College = 371 High School = 183	High school vs. college	Educational	HS athletes displayed prolonged memory dysfunction compared to College athletes

(*continued on next page*)

Table 1. *(continued)*

Authors, year	Study type	Sample size	Age groups	Age classification type	Age-related findings
Grubenhoff, Kirkwood, Gao, Deakyne and Wathen (2010)	Prospective, observational, cohort study	348	6–8 years, 9–11 years, 12–14 years, 15–18 years	Developmental	SAC tool differentiated only the 12–14 year old group from controls. Graded symptom checklist differentiated all groups from controls
Hunt and Ferrara (2009)	Cross-sectional study between groups design	198	Four groups: 9th through 12th grades	Educational	11th–12th graders stronger on information processing attention and motor dexterity than 9th graders. Recommend testing entering 9th grade and then entering 10th
Jinguji and colleagues (2012)	Prospective cohort study	214	High school: young and old, 13–15 years, 16–19 years	Educational	Younger group had fewer symptoms. Lowest immediate memory scores in older boys. Lowest concentration in younger boys. For balance-younger females better than younger males
Kerr and colleagues (2016)	Epidemological study	>3000	Youth vs. secondary school vs. college (3 groups) 5–14 years	Educational/Sport	Youth and high school athletes had higher probably of recovery taking greater than 30 days compared to college. Youth had higher probably of return in less than 24 hr post-injury compared to HS. More concussion symptoms reported in HS & college than in youth
Kontos and colleagues (2013)	Prospective cohort study	488	8–10 years, 11–12 years	Sport	Older group was 2.9 times more likely to sustain concussion
Lee, Odon, Zuckerman, Solomon and Sills (2013)	Retrospective study	184	13–16 years, 18–22 years	Educational- (mostly HS vs. college but some in middle school)	No difference in sx presence, severity, total at baseline or PC. No diff in return to baseline scores
Lichtenstein and colleagues (2013)	Retrospective study	502	10–12 years, 13–18 years	Developmental	Younger group had more “invalid” test results
Majerske and colleagues (2008)	Retrospective study	95	13–15 years, 16–18 years	Developmental (adolescents)	Younger group had more visual and verbal memory deficits than older group after concussion
McKay, Brooks, Mrazik, Jubinville and Emery (2014)	Prospective/cross-sectional study	704	Bantam (13–14 years) Midget (15–17 years)	Sport	Older group stronger in visual motor processing and impulse control than younger group
Meehan, Mannix, Monuteaux, Stein and Bachur (2014)	Prospective cohort study	531	7–26 years	Age was a continuous variable	Overall symptom burden was only independent variable to predict prolonged. Symptoms
Meehan, Mannix, Stracciolini, Elbin and Collins (2013)	Prospective cohort study	182	7–26 years	Age was a continuous variable	PCSS related to prolonged recovery-age and amnesia not related to prolonged recovery (longer than 28 days)
Moser, Schatz, Grosner and Kollias (2017)	Retrospective study	30	10–12 years	Educational, middle school	Verbal Memory/Visual Motor Speed stable on one year test–retest. Visual Memory, Reaction Time, Symptom Checklist less reliable. Conclude to baseline test yearly in this age group in contrast to HS athletes
National Electronic Injury Surveillance System NEISS (2007)	Epidemiological study	samples from 96 hospitals	0–4 years, 5–14 years, 15–24 years	Developmental	Estimates of injuries in different product and cause categories presented
Olsen (2012)	Prospective cohort study	852	11–13 years, 17–18 years	Developmental	No differences between genders or age cohorts
Quatman-Yates and colleagues (2014)	Retrospective medical review	20	8–13 years, 14–18 years	Developmental	Age may influence BESS scores. BESS not easy to interpret and use in youth

	and prospective cohort				
Ransom, Vaughan, Sady, Pratson and Gioia (2015)	Prospective cohort study	349	Kindergarten–5th grades, 6th–8th grades-middle school, 9th–12th grade-high school	Educational	"High school students who had not yet recovered reported significantly more adverse academic effects than their younger counterparts"
Register-Mihalik and colleagues (2012)	Prospective cohort study	40	High school vs. collegiate athlete	Educational	"Collegiate student-athletes performed better than high school student-athletes on ImPACT processing speed composite at all time points.no other age effects…"
Reynolds, Fazio, Sandel, Schatz and Henry (2016)	Retrospective study	2723	10–12 year olds	Developmental	"…10 year olds significantly differed from 11 and 12 year olds, and 11 year olds and 12 year olds were also significantly different on measures of Visual Memory, Visual Motor Speed, Reaction Time, and Impulse Control"
Sady, Vaughan and Gioia (2014)	Prospective cohort study	concussed = 633 Uninjured = 1273	5–7 years (younger child); 8–12 years older child; 13–18 years (adolescent)	Developmental	Study of Postconcussion Symptom Inventory. Support for querying fewer symptoms with younger children and "greater discriminability from parent reports"
Schneider, Emery, Kang, Schneider and Meeuwisse (2010)	Pooled data of three prospective cohort studies	4193	9–17 years: males = 11–12 years vs. 13–14 years; females = 9–10 years vs. 11–12 years vs. 13–14 years vs. 15–17 years	Sport	"The SCAT may need to be repeated regularly due to altered stages of devlopment which may affect performance"
Snyder and Bauer (2014)	Prospective, cohort study	761	9 –18 year olds	Age was a continuous variable	Teens perform higher on SCAT2 than younger children (9–11 years). Utility of SCAT2 for 9–11 year olds questioned
Tonks, Williams, Yates and Slater (2011)	Prospective study	28 injured; 89 controls	Two injured groups with matched controls: (1) 8–10 year olds; (2)10–16 year olds	Developmental	10–16 year old with traumatic brain injury scored lower on neuropsychological tests
Valovich-McLeod and colleagues (2012)	Descriptive epidemiological study	1134	9th, 10th, 11th, 12th grades	Educational (by grade)	On SCAT 2, males, 9th graders and those with history of concussion score lower than females, upperclassmen, and those with no concussion history
Williams and colleagues (2016)	Prospective, cross-sectional study	832	9–17 years: late childhood (9–12 years) young adolescence (12–15 years) late adolescence (15–17 years)	Developmental	Biggest change in baseline test results in the 9–12 year olds. Stable performance by 15 years
Zemek and colleagues (2016)	Prospective, multicenter cohort	3063 initial enrollment	5–7 years 8–12 years 13–18 years	Developmental	12 point risk score for prediction of persistent post-concussion symptoms (PPCS). Age 13 years or older associated with PPCS

Note: BESS = Balance Error Scoring System; ImPACT = Immediate Post-Concussion Assessment and Cognitive Test; LOC = loss of consciousness; PC = post-concussion; PCSS = Post-Concussion Symptom Scale; SCAT = Standardized Concussion Assessment Tool; TBI = traumatic brain injury.

(approximate ages 13–14) versus midget (approximate ages 15–18) in ice hockey. When age was studied as a continuous variable or when a sample was conveniently available, such as hospital visits to an emergency department, rationales for age groups were not specifically considered or evaluated.

Twenty of the 37 studies employed primarily "developmental" groupings, as opposed to educational, sport, or convenience groupings. For these studies, the age start and end points of each of the groups in each study are identified and graphically represented in Fig. 1. Thus, by aggregating the start and end points, where developmental age groups were used, it appears that ages 5, 8, 10, 12, 13, 15/16, and 18 years were most often used to identify the start or end of an age group that was examined. These age cutoffs may be seen as grossly corresponding to four developmental age groupings: 5–8/9 years (early childhood), 10–12 years (pre-puberty), 13–15 years (early adolescence), and 16–18 years (older adolescence). The age range of 12–13 years was clearly the midpoint, being used most frequently in the studies. This is not surprising considering that adolescence is often considered to begin at approximately that age, with entrance into Piaget's Formal Operations stage of cognitive development and final stage of abstract higher level thought, and with a corresponding peak in frontal/parietal brain growth that begins with the onset of puberty (Casey *et al.*, 2008).

Interestingly, there have been a number of studies that have reported no significant relationship between age and concussion in childhood [see Table 1 studies 13, 30, 34, 35, 38]. However, there have been other studies that have shown an association between adolescent age and greater likelihood of concussion [see Table 1 studies 20, 44], post-concussion symptoms [see Table 1 studies 15,19, 28, 48], hospital/ED visits [see Table 1 study 17], neuropsychological sequelae [see Table 1 studies 16, 22], and later return to school/longer recovery [see Table 1 studies 21, 23, 24, 28]. There is additional research to suggest that younger adolescents experience greater difficulties than older adolescents [see Table 1 study 40], as well as a general trend of increasing difficulty due to concussion as the child ages even before adolescence [see Table 1 study 18, 29].

Discussion

Despite the growing body of research on the incidence, assessment, and management of sports-related concussion in professional, collegiate, and high school athletes, there remains a paucity of research focusing on middle school and younger children (ages 5–11 years). This limited research may, in part, be due to a lack of adequate concussion tests and assessment tools for younger ages. In addition, the lack of research on middle school and younger children may be due to limited resources, especially in comparison to high school, collegiate, and professional leagues. Furthermore, younger children, due to their level of cognitive development and verbal skills, may not be capable of effectively communicating or endorsing symptoms, complicating the interpretation of research findings. Thus, it is not known if the current findings of greater concussion difficulties in older children are a function of better understanding of the injury and more sophisticated expressive ability commensurate with increasing age; adolescents may be more cognitively capable of describing their symptoms and completing the available concussion tests and symptom assessments. Additionally, the scholastic demands on adolescents are greater than on younger children, and as such, concussion symptoms may manifest more readily in the adolescent than younger child.

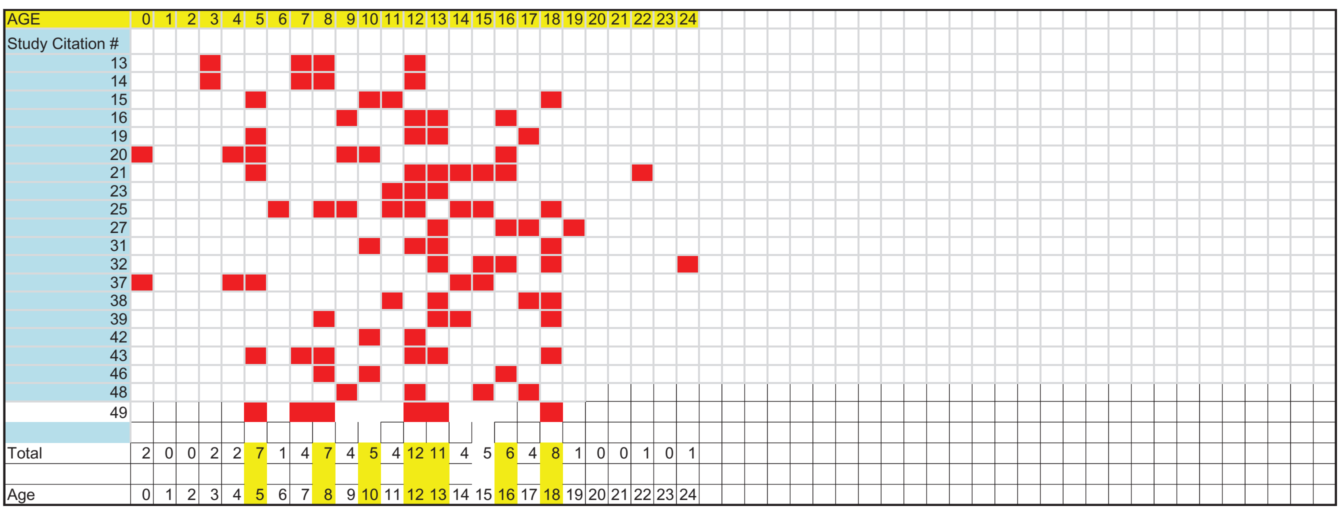

Fig. 1. Age cutoffs for groupings in 20 studies examining the age variable in a primarily developmental manner.

The variability of cognitive development and its influence on clinical presentation is reflected in studies of baseline neuropsychological testing that have shown lower one year test–retest reliability and greater incidence of invalid test results in preadolescent youth athletes (Lichtenstein, Moser, & Schatz, 2013). In addition, tests of balance and physical factors may not reliably capture the performance of younger athletes (Quatman-Yates *et al.*, 2014; Valovich-McLeod, Bay, Lam, & Chhabra, 2012).

Future research may do well to examine the concussion event in a more meaningful, directed manner, such as through developmental stages. For example, a cognitive Piagetian framework may offer a rationale to gauge possible differences in response to, and recovery from concussion across childhood and adolescence. Similarly, concussion differences across younger children, adolescents, and college-age youth may be better understood with frameworks similar to those employed in other areas of medicine. The Tanner five-stage model of physical development (Marshall & Tanner, 1969; Marshall & Tanner, 1970) focuses on the biologic transitions from prepubescent, to pubescent, to post-pubescent growth changes to help guide medical clinicians in the application of developmentally appropriate medical treatments. For example, in the treatment of HIV, dosing of medications is carefully executed to avoid toxicity depending on the physical development (rather than chronological age) of the youth (Rakhmanina, Capparelli, & van der Anker, 2008). It would be interesting if a similar model might be valid for the differential treatment of concussion across the age ranges.

Furthermore, research in brain development has documented the maturational changes in brain myelination, from early sensorimotor areas to later prefrontal/temporal areas, thus serving to provide a biologic basis for the development of higher executive functioning (Casey, Tottenham, Liston, & Dustin, 2005) and a possible model for differential management of youth across the age span. Neuroimaging, although not simple to facilitate, may be another promising avenue to explore. Studies have shown the changes in cerebral blood flow in youth who are concussed (Maugans, Farley, Altaye, Leach & Cecil, 2012), as well as neuromarkers that persist in concussed adults (Cubon, Putukian, Boyer & Dettwiler, 2011; Signoretti, Lazzarino, Tavazzi & Vagnozzi, 2011). Identifying how selected biomarkers return to baseline at different age points may provide a starting point to outlining tailored developmental management. Nonetheless, at this time there appears to be a lack of systematic reasoning when researchers employ age groupings.

The present review employed very strict inclusion and exclusion criteria, in order to conform to the specific requirements of the 5th International Consensus Conference on Concussion in Sport in Berlin 2016; as such, it is possible that some eligible articles may have been excluded, and any publications after May 2016 were similarly excluded. The question of what are the optimal age classifications or “age groups” for the study of childhood concussion remains unanswered. In addition, it is not clear whether “convenience groupings” (such as educational or sport levels) should be preferentially used in concussion research and management, rather than a more “developmental age” approach, that has child development theory for a rationale. Employing educational levels to group children can be problematic, as the nomenclature for educational levels/divisions are not internationally consistent, as is the case with the term “middle school.” Similarly, age cutoffs for sport levels may vary based on the individual sport, league, and country in which it is played.

At this time, there are no defined, evidence-based age groups for childhood concussion. Due to the current paucity of research in the younger athlete, specifically in the preschool to pre-high school range (compared to high school and college levels), the establishment of developmental classifications may be premature. It is clear that the published research on childhood concussion often lack significant controls, are retrospective in nature, include bias risk, or simply provide a lower level of scientific evidence. Despite this current state of research, some findings are emerging regarding developmental trends. Based on the studies reviewed here, there may be some support for the following:

(1) Concussion may present differently in different developmental stages of childhood.
(2) With increasing age, adolescents may exhibit more symptoms and difficulties from concussion.
(3) Existing research has used age groupings based on educational or sport level. Otherwise, when developmental age groupings are used, the 12–13 year range is most frequently implemented as the cutoff point between younger and older children.
(4) Research seems to employ four general developmental groupings: young child, pre-pubertal child, early adolescent, and late adolescent.
(5) Due to limited child-specific concussion assessment tools, and the challenges of testing/assessing younger children, the current research findings likely represent a very limited understanding of childhood concussion.

Conclusion

The available literature does not currently afford us with a valid answer to the question “at what age should young children be managed differently than adults or older adolescents?”

Ultimately, we will need stronger, more creative, effective tools and ways in which to gather data from younger athletes, as well as specific studies dedicated to the question of how concussion varies developmentally from preschool through late adolescence. We will need to create and test developmental/maturational models with rationales as platforms for these studies. These studies will also need to consider the different domains of concussion effects, whether cognitive, physical, emotional, or sleep, as well as socio-economic–cultural–ethnic–sex factors as they may interact with the age variable.

If we can identify how concussion may vary across the younger age span, we will be able to refine and tailor concussion protocols to the needs of the child. We will be better able to establish different developmental youth concussion classifications that will guide clinicians in their health care practices, as well as affect educational, advocacy, and legislative public health efforts.

Conflict of Interest

None declared.

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