

The Pediatric Athlete: Younger Athletes with Sport-Related Concussion

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KEYWORDS

- Concussion • Mild traumatic brain injury • Head injury
- Trauma • Injury • Sports

Most athletes involved in organized sports participation are pediatric athletes.¹ Approximately 25% of pediatric concussions presenting to emergency departments occur during athletic activity.² Fortunately, much of the published medical investigations were conducted in high-school and college athletes, therefore offering physicians some insight into the mechanisms, signs, symptoms, assessment, and management of a pediatric athlete who sustains a sport-related concussion (SRC).

Very little data regarding SRC, however, have been published in pre-high-school-aged athletes.³ This situation is concerning because the human brain continues to develop into young adulthood. The effects of concussive brain injury on the developing brain are not well understood. There is both scientific and clinical evidence that traumatic brain injury (TBI) in children differs from that in adults. In addition, children and adults differ in the role played by sports participation in their lives, the amount of knowledge they are expected to acquire on a daily basis, and the frequency with which their cognitive function is assessed or tested.⁴ Therefore, the recommendations

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for managing young athletes with concussion differ from those of adults. This article discusses the differences between pediatric and adult athletes who sustain SRCs.

EPIDEMIOLOGY

Concussion accounts for approximately 9% of all high-school athletic injuries.⁵ The rates of SRCs are highest in contact and collision sports.⁵⁻⁷ Most athletes engaged in such sports are younger than 19 years,¹ making concussion a major concern for clinicians caring for young athletes. Of all pediatric concussions presenting to the emergency departments, approximately 25% occur during sports.² Many athletes with SRCs do not present to an emergency department or seek medical attention.⁷⁻⁹ Surveys of the general population suggest that a higher percentage of concussions are due to athletics, with some studies suggesting that more than 85% of concussions in 16- to 34-year-old people are related to sports.¹⁰

MECHANISM/BIOMECHANICS

The biomechanics of concussive injury differs between adult and pediatric patients. Factors including differences in relative size of the head compared with the rest of the body, brain water content, vasculature, degree of myelination, and shape of the skull account for the biomechanical differences.^{3,4,11,12}

Concussion is caused primarily by a rotational acceleration of the brain.¹³⁻¹⁵ Clinicians have hypothesized that increasing both the cervical muscle strength and tone at the time of impact can reduce the risk of concussion by increasing the effective mass of the head, which becomes more of a unit with the rest of the body as the neck muscles strengthen. This, in turn, reduces the resultant acceleration for a given force.^{1,16} This difference in neck strength has biomechanical effects, shown both experimentally in animals and clinically in children.¹⁷ Recent evidence supports this hypothesis.¹⁸ Given the relatively weak cervical muscle strength compared with their older counterparts, younger athletes might be at increased risk for concussion when hit with the same magnitude of force. Of course, as other investigators have pointed out, this same decrease in muscle strength may result in less force delivered by the striking athlete at the time of injury, thereby decreasing the risk of injury.⁵

Countering this hypothesis, biomechanicians have demonstrated that greater force is required to cause similar concussive injury in smaller brains than in larger brains with greater mass.^{11,17} Thus, it has been suggested that children symptomatic after a concussion have sustained greater force than an adult with similar postconcussive symptoms.⁴ This would suggest that the weaker neck muscles and larger head may be a more important issue than the overall small size of the athlete because these weaker forces are disproportionately applied to the brain.

Clinically, the different effects of age on head injury have been investigated. An analysis by Berney and colleagues¹⁹ revealed that children younger than 3 years sustained head injuries associated with lower energy mechanisms and more skull fractures, subdural hematomas, and early seizures than their older counterparts. They were also less likely to lose consciousness than older children. Those children aged 3 to 9 years sustained head injuries after higher energy mechanisms, were more likely to lose consciousness, were more often comatose, had less subdural hemorrhages, and had more significant cerebral edema. Injuries sustained by children older than 9 years were more like adult injuries with high energy mechanisms and more extracranial hematomas. These age-dependent injury patterns warrant further investigation into the possible differences in concussive brain injury between patients of varying ages.

PATHOPHYSIOLOGY

Pediatric and adult brains are in different phases of development, with the child's brain growing and needing to acquire high volumes of new learning at a much faster pace. The pathophysiological response to TBI also differs between the mature and developing brain.^{12,20–22} Clinically, a syndrome of delayed deterioration after a lucid period without a focal structural injury has been described in children (sometimes referred to as “talk and die”); it is not often seen in adults.^{23–25} Another possible example of different responses to concussive brain injury between adult and pediatric patients is second impact syndrome, which has been described exclusively in teenagers and young adults.^{26–30}

Diffuse brain swelling after TBI is more common in pediatric patients and results from mechanisms different from that of adults. Although the exact reasons for this swelling are not known, differences in glutamate receptor expression, expression of aquaporin 4 by microglia, and brain water content may play a role.¹² Increased vulnerability to oxidative stress, differences in dopaminergic activity, vascular response to injury, and susceptibility of glutamate receptors between the developing and fully developed brain may also play a role in the difference in responses to TBI between adult and pediatric patients.^{12,31}

The possibility that the mechanisms, forces, biomechanics, and pathophysiological responses to concussive brain injury differ between adults and children needs to be further explored, because such differences could change the assessment and management of pediatric athletes who sustain SRCs.

UNDERREPORTING

The assessment and management of pediatric concussion is further complicated by the lack of injury reporting. In a 1983 study of football players in Minnesota high schools, 29% of athletes who sustained a concussion were not examined by anyone at all. Only 22% were examined by medical personnel. The remainder were attended to by a coach, parent, or teammate.⁹ More recent research suggests that underreporting continues. A 2004 study published by McCrea and colleagues⁸ revealed that only 47.3% of high-school football players report their injuries. Similar findings have been reported in other sports, including female athletics.³² Underreporting of concussion is not exclusive to pediatric athletes.^{33,34} However, pediatric athletic organizations are less likely to have a formal organized approach to concussion management, including preseason balance error scores, computerized neuropsychological testing, and dedicated personnel with concussion training, such as team physicians, athletic trainers, and neuropsychologists. This inherent lack of personnel and resources results in further reliance on self-reporting of symptoms in younger athletes, making underreporting more of an issue in pediatrics than in adult sports medicine.

ASSESSMENT

As mentioned earlier, younger athletes are often managed without the benefit of dedicated athletic trainers, team physicians, and neuropsychologists. Therefore, many of those athletes who seek medical care after a concussion are managed by primary care physicians who often do not have expertise in concussive brain injury or access to needed resources. In a 2006 survey of primary care physicians, many were unaware of published guidelines for the management of SRCs.³⁵ This lack of awareness likely reflects a lack of medical training in concussion management and the relatively small

proportion of patients presenting to the primary care physician for concussions when compared with other issues such as asthma, infectious illnesses, obesity.

NEUROPSYCHOLOGICAL EVALUATION OF THE PEDIATRIC ATHLETE

In high-school, college, and professional athletes, neuropsychological evaluation has been shown to be useful in the management of concussion. Defined as the applied science of brain-behavior relationships, neuropsychology involves objective assessment of cognitive, social, and emotional functioning. Data are used to identify individual strengths and weaknesses, make differential diagnoses, and plan appropriate interventions within environmental and developmental contexts.^{3,36–38} Sports medicine first recognized the utility of neuropsychological testing in the mid-1980s when the testing was used as part of a 4-year prospective study of mild TBI in college athletes.³⁹ A total of 2350 football players were evaluated with brief paper-and-pencil neuropsychological measures both pre- and postseason. Head-injured athletes were also evaluated 24 hours, 5 days, and 10 days after the injury. Compared with uninjured controls and their own preseason baseline performance, the concussed group demonstrated cognitive deficits for up to 10 days postinjury.

Subsequent studies have confirmed these findings, revealing several areas particularly sensitive to head injury: executive functioning, speed of information processing, attention, and memory.^{40–53} Results suggest that recovery typically occurs within 2 to 14 days, although some patients demonstrate significantly longer recovery times.^{40–43,45–52,54} There is also evidence that injured athletes who no longer report symptoms demonstrate worse performance on neurocognitive measures than uninjured controls, suggesting that there may be subtle deficits beyond the reported symptoms.⁴⁵ Neuropsychological testing is also sensitive enough to diagnose SRC, even in the absence of reported symptoms.^{44,48,50,55,56} Given these findings, the use of neuropsychological testing has been endorsed by experts in SRC.^{57–59} Neuropsychological testing can be especially useful for younger athletes to assist with planning academic interventions.⁵⁹

Studies examining outcomes from SRC in younger athletes are more limited. Initial findings, however, are consistent with more severe TBI research, which suggests that recovery may be age related, with younger athletes faring worse. Results from an investigation that compared concussed college and high-school athletes with uninjured controls found that high-school athletes take longer to recover than college athletes, despite reporting lower numbers of previous concussions and less severe in-season injuries.⁶⁰ In addition, a study of 2141 high-school athletes found that up to 23% of the concussed athletes continued to demonstrate difficulties on cognitive tasks 3 weeks after injury.⁶¹ In contrast, in a 6-year prospective study involving the National Football League (NFL) only 1.6% of the concussed participants took more than 14 days to recover.⁶² In a subset of the NFL players who underwent baseline neuropsychological evaluations and then completed a second evaluation within a few days after concussion, there was no statistically significant decline on any traditional paper-and-pencil measures of neuropsychological functioning.⁶² These data contrast findings of studies examining younger athletes, suggesting that age and developmental factors play a role in recovery from concussive brain injury.

Because an increasing number of sports organizations recognized the utility of neuropsychological assessment in managing SRCs, the limitations of traditional testing (paper and pencil) became evident. Most notably, the cost and availability of trained neuropsychologists to administer and interpret data for large organizations seemed prohibitive and led to the development and increased use of computer-based

neuropsychological testing. Computer-based testing is more efficient, allowing for entire teams to be tested in a single session. Computers also provide a more accurate measurement of cognitive function, such as reaction time and speed of information processing. This added precision may increase the validity of test results in detecting subtle changes in neurocognitive functioning. In addition, computerized testing allows for the randomization of test stimuli, which should improve reliability across multiple administration periods by minimizing practice effects.⁶³

Several computer-based tests exist at present, including Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT Applications, Inc, Pittsburgh, PA, USA), CogSport (CogState Ltd, Melbourne, Victoria, Australia), Concussion Resolution Index (HeadMinder, Inc, New York, NY, USA), and Automated Neurocognitive Assessment Metrics (US Department of Defense). Many present guidelines recommend that baseline neuropsychological assessment be administered before the start of the season. This model allows athletes to serve as their own controls and aids in the interpretation of data in light of preexisting or contextual factors that have been shown to affect neuropsychological performance. With some exceptions, normative samples of computerized tests used to manage SRCs are based on older athletes and are therefore less generalizable to children. Ongoing research to develop and validate cognitive tests for children has shown the potential for increased clinical application with this population.^{53,64}

In younger athletes, testing must be considered in the context of brain maturation and individual abilities. Rapid brain development, which continues through adolescence, may affect neuropsychological performance. Improvement in cognitive performance is likely, as new skills and abilities are acquired.^{1,4,38,64} In one study examining neuropsychological testing among high-school athletes, older students performed better than their younger peers, reflecting improvements in cognitive function with age and development.⁶⁵ Thus, more frequent baseline testing is necessary in younger athletes because their baseline function changes with age.

Developmental disorders including learning disabilities or attention-deficit/hyperactivity disorder can also affect neuropsychological functioning. Research has shown more severe cognitive sequelae in college football players diagnosed with a learning disability.⁴³ Students with self-reported academic problems also perform worse on some baseline measures of functioning.⁶⁶ There is some evidence that girls experience more significant neuropsychological difficulties after SRC.^{67–69} Other factors that may affect cognitive functioning include sleep deprivation, anxiety, and depression.^{38,70}

The neuropsychological literature has also documented the effect of motivation on performance. In forensic settings, symptoms or deficits may be exaggerated. In athletes, secondary gains such as the benefit of academic accommodations may negatively affect performance.³⁷ Moreover, intentional suboptimal performance on baseline tests, with the hope of showing less deterioration after injury, has been documented in college athletes.⁷¹ This area warrants further investigation. Careful consideration should be given to performing and interpreting neuropsychological tests, given the multiple factors that may affect performance in the developing child.

Given that some athletes deny symptoms and younger children may have difficulty verbalizing cognitive problems, objective neuropsychological data can aid return-to-play decisions. A score significantly lower than baseline or, in the absence of baseline testing, lower than premorbid estimates of functioning may reflect ongoing sequelae and preclude return to play. Acute findings can also help determine appropriate management strategies. In pediatric populations, neuropsychological assessment while the athlete remains symptomatic is useful in determining the appropriate

academic accommodations.^{38,59} In all cases, neuropsychological testing should not be used as a stand-alone measure but as part of a comprehensive assessment that includes a clinical interview, evaluation of symptoms, overall medical history, and physical examination.

Although there is some evidence that a history of concussion is associated with neuropsychological impairment, data concerning the long-term effects of repetitive concussions vary. The number or severity of previous injuries has not been shown to conclusively predict long-term sequelae.^{43,47,72–75} In general, studies of athletes with a history of concussion suggest an increased risk of sustaining additional concussions, worse on-field presentations with subsequent concussions, slowed recoveries, and greater acute changes in memory performance. In the extreme cases, such as boxing, findings suggest that the extent of neuropsychological impairments may be associated with the number of bouts fought.⁷⁶ The likely relationship between exposure and outcome argues for conservative management of the pediatric athlete.

Many physicians do not have easy access to neuropsychological testing. In one study, only 16% of respondents reported they could reliably access neuropsychological testing within 1 week of injury.³⁵ Because the most recent guidelines refer to neuropsychological testing as the cornerstone of concussion management,⁵⁸ it seems that even those aware of recent management strategies will often not have access to the needed resources to follow such guidelines. Furthermore, most of the assessments available, both symptom scales and neurocognitive assessments, have been researched in older athletes, leading to concerns over the appropriateness of the assessments in younger patients.⁵³ Although the utility of most currently available computerized measures in the youngest athletes is limited, specific pediatric versions are in development. These measures, and more traditional neuropsychological measures, are useful not only in assisting return-to-play decisions but also in guiding targeted academic accommodations for younger athletes by providing practitioners with objective evidence to support their treatment plans.

RECOVERY

Most athletes recover from SRCs in a relatively short period.^{47,59,77,78} However, studies have shown longer recovery times in younger athletes than in older athletes.⁵⁹ In a study using neuropsychological testing to track the recovery of high-school athletes compared with college athletes, Field and colleagues⁶⁰ have reported a protracted rate of recovery in the high-school athletes,⁵⁰ which may be related to age-dependent brain physiology.

Experimental models of concussion reporting a temporal window of vulnerability after trauma also suggest that the developing brain may be more susceptible to injury during the acute recovery phase.^{22,64,79,80} Research examining more severe pediatric head injury has shown a relationship between age and outcome. Rather than the younger brain being more “plastic” and thus better able to recover from injury, current theory suggests that early insult may have a significant impact on later development.^{36,81–83} Long-term sequelae have been documented in younger children with acquired brain injury. In research involving TBI, insult occurring during infancy and preschool age is associated with worse outcomes than injury sustained in later childhood or adolescence. Undeveloped or developing skills are presumed to be particularly vulnerable.^{81,82,84,85} Moreover, contextual factors, including access to care and academic demands, may affect recovery in younger individuals.^{3,38,53,59}

Furthermore, there is some evidence that concussive injuries sustained early in life may have minimal effect on already established cognitive skills but may significantly delay the development of future skills.^{83,86} Obviously, this effect is much more of a concern for the developing mind of a child than the fully developed mind of an adult athlete.

MANAGEMENT

Although much of the management of pediatric athletes who sustain SRC is at present similar to that of adults, there are some differences worth noting. As mentioned earlier, the mind of the pediatric athlete is still developing. Cognitive function continues to increase. Therefore, baseline testing should occur more frequently in younger athletes,^{4,87} and the clinician should be more sensitive to the relative vulnerability of the child's brain than with the adult. Because younger athletes require longer recovery times, more conservative return-to-play decisions should be considered for them.^{3,4,58,60,88–91} The American Academy of Pediatrics recommends conservative management of concussion.⁹²

Although cognitive function is compromised after concussion in both adult and pediatric athletes, younger athletes are unique because their cognitive function is constantly being assessed and tested in school. Furthermore, their cognitive performance is graded, and those grades are placed in their permanent academic records. There is the potential for greater secondary consequences of concussion in children, in whom social and academic progress rely on normal growth and development.^{3,4,84,85} Many of their future opportunities, such as college acceptance and employment, are based, in part, on their grades, which must be considered in their management. Academic accommodations should be put in place to help attenuate any effects their injury might otherwise have on their grades during recovery.^{3,4,59}

SUMMARY

TBI affects the developing brain differently than the fully developed brain. The specific effects of concussion on the developing brain are still being elucidated through clinical and scientific investigation. As compared with adults, clinicians should expect longer recovery times for younger patients after a concussion. Given the daily cognitive demands placed on school-aged athletes, concussion management in this age group should include, when available, neuropsychological assessment and appropriate academic planning. Given the increased vulnerability, ongoing development, and contextual factors that have the potential to complicate recovery from concussion in children, more conservative management is warranted.

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