Subacute Concussion-Related Symptoms in Youth

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KEYWORDS

- Concussion • Child • Subacute symptoms
- Postconcussive symptoms • Post-traumatic headache
- Post-concussive syndrome

Most athletes who experience a single sports-related concussion recover from the acute effects within a few weeks. However, a minority of children and adolescents with concussion experience symptoms for many weeks, or even months, after the injury.[1,2] Concern also exists that children may take longer to recover from concussion than adults,[3] and that symptoms, recovery patterns, and optimal treatment strategies may be different for children than adults. Subacute and chronic symptoms related to concussion are particularly concerning in children, because cognitive deficits, headache or neck pain, sleep dysfunction, and emotional dysregulation can affect school performance and social function at a critical period of development and maturation.

Postconcussive symptoms are divided into three major domains:

1. Somatic symptoms: including headache, nausea, photophobia, phonophobia, vision changes, sleep disturbance, and balance deficits.
2. Emotional disturbance: including irritability, apathy, depression, and anxiety.
3. Cognitive symptoms: including slow processing speed, attention deficits, impaired concentration, and poor performance on neuropsychological testing.

Some have previously questioned the existence of postconcussion syndrome in children,[4] but recent prospective controlled studies show that mild traumatic brain injury (mTBI) or concussion in children is associated with a constellation of postconcussive symptoms.[1,2,5] This article reviews the epidemiology of subacute symptoms after pediatric concussion and the current recommendations for the assessment and management of these symptoms in children and adolescents. However, any review of these subjects is limited by the fact that few long-term prospective controlled studies of outcome after concussion in adolescents, very few long-term

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studies of younger children with concussion, and no large controlled studies of management of subacute or chronic symptoms after concussion in children or adolescents have been performed.

EPIDEMIOLOGY OF POSTCONCUSSION SYMPTOMS IN YOUTH

Although few prospective, controlled studies have been performed specifically related to pediatric concussion in sports, several recent studies have examined postconcussive symptoms after mTBI treated in the emergency department and compared these with postconcussive symptoms after other injuries in children. In this field, the prevalence of postconcussion symptoms in an injured but nonconcussed population is important, because headache, irritability, sleep problems, and other subacute postconcussive symptoms are also common in the general population. Yeates and colleagues[2] found that, when parents were asked about these symptoms 1, 3, and 12 months after injury, children with mTBI were more likely to have a higher number of acute and persistent postconcussive symptoms than those who had experienced an orthopedic injury. In the acute period, within 3 weeks of injury, headache was the most commonly reported symptom (76%).

A controlled prospective study of mTBI in children (ages 1 month to 18 years) seen in the emergency department found that 11% of those with mTBI still had some complaints of postconcussive symptoms 3 months after their injury compared with 0.5% of those with extracranial injury (ECI). In children older than 6 years, 13.7% of those with mTBI and 1% of those with ECI were still symptomatic 3 months after injury. The most common postconcussive symptoms that were increased from baseline at 1 month after injury were fatigue (79%), "more emotional" (60%), irritability (58%), and headache (58%).[1] The comprehensive age range (1 month to 18 years) included in this study must be considered when evaluating these results in relation to sports-related concussion, because headache or other specific symptoms may be difficult for very young children to express to their parents, the pathophysiology of and recovery from mTBI are likely different in different age groups, and the mechanism of head injury may affect symptoms and recovery. The possibility that post-concussive symptoms may be related to age and injury severity is demonstrated by Barlow's finding that symptomatic children with mTBI were older than asymptomatic children and children with more severe mTBI had a significantly higher probability of remaining symptomatic over time. In this study 2.3% of those with mTBI remained symptomatic for longer than 12 months and 60% of these symptomatic children had chronic post-traumatic headache.[1]

Another controlled study comparing outcomes 3 months after mTBI and ECI (as part of a study examining an educational intervention for mTBI) found that mean postconcussive symptom scores were not different between the groups. However, 20% of the mTBI group had significant "ongoing difficulties" at 3 months after injury. These children tended to have a history of prior head injury, learning difficulties, other neurologic or psychiatric disturbance, or family stressors.[6]

In their study of postconcussive symptoms after pediatric mTBI (ages 8–15 years) or orthopedic injury treated in the emergency department, Taylor and colleagues investigated the time course of parental and child reports of somatic, cognitive, and emotional postconcussive symptoms after injury.[7] They found that higher parental counts of total postconcussive symptoms were associated with younger age at injury and female sex. Higher child ratings of somatic postconcussive symptoms were associated with lower socioeconomic status and female sex. They also found that somatic postconcussive symptom ratings were highest for mTBI acutely, then declined at 1 and 3 months and were not different from reports of those with orthopedic injury at 12 months. Ratings of cognitive postconcussive symptoms peaked at 3 months, and although these declined in both groups, they were still significantly different between mTBI and orthopedic injury groups at 12 months. Emotional postconcussive symptoms were associated only with preinjury postconcussive symptom ratings and were not significantly associated with mTBI.[7]

Studies of sports-related concussion provide further insight. Field and colleagues[3] found that high school athletes took significantly longer to recover to their expected performance level on neuropsychological testing after concussion (7 days) than college athletes (3 days). Athletes who reported 5 minutes or more of altered mental status with confusion or amnesia at the time of concussion were more likely to have longer-lasting memory deficits and complaints of postconcussive symptoms.[8,9] Concern also exists that prior concussion increases the risk of prolonged postconcussive symptoms after subsequent concussions. Even at baseline, high school athletes with a history of two or more concussions had significantly higher ratings of subacute concussion symptoms at baseline than athletes with a history of zero or one prior concussion, although all athletes had been free of acute concussion for at least 4 months before testing.[10] Lau and colleagues[11] found that self-reported cognitive decline, migraine symptoms, and slow ImPACT reaction time after concussion were each associated with prolonged recovery in high school athletes.

In summary, most children and adolescents recover to their preinjury baseline relatively quickly after concussion, but a few children experience prolonged symptoms. School-aged children and adolescents seem to be at higher risk for prolonged subacute symptoms after concussion than either very young children or college-aged adults. Other risk factors for prolonged postconcussive symptoms include more severe concussion and multiple past concussions. Learning disability, preexisting anxiety or depression, and presence of migraine or headaches before injury are also believed to be risk factors for prolonged symptoms after concussion,[11] although preexisting deficits can be difficult to differentiate from concussion-induced symptoms, and these factors have not been well studied after concussion in children or adolescents.

GENDER AND POSTCONCUSSIVE SYMPTOMS

The role of gender in risk of concussion and postconcussive symptoms is complex. Several studies have found that female athletes are at higher risk for concussion than male athletes participating in similar sports,[12,13] but data are conflicting regarding the role of sex in recovery from concussion in youth sports. Female sex was associated with a higher count of postconcussive symptoms in the months after pediatric mTBI (ages 8–15 years) evaluated in the emergency department.[7] Broshek and colleagues[14] found that female college and high school athletes were more likely to display cognitive deficits after concussion than males. However, other studies found no difference in return to play or duration of complaints of postconcussive symptoms between males and females but did find sex-related differences in the kinds of symptoms reported, and that female athletes performed significantly worse than male athletes on visual memory tasks after concussion.[15,16] Women and men also report different changes in postconcussive symptoms after exercise in general.[17] Preiss-Farzanegan and colleagues[18] describe a higher risk for several postconcussive symptoms 3 months after sports-related mTBI for adult women compared with men (including headache, dizziness, fatigue, irritability, concentration problems) but not for girls (ages 7–17 years) compared with boys. Complex interactions among age, sex, concussion, and postconcussive symptoms are likely, given that many biologic sex-related differences that may be associated with concussion risk and postconcussive symptom risk, including size, weight, muscle mass, strength, migraine risk, and hormonal milieu, become significant in adolescence.

GENERAL EVALUATION OF POSTCONCUSSIVE SYMPTOMS

As stated by many authors in this issue, athletes with a suspected concussion must be evaluated by a trained medical professional before considering returning to play. This evaluation should include directed questions regarding postconcussive symptoms. Many programs use some form of the Postconcussion Symptom Scale (PCSS). The athlete is asked to rate 22 symptoms, including somatic, emotional, and cognitive symptoms, on a 0- to 6-point scale (**Table 1**). Providers should ask the athlete and parent if physical or cognitive activity increases any of these symptoms. Athletes may not recognize signs of a concussion and may underreport symptoms,[19] and therefore these questions are important to address directly during the evaluation of an athlete after head trauma. The history should also include a detailed description of when and how the concussion occurred, presence and length of time of altered mental

Table 1
Postconcussion symptom scale

Current Symptoms	None	Mild		Moderate		Severe	
Headache	0	1	2	3	4	5	6
Pressure in head	0	1	2	3	4	5	6
Neck pain	0	1	2	3	4	5	6
Nausea/vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Sleep pattern changes	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling "in a fog"	0	1	2	3	4	5	6
"Don't feel right"/not like yourself	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering/ forgetfulness	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Nervous or anxious	0	1	2	3	4	5	6
More emotional/ emotions feel "closer to the surface"	0	1	2	3	4	5	6
Irritability/frustration	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6

How do you feel currently? Please circle a number for each of the symptoms listed above.

status or amnesia following the concussion, number and timing of past concussions, time to recovery from past concussions, and questioning about presence of symptoms on the PCSS before injury. The provider also should note any history of learning disability, attention deficits, headache, or mental health issues in the athlete before the concussion, because these factors may influence the risk of prolonged recovery after concussion. The results of neuroimaging and other testing should be reviewed, particularly if neuropsychological or cognitive testing had been performed before the concussion. Use of a standardized evaluation format that includes the PCSS is helpful so that change in symptoms can be followed objectively at each visit to document recovery or conversion to chronic postconcussion syndrome.

PHYSICAL EXAMINATION FOR POSTCONCUSSIVE SYMPTOMS

The physical examination of a child with subacute postconcussive symptoms may be focused on the athlete's complaints but should include a comprehensive neurologic examination, including evaluation of cranial nerve function, orientation, concentration, memory, coordination, vision, and balance (using the Balance Error Scoring System[20]) and a physical examination of the head and neck to detect evidence of pain or muscular tension in the neck, shoulders, and head. Postconcussive symptoms may be from direct head trauma but may also be related to a whiplash-type injury, which may cause additional cervical pain and symptoms. Fundoscopic examination should also be performed to look for papilledema or other signs of increased intracranial pressure or significant intracranial injury.

What Not to Miss

In the acute stage after sports-related concussions, rare but life-threatening entities to consider include intracranial hemorrhage, epidural hematoma, cerebral edema, cervical spine injury, other acute intracranial injury and skull fracture. At the subacute stage, other rare but potentially dangerous syndromes to consider in the appropriate setting include vascular dissection with transient ischemic attack or stroke-like symptoms, intracranial venous thrombosis, subacute subdural hematoma, and cervical spine injury. Indications for neuroimaging include seizures, repeated emesis, prolonged period of altered mental status, loss of consciousness longer than 30 seconds, or focal abnormalities on neurologic examination.[21] The role of neuroimaging in concussion is addressed in greater detail by McCullough and Jarvik elsewhere in this issue. Use of drugs and alcohol should also be addressed, because 40% to 50% of high school students use alcohol regularly[22] and use of alcohol or other drugs may complicate assessment of and recovery from concussion.

MANAGEMENT OF SUBACUTE SYMPTOMS AFTER CONCUSSION

Rest

Current guidelines stress the need for physical and cognitive rest after concussion, with a gradual return to activity when patients are symptom-free[21,23] (see article on Return to Play by Laker and Herring elsewhere in this issue). Many athletes report that their postconcussive symptoms worsen with either cognitive or physical activity. To prevent exacerbation of symptoms, they may need to temporarily stay out of school, reduce the length of time in school, reduce their academic workload, be allowed more time to complete assignments, have note takers provided, and have testing expectations altered (see article by Gioia elsewhere in this issue). Cognitive rest should also include eliminating or limiting time spent using computers, video games, and television, because these activities require attention and concentration and may exacerbate postconcussive symptoms. Because of slower reaction times, teens may also need to temporarily avoid driving.[21]

After concussion, athletes should rest physically and not return to play until they are symptom-free at rest. Once athletes are symptom-free at rest, they should be directed to gradually return to activity, as outlined in the Consensus Statement on Concussion in Sport[23] and reviewed by Guskiewicz and by Laker and Herring elsewhere in this issue. However, evidence shows that low-impact subthreshold exercise that does not exacerbate symptoms is safe and may be beneficial for adolescents with slow recovery after concussion.[24,25]

Concussion Education

Education about what to expect after concussion and strategies to deal with postconcussive symptoms seems to have a beneficial effect on outcome. Ponsford and colleagues[6] studied an educational intervention for 130 children with mTBI; 61 received a booklet outlining symptoms associated with mTBI, the likely time course of postconcussive symptoms, and coping mechanisms to deal with these symptoms, and 58 mTBI controls received traditional treatment. At 3 months after injury, parents in the mTBI control group reported that their injured children had significantly more postconcussive symptoms than those in the educational intervention group. Specifically, the education group had fewer complaints of headaches, sleeping difficulties, and problems with judgment than the control group. The control group also tended to report greater irritability, inattentiveness, and conduct problems than the intervention group. However, the proportion of children with "significant ongoing problems" requiring referral for additional assistance was similar in the intervention and control groups (21% vs 19%).

SUBACUTE SYMPTOMS OF CONCUSSION

Although the guidelines for concussion management apply to concussion and postconcussive symptoms in general, many athletes have one or two symptoms that are particularly problematic and disabling. This article discusses the evaluation and management of several of the most common subacute postconcussive symptoms. including headache, sleep disturbance, balance deficits, and emotional changes. Cognitive changes after concussion are of vital importance and are addressed in greater detail by Goia, Cantu, and Coppel elsewhere in this issue.

Headache After Concussion

Headache is one of the most common symptoms after concussion, reported by 72% to 93%[1,26,27] of children and teens with concussion or mTBI. Blinman and colleagues[26] found that 32% of children reported headache 2 to 3 weeks after mTBI. A study of concussions reported in the High School Reporting Information Online database, found that although more than 90% of high school athletes who experienced concussion reported headache initially, 83% had resolution of all symptoms within 1 week and only 1.5% reported symptoms lasting longer than 1 month.[27] However, in a prospective controlled study of mTBI in children aged 1 month to 18 years of age, Barlow and colleagues[1] found that 58% reported headache 1 month after injury and 9 of 670 children (1.3%) had chronic headache 12 months after injury.

Posttraumatic headache (PTH) is defined by the *International Classification of Headache Disorders: 2nd Edition* as a secondary headache that develops within 7 days of head trauma (or regaining consciousness after traumatic brain injury).[28] Criteria are based on severity of injury, latency from injury, and duration of the headache. No descriptions of headache localization, characterization, or accompanying features are used. Several studies in adult civilian and military populations have attempted to classify headache using primary headache criteria.[29] Although few studies have addressed the classification of pediatric PTH, adult studies of PTH have found that migraine and probable migraine accounted for approximately 57% of the population with headache at 3 months, whereas tension-type and cervicogenic headache accounted for 18% and 6%, respectively. Approximately 31% were unclassifiable using these criteria.[30] Given that PTH and the primary headache disorders share many similar characteristics, some investigators have postulated that the migraine and PTH may have common pathophysiologic mechanisms, but the mechanisms of both syndromes remains unclear.[31,32]

Women seem to be at higher risk of headache after mTBI than men, but this association was not found for younger girls (ages 6–17 years).[15,18] In another study, female sex was associated with higher number of total and somatic postconcussive symptoms 3 months after mTBI, but the authors did not mention headache specifically.[33] A study of high school athletes found that headache was reported acutely after sports-related concussion in similar numbers of boys and girls (95% and 97%, respectively),[15] and found a difference in the types of postconcussive symptoms reported by boys and girls, but no difference was seen in the number of postconcussive symptoms reported between boys and girls.

Although sex-related differences in risk of headache after concussion have not been studied in detail in children or adolescents, primary headache disorders such as migraine are more common in women than men, and the difference in migraine prevalence between men and women becomes pronounced around the time of puberty.[34] Thus, if similarities exist between migraine and PTH, adolescent girls may be at higher risk for significant headache after concussion than boys. One study of PTH in an adult population, women were more likely to report headache 1 year after injury (37% vs 18%; $P<.01$).[30]

Preexisting migraine is thought to be a risk factor for significant PTH in adults, and in a study of PTH in adults after complicated mild to moderate or severe traumatic brain injury, individuals with preexisting headaches were more likely to report headache at 3, 6, and 12 months after traumatic brain injury compared with those without preexisting headache (45% vs 19%; $P<.001$).[30] This relationship has not been explored after pediatric concussion. In addition, we believe that family history of migraine may be a risk factor for significant headache after concussion, because concussion may trigger or unmask an underlying headache syndrome or predisposition to migraine in vulnerable populations, but this relationship has not been well studied.

Postconcussive headaches are associated with significant disability for student athletes, and several authors have found lower performance on neurocognitive testing for concussed athletes with migrainous headache compared with those without headaches or with nonmigrainous headaches.[9,35] However, whether the headaches are a sign of a more severe concussion or are directly causing disability is difficult to determine. Migraine headaches after concussion are also associated with balance abnormalities[36] and prolonged recovery time.[11] However, even migraine headaches not related to concussion can affect testing performance, attention, and memory[37,38] and therefore severe headache after concussion, particularly when combined with the other sequelae of concussion, may lead to pronounced difficulties with concentration, attention, cognition, and school performance.

One of the most difficult questions facing providers is whether the occurrence of headache should limit the athlete's activities, particularly if the athlete experienced some headache before concussion. Current guidelines suggest that athletes with persistent headache or headache exacerbated by physical activity should not return to play,[23] and the American Academy of Pediatrics suggests that athletes with symptoms lasting 3 months or longer after concussion should consider prolonged time away from sports.[21] Although the optimal management of headache after concussion not affected by activity is less clear, these athletes are likely to be at substantial risk for developing more significant and prolonged symptoms if they experience another concussion.

Management of headache after concussion

Physical and cognitive rest is the mainstay of initial concussion management,[23] and education about postconcussive symptoms may help improve outcome,[6] but no other randomized controlled studies of the treatment of concussion-related headaches in youth have been performed. Certainly, typical strategies for headache management should be used, emphasizing maintenance of good hydration, regular sleep, regular meals, and avoidance of triggers and excessive stress. However, few firm guidelines exist for pharmaceutical treatment of these headaches in pediatric or adult populations, except that nonsteroidal anti-inflammatory drugs should not be used if hemorrhage is a concern, and therefore treatment practice varies widely.

Most athletes will not require aggressive management of headaches after concussion. However, when an athlete develops prolonged or disabling headaches related to concussion, active headache management with medications may be considered. Athletes who experience PTH must follow the typical lifestyle guidelines listed earlier for headache management. Evidence suggests that if symptoms do not improve within 4 to 6 weeks after concussion, providers may consider recommending low-impact subthreshold exercise, defined as a progressive low-impact aerobic exercise program that does not exacerbate postconcussive symptoms[24,25] (such as walking, slow swimming, or stationary biking, and **not** to be confused with active "return to play" exercise). This strategy seems to be safe and may be beneficial for adolescents with prolonged symptoms after concussion.[24,25]

Many providers use the primary headache characteristics of the PTH to guide treatment, and may try medications typically used for primary headache disorders to manage disabling or prolonged posttraumatic headaches. Once intracranial hemorrhage has been excluded through imaging or clinical parameters, use of ibuprofen, naproxen, and acetaminophen to control headaches in the first few weeks after concussion has been discussed.[39] Sumatriptan, a 5-HT1B/1D agonist postulated to block release of calcitonin gene-related peptide and other inflammatory neuropeptides, preventing neurogenic inflammation and causing vasoconstriction of dural-based meningeal arteries, has been used to successfully treat acute PTH.[40] However, patients and providers must set limits on use of over-the-counter analgesics, caffeine-containing compounds, opiates, and triptans to avoid the potential complication of medication overuse.

Physical therapy or massage therapy may also be helpful in the management of PTH, particularly in the presence of cervical muscular tenderness or strain. Biofeedback and behavioral therapies are often helpful in the management of adult and pediatric headache,[41,42] but this has not been studied in pediatric PTH. If patients have a chronic disabling headache with cervical or occipital tenderness, trigger point injections or nerve blocks administered by experienced providers in appropriate circumstances may be considered.

Many different medications have been used to help manage frequent PTH. Amitriptyline a tricyclic antidepressant, is one of the most commonly recommended by medical providers.[39] It is frequently used to treat primary headache disorders in children and adolescents and may help manage comorbid insomnia and sleep disruption in patients with concussion, although it may exacerbate excessive sleepiness and cognitive dysfunction. A few small studies in adults found that amitriptyline may be effective treatment for PTHs, but studies in children are lacking.[43] Topiramate is another commonly used medication for pediatric headache, and providers discuss its use in postconcussive headaches. However, concerns exist that topiramate may worsen concussion-related cognitive deficits in susceptible patients.

A small informal survey of pediatric headache specialists found that many medications are considered for the management of prolonged problematic headache after concussion, including amitriptyline, topiramate, magnesium, valproic acid, steroids, dihydroergotamine, gabapentin, propranolol, and selective serotonin reuptake inhibitors, although amitriptyline was the most commonly mentioned medication (American Headache Society: Pediatric & Adolescent Headache Section, personal communication of members of this group to H. Blume, 2011). This list of medications is similar to that outlined in a recent review of medical treatment of concussion.[39] In some refractory cases, a combination of therapies may be most effective. However, the choice of medication and therapy will depend on the patient's symptoms, history, and comorbidities. The use of daily medication to manage headache after concussion should only be considered by experienced and trained practitioners when an athlete has a disabling headache that is not following the expected course of improvement after concussion.

Sleep Disorders After Concussion

Complaints about sleep quality and quantity are frequent after concussion, as are complaints about fatigue, which may not be associated with poor sleep. A lack of restorative sleep may contribute to worsening of other postconcussion symptoms or disorders, such as headache, trouble concentrating, and depression.

A short review of sleep mechanisms can illustrate why sleep may be affected after concussion. Both sleep, defined as a natural and periodic state of rest during which consciousness of the world is suspended, and wake, defined as a state of alertness, are important concepts that have distinct neurophysiologic underpinnings. Normal sleep includes the states of sleep, defined by the presence or absence of rapid eye movements (rapid eye movement [REM] and non–rapid eye movement [NREM], respectively) and circadian rhythms. These aspects of normal sleep are different for children and adolescents compared with adults. In NREM sleep, muscles are not paralyzed and mental activity is fragmented, although dreaming is rare. Stage N3 of NREM sleep is characterized by deep slow wave sleep, and is when parasomnias such as sleep-walking most often occur. REM sleep is characterized by muscle atonia and dreaming, and comprises 20% to 25% of the sleep cycle.

The circadian rhythm is an approximately 24-hour cycle that, although regulated internally, is highly responsive to external stimuli such as light and is independent of prior sleep/wake duration. In addition, sleep has a homeostatic aspect, in that the longer one is awake, the sleepier one becomes. Conversely, the longer one sleeps, the less "pressure" they have to remain asleep. Areas of the brain that are key for initiating and maintaining sleep include the suprachiasmatic nucleus in the hypothalamus (affecting pineal gland secretion of melatonin) and the brainstem areas (eg, laterodorsal tegmental and pediculopontine tegmental nuclei, dorsal raphe nuclei, nucleus locus ceruleus). Wakefulness also is affected by the dorsal raphe and locus ceruleus and by neurons located in the lateral hypothalamus, projecting to the brainstem and forebrain areas that secrete hypocretin, a peptide that promotes wakefulness and inhibits REM sleep.

Sleep is essential to normal cognition, and disordered sleep can result in further impairment of cognition after concussion. During wakefulness, the brain can actively interact with the external world, accumulating information and experience. In NREM sleep, the brain is actively "off-line," and investigators believe that repetitive activity recorded as spindle and K complexes on electroencephalogram may be a reiteration of inputs that enhance memory consolidation. During REM sleep, the brain is reactivated with different patterns of regional blood flow and microchemistry that integrate recently stored memories with other stored memories during the dreaming process. Areas particularly activated with dreaming include the ventromedial and dorsolateral prefrontal cortex, the anterior limbic structures, and the inferior parietal and visual association areas in the posterior cortex.

Sleep characteristics change normally as children grow. Adolescents have the greatest rate and number of changes. Overall need for sleep decreases by a few hours, but the need for REM sleep remains the same. As puberty progresses, a change in circadian rhythms occurs with later onset of sleep. Latency of sleep often decreases and there is more perception of sleepiness. Sleep disorders in children may be associated with disordered nighttime breathing, external social influences, depression, academic challenges, impaired attention, and mood disturbances.[44]

Approximately 30% to 60% of persons complain of disordered sleep after traumatic brain injury, including insomnia, hypersomnia, respiratory associated disorders, and circadian rhythm disorders. Insomnia is defined as difficulty initiating or maintaining sleep for at least 1 month accompanied by subjective impairment in daytime functioning. Ouellet and colleagues[45] reported that 50% of persons with traumatic brain injury reported insomnia symptoms and almost 30% met criteria for insomnia syndrome. Among the cases of insomnia, 60% were severe and chronic. Factors associated with this included mTBI, fatigue, depression, and pain. Fichtenberg and colleagues[46] reported insomnia in similar proportions of hospitalized patients with traumatic brain injury. Sleep disorders seem to be more common among patients with moderate to severe traumatic brain injury than among uninjured controls, with 80% complaining of insomnia symptoms compared with 23%, respectively.[47] These symptoms seem to be long-lasting; those with persistent insomnia complaints also had greater neurobehavioral impairments and worse occupational outcomes.[48] Although fatigue is a common complaint among those with traumatic brain injury, it is likely to be multifactorial, with insomnia, pain, depression, and cognitive effort all contributing to the perception of fatigue.

Sleep apnea may also be more common after traumatic brain injury. For patients in an inpatient rehabilitation unit, disordered respiration was more common (36%) than would be predicted by age norms.[49,50] Studies using polysomnography have produced mixed results, with some finding discrepancies between self-reports of sleep disturbance and polysomnographic findings. Circadian rhythm disturbances are often misinterpreted as insomnia. Ayalon and colleagues reported that 15 of 24 patients with traumatic brain injury and complaints of insomnia actually had circadian rhythm sleep disorder.[51] Complaints of daytime sleepiness may be associated with low hypocretin levels.[52,53]

Few studies describe sleep in children and adolescents after sports-related concussions or other types of mTBI. After mTBI, children ages 12 to 17 reported that excess sleep was the most common postconcussive symptom in the postacute period (36%), whereas difficulties falling asleep were the most severe symptom.[27] However, for children and adolescents with mTBI, polysomnographic findings are mixed. In one study, reports of sleep difficulties did not correlate with polysomnographic findings.[54] Another study described lower sleep efficiency, more awakenings, and more wake time in adolescents with mTBI.[55]

Management of sleep disorders after concussion

Management of sleep disorder can be particularly challenging in adolescents with concussion. The disorder must be defined first to ensure that associated factors, such as pain, depression, or respiratory disorders, are addressed. Inquiring about pre-injury and family sleep patterns is also useful. A sleep diary may be helpful to outline prebedtime activities, use of caffeine or alcohol, and the sleep environment. No specific interventions have been well studied for sleep disorders after concussion. However, it is reasonable to first address sleep hygiene, including banning television or computer use before bedtime, restricting caffeine use, and encouraging aerobic exercise during the daytime and a dark, quiet sleep environment. Ouellet and Morin[56] successfully used cognitive–behavioral treatment in a small group of persons with traumatic brain injury to improve sleep efficiency and reduce symptoms of fatigue. Graduated bedtime/wake time adjustments, the use of melatonin, and bright light therapy may be useful in circadian rhythm sleep disorders. Caution is highly recommended regarding the use of sedative-hypnotics in children and adolescents to treat insomnia (**Table 2**).

Balance Disturbances After Concussion

Balance disturbances are common immediately after concussion at all ages. Disordered balance after concussion has several potential causes, including central and peripheral mechanisms. However, most data exist for college-age athletes, and very few studies address younger children. None of the current balance screens used for postconcussion testing have been normed for children younger than 16 years, and children do not reach adult levels for visual and vestibular afferent function until approximately age 15 to 16 years.[57,58]

Table 2
Comparative normal sleep characteristics for children and adolescents

	Sleep Stages	Required Number of Hours	Awakenings	Sleep Difficulties
Children (ages 5–12 y)	—	Age 5 y: 11 Age 12 y: 9.5	2	20%–41% (parasomnias: chronic in 1%–6%; bedtime resistance)
Adolescents and teens	Decreased stage 3/4 non–rapid eye movement sleep	9–10	—	Increased sleepiness, excessive somnolence, increased sleep latency, awakenings, movement during sleep, delayed sleep phase disorder (7%)

Data from Millman RP. Excessive sleepiness in adolescents and young adults: causes, consequences, and treatment strategies. Pediatrics 2005;115(6):1774–86; and Carno MA, Hoffman LA, Carcillo JA, et al. Developmental stages of sleep from birth to adolescence, common childhood sleep disorders: overview and nursing implications. J Pediatr Nurs 2003;18(4):274–83.

College-age football players return to normal levels of balance within 5 to 10 days.[59,60] Persons with mTBI have increased reliance on visual inputs for balance and are less able to use vestibular orienting information on balance testing.[61] As with many other features of concussion, college-age players with slower symptom resolution also show more persistent signs of postural instability.[62] In addition, as noted earlier, college athletes with persisting posttraumatic headache had worse scores for balance and other physical tests after concussion.[36]

Few studies of younger children after concussion or mTBI exist. Gagnon and colleagues[63] noted that children with mTBI (with a mean Glasgow Coma Score of 14.8) without persisting balance complaints showed abnormalities on postural testing compared with controls. These findings were particularly notable during testing when vision was occluded and for postural tasks requiring higher levels of coordination. In fact, other authors have noted that postural stability testing may be more sensitive if the athlete is concurrently performing a cognitive task.[64]

Children with persisting balance disorders after concussion seem to respond to vestibular rehabilitation treatment, as do adults.[65]

Cognitive Symptoms After Concussion

The risk of subacute and long-term cognitive deficits associated with sports-related concussion is one of the most concerning topics for athletes, parents, providers and researchers. Cognitive symptoms such as slowed processing speed, memory impairment, poor attention, and confusion are common after concussion. Detailed neuropsychological testing often shows mild deficits even after athletes feel they are back to baseline, providing evidence for the value of including baseline and post-injury neurocognitive assessment in the complete assessment of the concussed athlete. In addition, athletes with a history of two or more prior concussions have lower scores on baseline testing than those without concussion,[10] although whether those with lower scores are more prone to concussion or if multiple concussions lead to poorer scores on testing is unclear. Given the significance of questions regarding subacute and long-term cognitive assessment and cognitive change after concussion, these complex questions are addressed in greater detail in three different articles by Goia, Cantu, and Coppel elsewhere in this issue.

Treatment of cognitive deficits after concussion may involve modification of school expectations for several weeks or even months, and support from teachers, school counselors, and family (see the article by Goia elsewhere in this issue). Fortunately, most athletes do not experience significant long-term cognitive deficits after a single concussion. However, the individuals who do experience long-lasting symptoms may benefit from consideration of further therapy. Small trials examining the use of stimulants, such as methylphenidate, after pediatric traumatic brain injury have shown equivocal results.[39] The use of amantadine to improve cognitive function has also been studied after more significant traumatic brain injury. However, the risks of these medications generally far outweigh the possible benefits for most children and adolescents with sports-related concussion.

Mood After Concussion

Athletes may develop emotional dysregulation after concussion and experience irritability, sadness, and emotional lability. Athletes who experience prolonged symptoms after concussion are at risk for mood or behavioral changes for many reasons including: a direct result of their concussion, difficulty coping with other symptoms, restriction from participation in their sport (either temporarily or permanently), modification of future plans that centered on athletics, and the loss of identity as an athlete.

Complaints of mood changes after concussion are common. Barlow and colleagues[1] report that at 1 month after injury, 60% of children with mTBI were more emotional and 58% were more irritable than baseline. In the acute period after pediatric mTBI, Blinman and colleagues[26] described complaints of sadness in 34% of children, nervousness in 44%, irritability in 40%, and feeling more emotional in 41%. A few weeks after mTBI, fewer children had emotional symptoms, including sadness in 19%, nervousness in 22%, irritability in 30%, and feeling more emotional in 25%.

In studies of adults with mTBI, those with depression or anxiety and mTBI have more postconcussive symptoms and tend to have longer duration of symptoms than those without these comorbid factors.[66,67] However, Taylor and colleagues[7] did not find a significant correlation between mTBI and emotional postconcussive symptoms, but did find a correlation between emotional postconcussive symptoms and preinjury emotional distress. Depression and anxiety in the absence of traumatic brain injury are also often associated with symptoms reported on the postconcussion checklist, including cognitive complaints, somatic complaints, and sleep disturbance. Thus, although depression or other mood changes after concussion should be addressed, some of these complaints may be related to preinjury factors in addition to factors associated with the concussion.

For most athletes, significant emotional dysregulation after concussion is short-lived and should be addressed with discussion of coping strategies, understanding and support from family and friends, and counseling with a trained therapist if needed.[39] However, occasionally these athletes may benefit from medical management of their symptoms with an experienced medical provider, particularly if other factors are contributing to their emotional symptoms, such as prolonged absence or retirement from sports or other preexisting emotional problems or family issues. Although no trials of medication or other therapy for depression related to concussion in children or adolescents have been performed, tricyclic antidepressants and serotonin reuptake inhibitors have been recommended for treating depression related to traumatic brain injury in adults.[39] However, medical management of emotional problems after concussion should only be considered by an experienced provider when the symptoms are not following the expected course of improvement.

SUMMARY

Fortunately, most youth do not experience prolonged somatic, cognitive, or emotional symptoms after sports-related concussion. However, current evidence indicates that younger athletes may have a longer recovery period than collegiate athletes, and that females may have a higher risk for more significant postconcussive symptoms than males. Given that millions of athletes experience concussions annually in the United States, if even a small fraction of concussed youth have prolonged or disabling subacute postconcussive symptoms, then thousands of young athletes and their families must deal with symptoms that interfere with critical academic, cognitive, and social development each year. Further rigorous research is essential to determine which athletes are at greatest risk for disability after concussion and to develop treatment strategies to minimize disability and promote a full recovery in children and adolescents after concussion.

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