Updates and Evidence Concerning Concussion in the Physically Active Population

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The definition of concussion has evolved dramatically over the past 50 years. Despite this progression, there is still much discussion over the precise definition for this complex injury. Many early definitions and severity grading scales implied that loss of consciousness (LOC) was the primary indicator of concussive injury and severity. However, recent evidence highlights that LOC is not an indicator of concussion and recommends avoiding the use of a grading scale and to wait until the concussion has resolved to assign an injury severity level (1). More recent data suggests that LOC is not strongly correlated with recovery, neurocognitive deficits, or symptom severity following concussive injury (20,34,49). The role of amnesia is controversial. Recent research suggests amnesia is related to neurocognitive and symptom deficits following an injury (20,24,49). Over the past 10 years, the data suggests that only 9% of individuals presenting with concussion experience LOC and only 23% experience post-traumatic amnesia (PTA) (6). Following recent advancements in concussion research, new grading scales and return to play guidelines now account for the duration of signs and symptoms (9,10,11,24,42). Many sports medicine groups have also developed consensus statements in an effort to help standardize and clarify the management of these injuries (1,29,56).

With this in mind, the most comprehensive and widely accepted definition emerged from the Concussion in Sport's consensus statement on concussion (57). This definition states: "Concussion is a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces." This definition includes specific features of concussion and was one of the first to outline the factors unique and specific to concussion and to highlight concussion as a functional injury versus a structural injury. Furthermore, it provided a consensus definition that was acceptable and useful across various medical disciplines.

Epidemiology of Concussion

Despite being a common injury, traumatic brain injury (TBI) is one of the most burdensome public health problems across the United States. Traumatic brain injury results in an estimated 1.22 million emergency department visits, 290,000 hospitalizations, and 51,000 deaths each year (78). The disabilities following concussion can lead to many problems that decrease quality of life and include emotional, physical, academic, cognitive, and social deficits. An estimated 1.6 to 3.8 million sports-related brain injuries occur each year, according to the Centers for Disease Control and Prevention, with the majority of these injuries being mild in nature (45). More recent reports suggest concussion alone accounts for up to 14% of all injuries occurring in sport (60). Among high school athletes, it is estimated that more than 700,000 concussions occurred from 2005 to 2010, with 13% of these injuries being recurrent or subsequent concussions (13). Across all ages, concussion rates are highest in football and soccer, but it should be noted that concussions occur in all sports and activities (27). Gessel et al. (27) observed that the rate of concussion was higher in practices than in games or events.

Recent studies also suggest that females may be at greater risk for concussion than male athletes, specifically among female soccer and basketball athletes (22,27). Very few explanations for these gender differences have been examined. However, with the possibility of a large number of concussions being unreported, this finding is difficult to generalize because females are more likely than males to seek medical care and report symptoms of many medical conditions (23,83,84). Covassin et al. (22) also inferred that female athletes sustain a higher percentage of concussions during games than males. Overall, the literature is consistent that in male and female matched sports, females have a higher incidence of concussion. Additionally, recent publi-

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cations indicate that in similar sports, females' risk of concussions is almost twice that of males (46).

Because there is no gold standard of diagnosis for concussion, quality epidemiologic data can be difficult to obtain. One of the major issues involves the definition of concussion used in various studies. Many of the early epidemiologic studies only included concussions resulting in LOC, which resulted in estimates as low as 300,000 sports-related brain injuries each year (82). Other studies, such as Gessel et al. (27), defined injury more broadly, thus leaving less laterality over what would be considered a concussion. In many cases—specifically milder concussions—these injuries must be reported by the athlete and thus may only be reported in about 50% of those who experience a concussion (53). Also, much of the information pertaining to the epidemiology has come from schools with access to a certified athletic trainer, which may also influence results of these studies. Lastly, identifying a concussion can be difficult because many of the signs and symptoms may overlap with other conditions and may be influenced by hydration level, fatigue, and the time of season with respect to training status (39,46,85).

PHYSIOLOGY AND EFFECTS

Pathophysiology

The pathophysiology of concussion may be a reason why concussion is difficult to assess and understand. Concussion is a diffuse injury, resulting in a variety of signs and symptoms that often differ with each individual concussive incident. This diffuse injury is functional and not structural in nature, leading to the difficulty developing a gold standard for diagnosis. Concussion does not result in abnormal neuroimaging on standard measures (61,80), such as magnetic resonance imaging (MRI) and computed tomography scans (CT). As a result, concussion is often undiagnosed by traditional measures. Concussion often results from acceleration-deceleration forces transmitted through the brain. From these forces, coup (same side) and/or contrecoup (opposite side) injury may result. These forces produce a complex neurometabolic cascade of events, leading to a variety of signs and symptoms of concussion.

This cascade is characterized acutely following injury as an abrupt, indiscriminant release of neurotransmitters and unchecked ion influxes. There is then neuronal depolarization with an efflux of potassium and an influx of calcium to the injured area, which all lead to ionic shifts resulting in changes in cellular physiology and function. During this time the sodium-potassium pump works beyond a normal limit, which requires increased ATP supply and use. This increase triggers a dramatic jump in glucose metabolism, which occurs in the setting of decreased cerebral blood flow. The subsequent disparity between glucose supply and demand triggers an energy crisis. This mechanism is thought to be the cause of the post-concussive vulnerability (28). Following this cascade, the concussed brain then goes into a phase of reduced metabolic rate. Increases in calcium may impair cell function and worsen the energy crisis. Unchecked calcium accumulation may also lead to cell death. Although the majority of what is known regarding the neurophysiology of concussion comes from animal studies, new functional imaging techniques are providing additional insights, which are paralleling these findings in humans (16,50,68).

Signs and Symptoms of Injury

This neurometabolic cascade results in a variety of signs and symptoms in individuals following concussion. The most common symptom of concussion is headache, occurring in up to 96% of concussed individuals (32,35,72). However, headache is also common in nonconcussed and various types of headache (e.g., migraine) can result in signs and symptoms similar to those of concussion, often making it difficult to identify the source of headache in an athlete (36,43,44). The major determining factor is often a mechanism of injury that could result in a concussion. Second to headache, dizziness and confusion are the most common of the post-concussion symptoms (34).

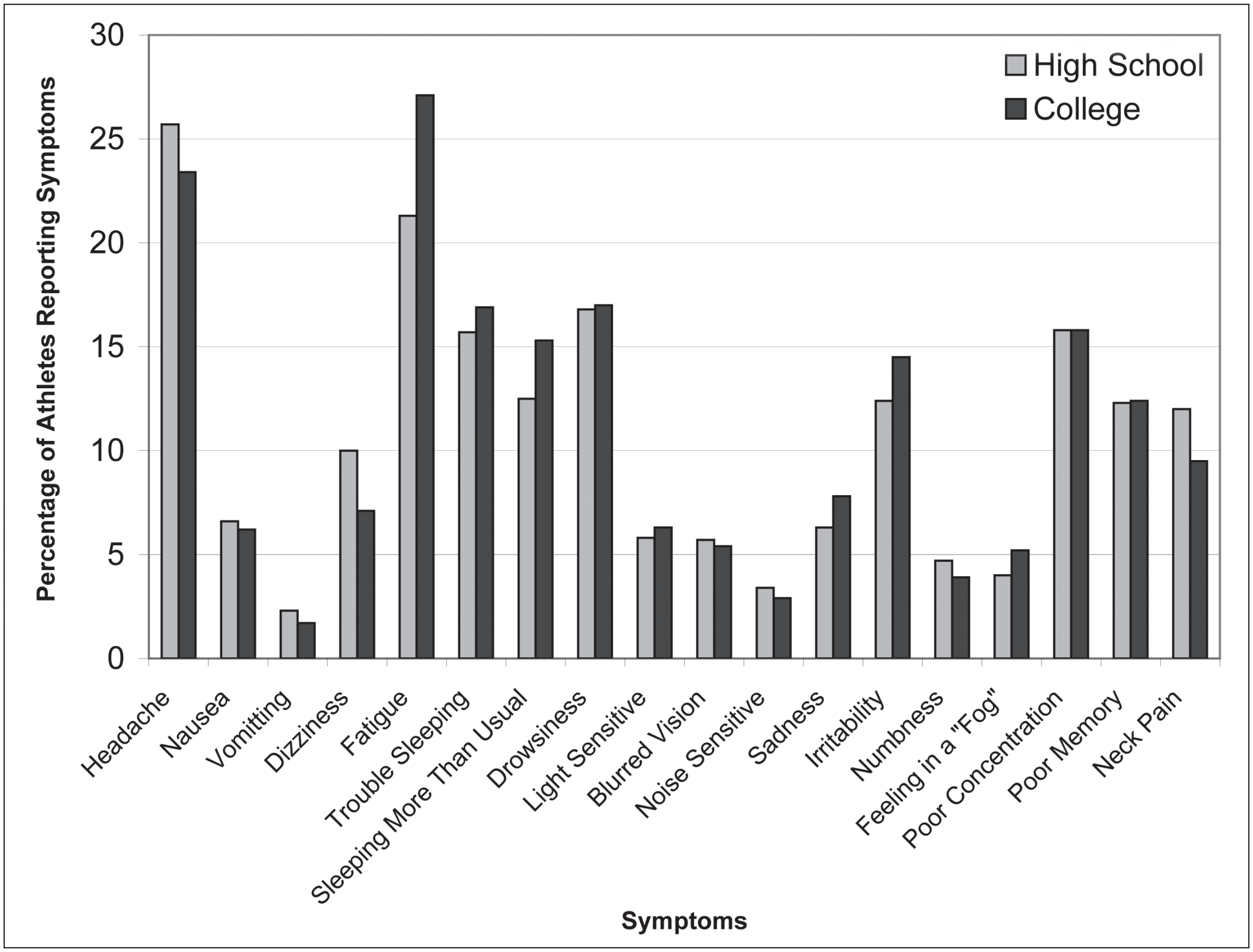
Many post-concussion symptoms resemble such conditions as depression (39), fatigue (87), and dehydration (64). The base rates of many post-concussive symptoms are relatively high in healthy, normal individuals (20) (Figure 1). Some of the most frequently stated symptoms include headache, fatigue, longer time to think, poor concentration, sleep disturbance, and irritability (38,85). In some instances, athletes may have a difficult time associating these signs and symptoms with a concussive injury, making it even more important for individuals assessing athletes to recognize the signs and symptoms of a potential concussion.

The signs and symptoms of concussion may present in a variety of combinations and change in presence and severity during the recovery phase following a concussive injury. In approximately 20% of concussed individuals, there is a delayed onset of symptoms in which these increase in number and severity at around 48 h post-injury (52). Also, athletes with delayed onset may be more likely to report the concussion only once the symptoms worsen. This can be alarming because a more severe brain injury, such as a subdural hematoma, may also present in this manner, and continuing to compete with a possible brain injury may place an athlete at risk to incur a subsequent and possibly more severe and even deadly injury (3,47).

Signs and Symptoms During Recovery

Most studies examining recovery following sports-related concussion have examined short-term recovery on symptoms, balance, and/or neurocognitive measures (19,26,34,72,77). Many of these studies compare subjects to their own baseline measures and/or to a control group in order to investigate the time period of recovery from concussion. From the combined results of these studies, most individuals return to baseline symptom levels, baseline neurocognitive performance, and baseline balance performance within 7 to 14 d post-injury (52). Balance typically recovers between days 3 and 5 post-injury (33,34,76), with symptoms often returning to normal between 7 and 10 d (24,34).

FIGURE 1. Baseline symptom presence of common post-concussive symptoms in high school and college athletes.



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Neurocognitive measures also have recovery time frames in this range of 7 to 14 d. However, one recent study demonstrated that 38% of individuals in the sample still displayed deficits in at least one neurocognitive area in which they once reported as asymptomatic following the concussion occurrence (6). These recovery times may be affected by a variety of factors, including age (26,62), previous concussion history (21,32), and management of previous injuries. However, novel and sophisticated assessment measures, such as nonlinear assessments of balance, electrophysiological findings, and functional neuroimaging, have observed deficits at 30 d or greater after the concussion occurrence (14,67,81). These recent findings are suggestive that more sophisticated measures are needed in the assessment of concussion in conjunction with an understanding of these deficits on patient function in acute and long-term settings.

Long-Term and Cumulative Effects

Recent research has focused on the long-term effects and outcomes following concussion. Some studies, using retired professional football athletes, suggest that clinical depression, mild cognitive impairment, and overall decreased quality of life may all be consequences of multiple concussions. This is particularly the case if one has had 3 or more concussions (30,31). In high school athletes, individuals with a history of multiple concussions report decreased grade point averages (62) and increased onfield severity of subsequent injuries (21). The presence of headache on a regular basis is also associated with previous history of concussion in high school and college-aged athletes with a history of 3 or more concussions. These individuals are more than 3 times likely to experience headache on a regular basis (72). Although these studies are important because they indicate the risks of sustaining multiple concussions, many of them were based on a small number of subjects with repeat injuries. Despite these limitations, each of these consequences can lead to a decreased quality of life at a young age. This is related to decreased school success and possible lasting symptoms. Many individuals may not realize these consequences and continue to choose to not report possible concussions to someone in an authoritative position because younger athletes may feel they are invincible to these effects.

One of the few prospective studies followed people for 5 to 7 yr following concussion and found that individuals who had suffered a concussion reported more post-concussive symptoms and decreased health-related quality of life compared with matched controls. This occurred out to 7 yr after the brain injury (40). This study reveals possible long-term effects of mild concussions. Reports also suggest that overall outcome may be related to an individual's perception of the negative consequences of the concussion and symptoms (86). However, Ettentopher et al. (25) suggested that a single concussive incident may have little to no effect on overall outcome. This finding is consistent with the sport concussion literature suggesting a significant difference in recovery between individuals with 3 or more concussions compared with those with 1 or 2 concussions or even no previous history of concussion (21,30,31,32). However, individuals who have suffered a concussion are more likely to suffer subsequent concussions (88), especially within the first seven days after the injury (32).

Children with such injuries as intracranial bleeds or other structural injuries in addition to concussion may be more likely to experience mild neuropsychological impairment throughout life compared with adults who experience the same injury. It is also suggested that the best predictors of long-term neuropsychological outcome are length of post-traumatic amnesia (PTA) and EEG activity within 24 h of injury (37). In cases of an impact occurring while the brain is in a vulnerable condition, second impact syndrome (SIS) may result. Second impact syndrome occurs when the brain loses auto-regulation of blood flow; extreme intracranial bleeding occurs and results in 50% mortality and 100% morbidity (2,8,12,68). Second impact syndrome is not agreed upon across the medical community, as some clinicians and researchers question the diagnosis (58,59). Another term used for this type of event is malignant cerebral edema (58). The argument behind this terminology is that a SIS does not have to occur for the type of lack of autoregulation of blood flow leading to catastrophic outcomes to result (58). However, a growing number of cases suggest it to be a rare but realistic phenomenon isolated to young athletes (17,75).

More recently, discussion has focused on not only long-term concussion effects but also multiple impacts to the head, also known as chronic traumatic encephalapothy (CTE). This neurogenerative disease is often noted in those who were former boxers, football players, wrestlers, and ice hockey athletes and is characterized by a diffuse tauopathy with tauimmunoreactive neurofibrillary tangles and neutropile threads (4). This degeneration is associated with judgment impairment, memory loss, confusion, issues with impulse control, aggression, and depression. Eventually, this can progress to dementia. Recommendations from these early findings are to limit exposure to head impacts over a person's lifetime. More research is needed to determine the true cause and effect relationship between head impacts and SIS.

ASSESSMENT AND MANAGEMENT OF CONCUSSION

Assessment of concussion can be a difficult task because there are many clinical assessment items to consider and symptoms are based on self-report from the individual. The recommendation for those diagnosing and managing concussions is that these individuals should be medical professionals trained in concussion management and that individuals suffering concussion should follow up with a physician through the course of their injury recovery (1). Current literature and experts suggest a comprehensive approach by using a clinical evaluation, a symptom assessment, a balance assessment, and a neurocognitive assessment.

Broglio et al. (7) found that using a combination of a symptom checklist, a balance assessment, and a neuropsychological test yields a concussion diagnostic sensitivity of more than 90%, while neuropsychological testing alone is only around 79%, symptom assessment 68%, and balance assessment only 62% sensitive. Using this compilation of assessment tools may lead to a more complete clinical profile and may in turn help clinicians make better, more informed decisions surrounding post-concussion management and return to play. If measures are not used in combination, many concussions may go unrecognized. This is likely an important contributing factor to the large number of unidentified concussions in the high school athlete. Furthermore, the overall clinical evaluation, including the patient history and observation by the clinician, is an important component in this multifaceted approach to concussion assessment, and it should not be neglected.

Symptom Assessment

A symptom checklist is one of the most commonly used clinical measures in the assessment of concussion. Approximately 75% of certified athletic trainers employ some form of a symptom checklist in the evaluation of concussion (63). A symptom checklist is used in various studies and shown to be a valid and reliable clinical tool (48,51,65,66). Studies suggest a symptom checklist is reliable and valid when administered by the clinician and across age groups from children to adults (48,51). These symptom checklists typically include such symptoms as headache, fatigue, neck pain, and drowsiness. It is noteworthy that these symptoms are also commonly experienced on a regular basis by healthy individuals (85). This reinforces the need for an accurate assessment of symptoms pre- and post-injury. These checklists allow for the monitoring of the presence and severity of symptoms throughout the clinical pathway following injury. Table 1 presents the symptoms most commonly included in these checklists.

Neurocognitive Assessment

Neurocognitive assessment has risen to the forefront of concussion evaluation over the past 15 yr (5,6,15,18,19,20,34) by providing objective assessments of cognitive function for use by clinicians. Neurocognitive measures range from

TABLE 1. Common post-concussive symptoms.

• Headache	• Sensitivity to light
• Nausea	• Sensitivity to noise
• Emesis	• Increased sadness
• Balance problems	• Nervousness
• Dizziness	• Feeling more emotional
• Fatigue	• Numbness or tingling
• Trouble falling asleep	• Feeling slowed down
• Sleeping more than usual	• Sensation of being “in a fog”
• Sleeping less than usual	• Difficulty with concentration
• Drowsiness	• Difficulty with memory
• Irritability	• Visual problems

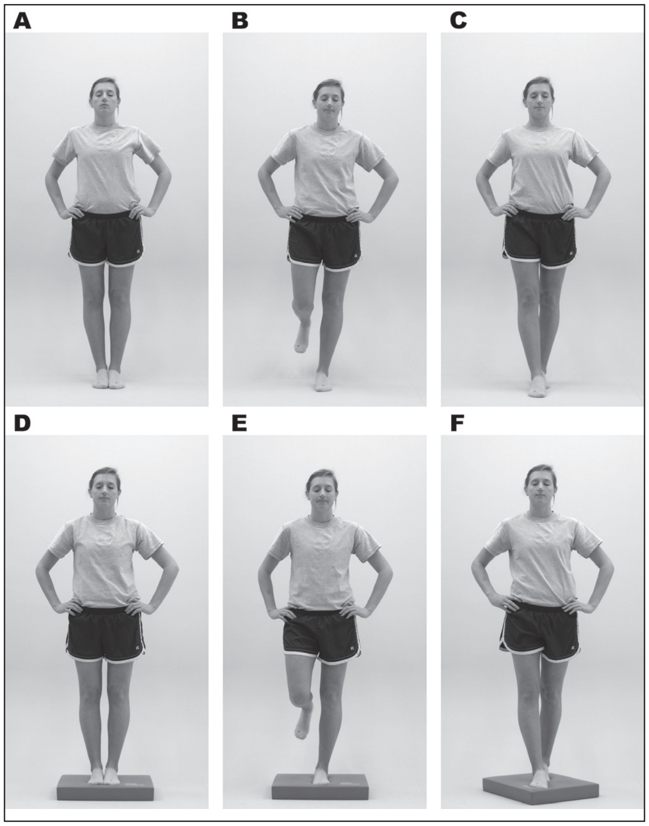
simplistic to complex computerized measures. Some of the most common simple cognitive tasks include 3-word recall, delayed recall, “serial 7s” (i.e., counting by 7s), and reciting months of the year backward. One other quick cognitive tool is the Standardized Assessment of Concussion (54,55) that was designed as a sideline assessment tool of mental status. Although it is not a neuropsychological test, it can give a more objective measure of mental status or basic cognitive functioning than other testing measures.

Recent literature questions the utility of many of the computerized tests and batteries due to low reliability and limited psychometric research (69,70,71). Much of this research centers around computerized neurocognitive batteries, which have such advantages as quicker testing times, less training needed for administration, and more accurate reaction time assessments. However, these computerized testing programs have disadvantages in that they can be costly, issues outside of the concussion can dramatically influence scores, and trained individuals, such as a neuropsychologist, are needed to accurately interpret the results. Furthermore, recent literature has raised the question of the utility of baseline assessments on these measures and considerations of age and sex matched normative values (79). Nonetheless, these tests may provide valuable information following possible injury. Many consensus statements have recommended the use of some form of neurocognitive assessment into the evaluation of concussion (1,29,56). These measures, as with all others, should be considered a piece of the evaluation process and should not be used as the sole determinant of concussion recovery.

Balance Assessment

Balance assessment is also recommended as a component in a concussion assessment program. Like neurocognitive testing, there are many methods to assess balance. These range from a simple Romberg test to computerized forceplate measures (34,41). There is also a clinical field test—the Balance Error Scoring System (BESS)—that offers a reliable, inexpensive, and objective methodology to assess balance on the field following a possible concussive injury (75). During this assessment, the athlete performs six trials consisting of three different stances performed on a firm surface and a foam surface. The stances are the double leg, single leg (on the stance leg), and tandem (with the stance leg in the back) stances (Figure 2). Errors are recorded if the individual lifts his or her hands off his or her iliac crest, abducts or flexes his or her hip to greater than 30 degrees, steps, stumbles or falls,

FIGURE 2. Balance error scoring system (BESS) stances.



opens eyes, lifts toes, or remains out of the testing position for more than 5 s. A higher error score indicates a greater deficit in postural stability.

Due to individual variability, baseline measures are important to determine the severity of deficit following injury (74). Although the BESS and/or other postural stability tests provide a valuable piece of information regarding deficits following a concussive injury, it should be used in conjunction with other clinical assessment measures. More recent literature suggests the use of divided attention tasks to assess postural control in the presence of a cognitive task. This body of literature is continuing to grow and support the concept of these types of tasks in the functional assessment process.

Return to Activity

In 2008 (published in 2009), the International Concussion in Sport group produced a set of return to play guidelines that focused on a graduated return to full physical activity following a concussion. The first component of the graduated return is that the individual be symptom-free prior to initiating any physical activity and then follow a slow, controlled, and supervised (by medical personnel) return to activity by beginning with light exercise and progressing to full return to contact or effort if a noncontact sport. Although no actual evidence exists on how to best return individuals into such cognitive activities as school or work following concussion, groups are beginning to discuss the development of such protocols and are working on developing a body of evidence to support physical and cognitive rest with a graduated return to physical and cognitive activity during the post-concussion period.

ADVANCES IN PREVENTION AND MANAGEMENT

Recently, there has been a dramatic increase in the overall public awareness concerning concussion with advancements from the Centers for Disease Control and Prevention, organizational mandates, and state laws concerning concussion awareness and management. These advancements resulted in policy changes at many levels (Table 2), highlighting the importance of concussion education, emergency event planning, no return to participation on the same day of injury, and proper evaluation in the event of a suspected concussion. However, there is little data about how these recent advancements have impacted outcomes of injury occurrence. Additionally, new equipment technology, such as redesigned helmets and real-time head acceleration measurement devices, have come to the forefront of discussion on prevention and understanding of the injury.

SUMMARY

With the recent attention on concussion, new advancements are occurring each year. Future directions that will benefit the treatment of those who have suffered a concussion include a better understanding of the role of medications in treating/managing concussions, the role of rehabilitation following concussion, the impact of return to cognitive and physical activities too soon, and better diagnostic and prognostic indicators for concussion. In addition, a better understanding of how behavior modifications and changes in equipment design may impact prevention and outcomes is needed. At present, the emerging consensus from experts and the literature is that no individual should return to activity the same day as suffering a concussion. They should also not return to physical activity until symptoms from the concussion have resolved and they are cleared by a medical professional to return to cognitive and physical activities. An individual's concerns as well as his or her signs and symptoms must be strongly assessed and considered when making recommendations for return to cognitive or physical activity following concussive injury.

TABLE 2. States with concussion legislation in place as of December 2012.

• Alabama	• Missouri
• Alaska	• Nebraska
• Arizona	• Nevada
• California	• New Hampshire
• Colorado	• New Jersey
• Connecticut	• New Mexico
• Delaware	• New York
• District of Columbia	• North Carolina
• Florida	• North Dakota
• Hawaii	• Ohio
• Idaho	• Oklahoma
• Illinois	• Oregon
• Indiana	• Pennsylvania
• Iowa	• Rhode Island
• Kansas	• South Dakota
• Kentucky	• Texas
• Louisiana	• Utah
• Maine	• Vermont
• Maryland	• Virginia
• Massachusetts	• Washington
• Michigan	• Wisconsin
• Minnesota	• Wyoming

Adapted from KnowConcussion [Internet]. The Center for Sports Concussion at Idaho State University. Concussion legislation in the USA [cited 2013 Feb 7]. Available from: http://www.knowconcussion.org/resource/concussion-legislation-map/

Keywords: brain, injury, head

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