ELSEVIER

Seminars in
Pediatric
Neurology

The Role of Neuropsychology in the Evaluation of Concussion

Neal McGrath, PhD,[*,†] and Janelle Eloi, MA[*,†,‡]

Neuropsychologists play an important role in the clinical evaluation of many children and adolescents who have sustained concussions. This paper discusses clinical approaches and concerns in conducting neuropsychological evaluations of middle and high school aged students during the acute, subacute, and more chronic phases of concussion recovery. Issues of baseline testing and validity assessment are reviewed. Typical clinical recommendations arising from the neuropsychological evaluation are outlined, with an emphasis on the relationship between test findings and common academic accommodations.
Semin Pediatr Neurol 30:83-95

Introduction

Neuropsychology has been at the forefront of developments in the clinical assessment of mild traumatic brain injury (mTBI)/concussion as focus on these injuries has received increasing public and professional attention over the last 2 decades.[1-6] While much of the research and clinical practice in this area has grown out of evaluation and treatment of sports-related concussion, advances in assessment and management of cognitive and psychological aspects of recovery are applicable to the full range of patients suffering from this level of brain injury.

Clinical practice and research have led to the recognition that concussion may manifest in a variety of ways, which may necessitate the involvement of various members of an interdisciplinary clinical team for different patients. While most concussion patients have uncomplicated recoveries in 1-2 weeks, *"For the remaining 15%-20% with persistent symptoms, guidelines for management have not been established. Historically, patients complaining of persistent symptoms such as headache, dizziness, imbalance, fogginess, and difficulty concentrating have been lumped together as a suffering from PCS (post-concussion syndrome), a unifying diagnosis with no available treatment."*[7].

Emerging models of concussion diagnosis and treatment have proposed that postinjury dysfunction presents in various domains, the understanding of which can much more effectively guide patient care. Collins et al[3] have presented the first comprehensive model, outlining trajectories of evaluation and treatment that include headache/migraine, cognitive deficits, psychological distress (particularly anxiety and/or depression), vestibular dysfunction, oculomotor deficits, and cervical trauma associated with headaches. A subsequent model by Ellis et al[7] similarly identifies vestibulo-ocular dysfunction and cervicogenic symptoms but also identifies a range of exertion-related symptoms thought to be associated with persistent alterations in cerebral metabolism. They, too, recognize the prevalence of post-traumatic mood disorders and the development of migraine headaches as potential clinical concerns. It is incumbent upon each member of the clinical team to recognize the typical presentation of symptoms within these domains in order to be able to identify referrals potentially needed to address each patient's unique constellation of symptoms.

As a member of the clinical evaluation team, the neuropsychologist brings expertise in the areas of cognitive and psychological assessment, along with an understanding of the potential impact that symptoms in other domains may have on a patient's neuropsychological presentation and the ways in which postconcussive cognitive dysfunction and mood changes may in turn affect the presentation or persistence of symptoms in other domains. The focus of this paper will be on practical aspects of neuropsychological evaluation of middle school and high school-aged patients in the clinical setting, highlighting cognitive and psychological assessment approaches designed to complement the neurological evaluation and other clinical assessments performed by members of the neurorehabilitation team.

From the *Sports Concussion New England, Brookline, MA.
†Robert C. Cantu Concussion Center, Emerson Hospital, Concord, MA.
‡William James College, Newton, MA.
Address reprint requests to Neal McGrath, PhD, Sports Concussion New England, Brookline, MA. E-mail: drneal@sportsconcussion.net

https://doi.org/10.1016/j.spen.2019.03.013
1071-9091/11/

The Neuropsychological Evaluation of Concussion

The American Psychological Association (APA) defines clinical neuropsychology as a subspecialty of clinical psychology in which the focus of study and practice is on the applied science of brain-behavior relationship (American Psychological Association, 2018). Neuropsychologists have specific knowledge of neuroscience, functional neuroanatomy, brain development, normal and abnormal brain functioning, neurological disorders and etiologies, neurodiagnostic techniques, and neuropsychological and behavioral manifestations of neurological disorders. Clinical neuropsychologists have specialized training in the assessment, diagnosis, treatment and rehabilitation of individuals with medical, neurological, psychiatric, cognitive and learning disorders across the lifespan. Pediatric clinical neuropsychologists provide these services to children, adolescents, and their families and use this knowledge and training to evaluate patients' functioning, establish or confirm diagnosis, create interventions, and estimate relevant functional outcomes.

Clinical neuropsychologists perform evidenced-based neuropsychological assessments to address specific referral questions. Neuropsychological assessments involve a clinical interview that gathers information on a patient's medical, psychological, developmental, educational, psychosocial, and injury history along with the current functioning and symptoms that the patient may be experiencing relevant to the referral question.[8] Then brief or more comprehensive testing (paper and pencil, computerized, or a hybrid approach of both types of testing) is administered that can assess a range of cognitive skills such as attention, reaction time, memory, processing speed, executive functioning, visuospatial skills, motor skills, somatosensory skills, language, academics, and psychiatric, psychological and behavioral functioning (Division 40, APA, 2010). Not all of these cognitive skills are assessed in every neuropsychological evaluation. In a brief neuropsychological assessment, the typical cognitive domains assessed might include memory, attention, reaction time, processing speed, and executive functioning. In a more comprehensive evaluation, additional cognitive areas assessed may include intellectual, visuospatial, motor, and somatosensory skills, language and, especially for pediatric patients, academic functioning.[8] Validity testing is also incorporated in neuropsychological evaluations. Symptom validity tests and performance validity tests include embedded measures, stand-alone tests and questionnaires designed to assess effort, response bias, and symptom exaggeration throughout the evaluation. Questionnaires are generally incorporated in a neuropsychological evaluation and provide information complementary to cognitive tests results, covering areas such as social, cognitive, psychiatric, psychological, behavioral, and health-related functioning. In a neuropsychological evaluation for concussion, such data will be correlated with postconcussive symptom questionnaires. All this information is then consolidated into a detailed report with clinical recommendations.[9] During the feedback session, the neuropsychologist provides the patient and parents with the results and recommendations for further clinical management.

Due to the typically evolving nature of the clinical presentation during concussion recovery, neuropsychological evaluation of these younger patients requires a flexible approach that must be adjusted according to factors such as recency of injury, type and level of symptoms present, the capacity of the patient to tolerate testing, and the referral questions being posed at different stages postinjury. It has been proposed that children, adolescents and young adults are more susceptible to concussion sequelae due to "the structure of the brain in relation to the skull and its musculature."[10] The acute signs and symptoms of a concussion, including cognitive, physical, sleep, and emotional changes may be similar at all ages. However, the longer-term effects of a concussion may be different for younger patients, due to developmental factors present during earlier lifespan stages.

The exact effects of a concussion on the developing brain of a child, adolescent or young adult have yet to be fully understood.[11] However, there are a few distinct differences between the fully-developed brain and the developing brain that are important to consider. First, in response to a concussion, immature neural tissue, which has higher water content and less myelin in children, may respond differently with respect to its plasticity, resulting in "altered developmental trajectory."[11,12] Second, in regard to the skull and its musculature, children have less neck strength, which can increase the acceleration-deceleration forces that occur during a head injury. Such biomechanical differences may increase the "potential for brain tissue displacement and shear injury" in younger individuals.[12] These mechanical and compositional characteristics of the developing brain "can amplify the complex neurometabolic cascade that follows a concussive injury, resulting in increased vulnerability of the immature brain to secondary insults (eg second-impact syndrome) and prolonged recovery."[12] Third, disruption of function of the prefrontal cortex, which is notably immature in children and still very much in development in adolescents, can result in problems with executive functions including impulse control, emotional control, cognitive flexibility, working memory, self-monitoring, planning and prioritizing, task initiation, and organizational skills.

It is also important to consider other environmental differences that are specific to children and adolescents that can impact recovery from a brain injury.[12] These include home atmosphere, educational and community supports, and specific educational, societal and recreational demands placed on these patients. Taking all of these developmental factors into consideration, the following discussion will review how elements of the traditional neuropsychological evaluation can be tailored to meet the needs of middle and high school students in concussion recovery.

The Clinical Interview

To be able to place neuropsychological test findings in proper context for any patient suspected of having had a brain injury, relevant information must be collected in the clinical interview from the patient and from an informant who knows the patient well. For middle school and high school students recovering from concussion, this will usually be one or both of their parents. Given that the evaluation will focus on cognitive and emotional functioning, any

background of learning disabilities, ADD/ADHD, and/or mental health concerns — whether diagnosed and treated or only suspected — must be understood to better appreciate baseline expectations to which test findings can be compared. Substance use or abuse pre-dating or following a concussion should be considered. The availability of any prior neuropsychological test results that can be used for comparison should also be explored, including preseason baseline testing for sports participation, any evaluations conducted for learning purposes, and any testing following previous brain injuries. Use of prescription medication for mood or attention must be considered, including whether such medication was being taken at the time any prior test results were obtained and which medications the patient is taking at present.

Specific to concussion, the interview must also include a history including number of previous injuries as well as type and duration of symptoms. Details of the current injury, such as any loss of consciousness or amnesia, and whether the concussion appears related to a single identifiable blow or multiple compounding blows, may also be important in appreciating factors contributing to a slower, more complicated recovery, particularly if there has been re-injury before the patient has fully recovered from pre-existing concussion symptoms.

In the case of young athletes for whom an immediate concern may be their strong desire to return to play in a contact sport, it is well understood that persistent postconcussive symptoms may be denied or minimized. It is therefore important to consider the presence of symptoms from multiple viewpoints. What does the patient report on direct questioning? Any discrepancy between that report and what the patient acknowledges on symptom rating forms should be explored. What have parents observed in everyday school and home behavior? What is reported by teachers? Sady, Vaughan and Gioia[13] have recognized that use of symptom checklists developed for adults and older adolescents cannot be expected to yield meaningful information from younger children and they have simplified a postconcussion symptom scale for younger patients accordingly.

The interview should also include discussion with both the patient and parents about any effects that cognitive and/or physical exertion may be having on the patient's symptom profile. Vulnerability to exacerbation of postconcussive symptoms through overstimulation (large group gatherings, video screen activity, motion sensitivity, repetitive visual stimulation, light/noise sensitivity) should be explored. Lack of restorative sleep is common, whether patients may be under- or oversleeping, so recent sleep patterns should be considered to understand if this may be contributing to the larger symptom profile including cognitive inefficiency.

For the middle and high school student, a review of recent progress in their classes can provide an understanding of their capacity to maintain regular pace in assigned work as well as any manifestations of cognitive limitations or other postconcussive symptoms that may be associated with sustained cognitive exertion and would indicate a need for academic accommodations. This information can be of particular value in designing neuropsychological testing to address the patient's individual issues.

Neuropsychological Testing

Once the clinical interview is complete, testing may consist of paper-and-pencil and/or computerized cognitive testing, questionnaires, and validity testing. The literature on the natural course of concussion recovery has defined 3 stages in recovery: the acute period, subacute period, and a chronic period.[8,14-17] Throughout the literature, the timeframe for each of these periods varies somewhat, but the symptoms that characterize each period and the assessments and interventions that are utilized are relevant to the neuropsychologist's approach.[5,8,14,15,18,19] Neuropsychologists can assist during all 3 stages of postconcussion recovery and can be expected to employ different testing strategies based on the range, intensity, and duration of postconcussive symptoms. To fully appreciate these strategies, some discussion of the options and relative value of various approaches to neuropsychological testing of concussion patients is in order.

Traditionally, comprehensive neuropsychological testing includes an intellectual profile along with measures in the functional areas of attention/concentration, verbal/language functions including academic abilities, visuospatial functions, memory and new learning, processing speed, executive function, fine motor speed and dexterity, and emotional/psychological status. However, functions more associated with speed and efficiency of information processing are most relevant earlier in recovery. As a recovery becomes more prolonged, these issues remain very important, but a broader assessment base is often helpful to provide more perspective about the patient's cognitive and psychological needs, as he or she becomes more vulnerable over time to struggling with academic and psychological stress related to living with symptoms, falling behind in school, and isolation from peers socially and in team sports. A key consideration is the extent to which the neuropsychological evaluation can utilize data from symptom reports, more traditional paper-and-pencil (PnP) testing, computerized neuropsychological test (CNT) batteries, and psychological assessment at various stages of recovery.

The use of neuropsychological testing in concussion has been inextricably linked to and informed by clinical evaluation in the world of sports. The seminal work of Barth et al[20] with collegiate athletes focused on evaluating the various domains of cognitive functioning that are most affected by concussion including reaction time, processing speed, memory and concentration/attention and used a PnP battery consisting of the Trail Making Test Forms A and B, the Symbol Digit Modality Test, and the Paced Auditory Serial Attention Test.[6,21,22] The Pittsburgh Steelers' neuropsychological consultants created a similar battery in the late 1980s and early 1990s that took about 30–35 min to administer and consisted of PnPs including the Symbol Digit Modality Test, the Trail Making Test, Grooved Pegboard Test, the Controlled Oral Word Association Test, Hopkins Verbal Learning Test, and Digit Span.[6] Traditional PnP testing has the advantage of

being able to flexibly provide data from all functional areas. The face-to-face interaction with the test-taker allows the examiner to customize testing to assess functions of greatest concern, monitor the clinical presentation of the test-taker for symptom change, and pace the evaluation to take breaks and discontinue testing as needed if symptoms flare up.[6,23] However, it can therefore be fairly time consuming to administer for both patient and professional, and such tests are not often available in alternate forms for the serial testing over time that some concussion patients require. Staffing needed to administer and score PnP can be cost-prohibitive in athletic programs seeking to provide baseline and postinjury testing. Furthermore, the stopwatch-based time measurements inherent in PnP may not be sufficiently sensitive to the subtle changes in reaction time typical in concussion recovery.

Therefore, over the last 2 decades, computer-based platforms have emerged that have been designed with the aim of integrating traditional neuropsychological challenges such as immediate and delayed memory for words, visual figures, and spatial locations; paired associate learning; simple and choice reaction time; inhibitory control; multi-tasking efficiency, and susceptibility to interference. CNT batteries do offer several alternate forms to help minimize practice effects with repeated testing as well as reaction time measurements on the order of 1/100th of a second. They do not require neuropsychologists for administration, though test proctors must be trained to provide proper test conditions both at baseline and postinjury. They do, however, require interpretation by a neuropsychologist to gain full understanding of the meaning of CNT test data, particularly in cases with preexisting LD or ADD/ADHD, or atypical score patterns. These batteries are certainly more time efficient, usually requiring under 30 min for administration, but when used alone they provide only a screening without the additional clinical information that can be gained from face-to-face administration of PnPs. Given their development to allow group administration in computer labs, CNTs utilize only visual stimuli to allow for a quiet group testing environment. While this means that auditory processing cannot be assessed, it is often tolerance for screen-based visual stimulation that is more challenging for recovering concussion patients and CNTs can therefore provide key insight into a student's capacity to sustain an activity that is central to regular academic work. Other CNT advantages include the ability to test groups of athletes simultaneously, assessment in many different languages, automated randomization of test stimuli on alternate forms, and automatic scoring and data storage. CNT data allow the clinician to more efficiently review and compare cognitive performance over time. The accessibility and efficiency of CNTs is also an advantage because the modality allows for quick turnaround for the evaluation of cognitive functioning when only a screening is needed. Some research has shown that CNTs are just as effective as traditional PnP measures in assessing cognitive functioning and they also demonstrate sensitivity to the effects of concussion in adolescents and adults.[24,25] In addition, Broglio et al[26] found that computerized test batteries (ImPACT and Concussion Resolution Index – CRI) produced higher sensitivity to concussions occurring in the past 24 h (ImPACT: 79.2%; CRI: 78.6%), as compared to symptom reports (68%%), postural control data (61.9%%), or pencil and paper measures (43.5%). Furthermore, that study emphasized that computerized testing can measure processing speed and reaction time much more precisely than traditional PnP testing. In practice, most neuropsychologists will combine the benefits of these 2 modalities in using a method generally termed as the *hybrid approach*.[24,27]

The Acute Period

In the early days postinjury, assessment of clinical history and symptoms is the most immediate concern in diagnosis of concussion. Neuropsychological testing during the acute phase can be deferred when the evaluating clinician has confirmed the diagnosis and prioritizes cognitive and physical rest to facilitate recovery and avoid undue symptom exacerbation. Research has also shown that solely using early symptom reporting can help predict recovery time. Iverson et al[9] reported that by reviewing the ImPACT postconcussion symptom scales obtained from athletes within 24 h of injury, they were able to identify those who would recover quickly (10 days or less) and those who had longer recoveries. Those with faster recoveries were less likely to endorse symptoms of dizziness, memory problems, noise sensitivity, and headaches. McCrea et al[15] studied the predictors of concussion recovery time and found that elevated symptom scores during the acute phase of the injury predicted a prolonged recovery.

Tracking postconcussive physical/somatic, cognitive, emotional/affective, and sleep-related symptoms is helpful for managing one's recovery.[14] There are numerous symptom assessment tools that have been shown to have good psychometric properties in both children and adults.[5,28,13] In pediatric populations, postconcussion symptom rating scales are given to both children and their parents to get a more well-rounded view of the child pre-and postinjury.[13]

In the most minimal approach to the use of neuropsychological testing for individuals recovering more quickly from concussion over days to weeks, testing can be deferred until the patient is symptom-free and sufficient performance on cognitive testing becomes one of the last criteria to attain before clearance is given to return to regular activities, particularly contact sports. Iverson and Schatz,[23] however, have identified clinical utility in beginning neuropsychological testing while the patient is still symptomatic because early testing may help predict recovery time and assist with initial concussion management recommendations. When CNT testing is available, initial testing beginning at one day postinjury (never on the day of injury) can assist in objectively measuring the patient's degree of cognitive inefficiency in new learning and processing speed/reaction time in the context of symptoms present both before and immediately after the brief (15–20 min) cognitive exertion of testing. In the acute period, objective demonstration of deficits in CNT performance in relation to the patient's own pre-season baseline when available, and/or to national norms, can help provide

perspective for the patient, parents, school, and physician as to the degree of early cognitive deficit and symptom exacerbation associated with even brief cognitive exertion and thereby facilitate cooperation with clinical concussion management recommendations. Such results can also better demonstrate and inform the need for academic accommodations. This potential value often offsets any transient exacerbation of symptoms caused by taking the CNT. On the other hand, the lack of cognitive deficits or symptom exacerbation on CNT screening may help confirm that recovery is already progressing and encourage normal school activity as tolerated. If, however, the main question in considering the need for neuropsychological testing is an athlete's readiness to return to play in a contact sport, apparently "normal" cognitive results on CNT should never be considered justification for contact activity before the patient has become fully symptom-free and completed a graded return-to-play protocol.[29] In such cases, any neuropsychological testing can wait until the patient is symptom-free before beginning to make that determination and a testing approach can then be selected to help confirm that cognitive function has recovered. In cases involving historical factors such as pre-existing LD or ADD/ADHD, or multiple, severe, and/or complicated prior concussions, use of hybrid testing may offer more thorough reassurance of cognitive recovery.

Multiple studies support the adoption of a multimodal approach when assessing concussions.[4,15,30,31] In the acute period, Brooks and colleagues[32] studied the possible effects of a concussion on cognitive abilities and whether these cognitive outcomes could predict and/or differentiate poor symptom recovery following a pediatric mTBI. They assessed 77 children who had sustained a concussion and had them complete a computerized cognitive testing battery immediately after an ED evaluation. In addition, postconcussive symptom inventory ratings were obtained for pre-injury and post injury (7-10 days, 1 month, 2 months, 3 months) status. The study showed that youth with low scores in reaction time and/or cognitive flexibility were 15 times more likely to remain symptomatic at 1-month postconcussion. These findings suggest that brief cognitive testing in the acute phase may be helpful with predicting concussion recovery outcome. Other studies have shown that during the acute period, children and adolescents who have sustained a concussion may have deficits in the areas of executive functioning (inhibition and set-shifting), attention due to slower reaction time and poor processing speed, and orientation.[32-34]

Iverson[35] examined the predictive quality of ImPACT in distinguishing athletes who had sustained more complex concussions and in turn highlighting those who may have a slower recovery. He administered ImPACT to 114 concussed high school football players within 72 h of the initial injury.[9] These concussed athletes were then classified as "simple" or "complex" (a short-lived terminology that arose from the Second International Conference on Concussion in Sport) based on their recovery time. Athletes categorized as having had "complex" concussions, and therefore more delayed recoveries, were 18 times more likely to have 3 unusually low cognitive test scores compared to athletes with "simple" concussions. In general, the research community at large agrees that the clinical utility of neuropsychological assessment in the context of concussion management is maximal within 24 h after injury or after symptom resolution.[36]

During the acute period, clinical neuropsychologists can provide brief and early educational sessions to the patient and family. Prince and Bruhns[18] stated that psychoeducational early intervention is the most promising and empirically validated intervention for combatting persistent PCS. Psychoeducation allows the patient to receive information on the typical course of recovery for a concussion, and to provide reassurance for a positive recovery and information on one's gradual return to activities and school.[37] In addition, early intervention can also involve cognitive restructuring, cognitive remediation and cognitive behavioral therapy.[18] In pediatric populations, the neuropsychologist should consult with a child's school to educate administrators on concussion management and recovery and to assist with implementing proper interventions and assistance for the child during their recovery.[14]

In summary, a flexible approach to neuropsychological assessment can be used during the acute phase, including symptom analysis alone, CNT with integrated symptom analysis, or use of a focal hybrid battery when symptom recovery appears quick. In considering use of neuropsychological testing during the acute period, particularly within the first week postinjury to help ascertain a middle or high school-aged student's readiness to return to play in a contact sport, however, it is important to remember that in addition to full symptom remission and normal cognitive test scores, sufficient postinjury recovery time must also be allowed for in the judgment of the attending clinician in view of any potential modifying factors such as concussion history, younger age, sport, comorbidities, etc.[29]

The Subacute Period

As recoveries progress from 1 week up to several weeks, middle and high school students are typically dealing with more extended academic stress, symptomatic discomfort, and perhaps temporary disruption of their social connections. They may also benefit from short-term interventions such as medication for headache, cervical treatment for whiplash, or vestibular evaluation.[3] For the patient who remains symptomatic but is making clear progress within this time frame, further testing beyond the approaches described above for the acute period is more likely to involve a hybrid battery. In conjunction with any CNT data on short-term memory efficiency and processing speed/reaction time, brief batteries of PnP testing can include other measures of attention, working memory, new learning, processing speed, and executive function. When students have histories of LD or ADD/ADHD, prior PnP testing may be available to use as a baseline reference. Scales designed for reporting of mood changes can also be included if emotional symptoms seem more prominent. However, while increased irritability is common in the early days to weeks postinjury, reactions involving depressive and anxiety symptoms are less likely when recovery is progressing well during the subacute period. Exceptions

may be seen when students have pre-existing mood issues and a history of mental health services. Patients reporting notable levels of anxiety or depressive symptoms should be monitored closely to limit complications from such reactions. Psychoeducational support to help put concussion symptoms in perspective and manage stress can often be effectively provided by the neuropsychologist in the clinical interview and feedback sessions of the evaluation. For students coming for neuropsychological follow-up within several weeks postinjury, a hybrid battery typically lasting 30-90 min can evolve from session to session. Tests that have previously been completed satisfactorily can be omitted and other more extended and ecologically relevant measures can be introduced such as timed tests of academic efficiency including math calculation, essay composition, and reading comprehension.

Periodic re-evaluation of postconcussive symptoms will be beneficial to guide treatment and management recommendations, track the recovery, and identify any symptomatic inconsistencies. Youth who endorsed elevated levels of postconcussive symptoms during the subacute period, have been found to have more extended recoveries.[14] McCrea et al[15] found that elevated symptom scores during the subacute phase of the injury predicted a prolonged recovery. Meehan et al[38] tracked the postconcussive symptom rating of athletes and found that 14% reported minimal postconcussive symptoms 7 days post but endorsed elevated symptoms 28 days post. Psychological symptoms need to be evaluated to help distinguish postconcussive symptoms from comorbid psychological problems.[14] The postconcussion symptom scale should be reviewed with the patient both at the start and the end of the test session to yield an understanding of any cognitive exertion-related symptom exacerbation in conjunction with their actual level of cognitive test performance. Symptom ratings from the parents' perspective also remain important throughout recovery.

Recovery within the subacute period will typically *not* entail a traditional comprehensive neuropsychological evaluation. Such extensive testing is much more than is needed to address the question of recovery within a time frame of up to several weeks from a concussion. Even if in the course of a neuropsychological concussion evaluation it becomes known that a patient's pediatrician, parents, and/or school had been interested prior to the injury in having the student undergo comprehensive neuropsychological evaluation to rule out LD, ADD/ADHD, or other issues, it is best to wait until more recovery time has passed and the student is consistently back to baseline functioning in order to better assure that any residual effects of the concussion have more fully cleared before undertaking a comprehensive neuropsychological evaluation.

The Chronic Period: Postconcussion Syndrome

Riggio and Jagoda (2016) found that 15% of patients who have sustained a concussion may go on to have neurobehavioral sequelae that persist beyond 3 months, which may impact aspects one's occupational and social life.[39] They described the sequelae features, or PCS, as persistent somatic (headache, dizziness, sleep etc.), cognitive (memory, attention, executive function etc.) and/or psychiatric features (anxiety and depression) that exist beyond the usual recovery time. These persistent symptoms have been associated with litigation, social and psychological disturbances, and turbulent economic standing. Other well-controlled longitudinal studies of PCS in adults have shown mixed findings with respect to the persistence of PCS. Losoi et al,[40] found no difference between concussion patients and orthopedic injury controls in terms of postconcussive symptoms and quality of life ratings by 1 year postinjury, with a large percentage of those patients who had persistent symptoms having a modifiable psychological risk factor at 1 month postinjury, such as traumatic stress, depression, and/or low resilience. Novak et al[41] highlighted the importance of tracking postconcussive symptoms in pediatric populations. They found children with persistent postconcussive symptoms and elevated symptomatology at 12 weeks postinjury to have lower quality of life scores than those who had recovered from a concussion. In pediatric populations, pre-existing mental health issues (ie anxiety and depression), pre-injury somatization, and postinjury neuropsychological functioning can negatively impact concussion recovery.[42-44] Hiploylee et al[45] studied a series of concussion patients, who were not in litigation and who had passed cognitive validity testing, using follow-up questionnaires. They found only 27% of that group eventually reported full recovery, with those who did not recover more likely to have been noncompliant with do-not-return-to-play recommendations in sports. The more symptoms patients reported, the longer their times to recovery. No respondent reported recovery from PCS lasting longer than 3 years.

Furthermore, several other studies have explored predictors of persistent PCS. Riggio and Jagoda[39] highlighted that older age and the initial symptoms of level of consciousness and headache were predictive. Zemek et al[46] performed a systematic review of literature that looked at PCS predictors in patients aged 2-18 years and found that loss of consciousness, and headache and/or nausea (or vomiting), along with premorbid conditions such as prior head injury, learning disabilities, and behavioral problems were predictive. McCrea et al[15] identified high initial levels of symptomatology, loss of consciousness and posttraumatic amnesia. Guay et al[47] asserted that currently there are no specific factors that are predictive of who is most likely to have PCS, but that such symptoms are more likely sustained by psychological factors such as anxiety and depression, and lack of psychoeducation regarding concussion recovery. Silverberg and Iverson[44] found that psychological factors associated with prolonged recovery and PCS include insomnia, chronic pain, anxiety, depression, and post-traumatic stress syndrome. Ponsford et al[48] assessed 123 patients with mTBI and 100 trauma patient controls upon initial admission to a hospital emergency department and again at 1 week and 3 months postinjury using a CNT (ImPACT) with its postconcussion symptom scale as well as PTSD, anxiety, and depression questionnaires. Pre-injury psychiatric problems were found to most strongly predict

persisting symptoms. An individual's pre-injury anxiety level significantly predicted PCS at 3 months. Cognitive measures were not predictive of PCS at 1 week or 3 months. Management of anxiety in response to concussion was recommended to minimize or prevent PCS.

Evaluation of the PCS patient who is 3-6 months postinjury may remain quite similar to that conducted for the subacute student when continuing progress is being seen in recovery. Brief serial assessments, with an emphasis on helping the patient appreciate any progress in recovery and updating management recommendations to be consistent with the type and level of postconcussive symptoms and demonstrated strengths and weaknesses in testing, may assist in helping stave off the adverse effects of anxiety and negative expectations about their condition. Testing in this phase can flexibly employ cognitive measures of attention, concentration, working memory, new learning, executive function, and/or processing speed. Brief measure of academic efficiency such as timed math calculations and reading comprehension are often appropriate as well. Screening instruments for depression and anxiety, which can be repeated over time, can help monitor levels of psychological stress as a component of recovery. Validity measures should be utilized intermittently to monitor for level of test effort or exaggeration of disability.

As recoveries stretch into several months and even years, however, and when patients are reported to be functioning at a more sustained plateau of PCS, evaluation often begins with a more comprehensive test battery to provide a broader overview. Such evaluations usually include multiple and more in-depth psychological measures to appreciate levels of depression, anxiety, and other psychological factors that may well have become elements of the condition, and which may in turn influence intellectual and cognitive test results. When a concussion has occurred in an emotionally traumatic context (eg trapped in a car with "smoke" from deployed airbags after a collision) screening for Post-traumatic Stress Disorder (PTSD) should also be included. Validity measures must also be utilized, particularly at the beginning of test sessions, to provide perspective on level of effort, potential interference from pain problems such as headache, and to help rule out symptom exaggeration or malingering. It is not uncommon for initial validity testing to be questionable at best for some of these patients. When that is the case, the best strategy is usually to move directly from validity testing into psychological assessment, including both screening tools and a more extensive personality inventory. With perspective from those measures, along with history and clinical status observations obtained in the clinical interview, psychiatric or psychotherapeutic treatment may become a priority, with formal intellectual and cognitive testing deferred until a time when better test engagement can be gained.

Monitoring of pain and recent sleep pattern during the evaluation is important in many cases. Testing should also be scheduled at a time when any medication changes have been stabilized so that there can at least be an understanding of how test results relate to a more fixed regimen of psychotropic and/or pain medications. Some patients with PCS-related attentional deficits are being treated with neurostimulants such as methylphenidate, amphetamine, or amantadine. In such cases, a decision must be made in conjunction with the referring physician and the patient as to whether it would be more valuable to have results reflect underlying capacities (testing without medication) or augmented capacities (testing on medication). If the evaluation is being performed in more than one test session, there may also be some opportunity for completion of limited attentional testing both with and without neurostimulant medication.

Once a full evaluation has been completed, a plan for addressing lingering PCS in the context of cognitive psychological, and validity test results can be developed. Neuropsychological follow-up can then take the form of periodic brief reassessments of identified deficit areas as intervening initiatives such as vestibular treatment, optometry consultation, headache management, changes in other pain remedies, or psychotropic medication treatment are implemented.

In any neuropsychological evaluation of a concussion patient at any point in recovery, the clinical interview, testing and feedback sessions will always provide opportunities for intervention through education, coaching, and reassurance. Even with the most complex PCS patients, continuing improvement is anticipated with time, proper management, and appropriate treatment and this context can be conveyed to the patient with realistic consideration of any pre-existing or postinjury challenges that he or she may face.

Other Testing Considerations

Baseline Testing. Traditionally, neuropsychologists have not typically had baseline test data available for comparison in most clinical cases. However, with the advent of sports neuropsychology and the work of Barth et al,[20] groups at risk for concussion (contact sports athletes) were identified and baseline testing of individually normal cognitive functioning was proposed as a means of improving on standard comparison of postinjury test results to population norms alone. In the 1990's baseline neuropsychological testing was conducted in collegiate and professional sports mainly using PnP measures. As CNT became more widespread at the turn of the 21st century, and as this approach to testing has become common in schools across the country, most baseline testing in professional sports now involves a hybrid model, and most middle and high school students and their parents and coaches understand "baseline" testing to include a pre-season CNT. Baseline CNTs are available in some schools for athlete and non-athletes alike. Baseline PnP test data also exists, of course, for students who have undergone earlier neuropsychological or psychoeducational testing for learning purposes, and many measures in such batteries can be referenced and repeated following a concussion.

With this surge in the use of baseline CNT testing, its value in improving clinical decision-making in the management of concussions has sometimes come into question. Randolph et al,[16] in a comprehensive review of literature including all prospective and controlled studies of neuropsychological testing in sport-related concussion from 1990 to 2004, found that the effects of concussion on neurocognitive

scores were subtle and failed to meet statistical significance even during acute phases of the injury (1-3 days postinjury). He concluded that neurocognitive tests (including baseline testing) had not been empirically found to add value to concussion management. However, Echemendia et al[4] found that in a sample of 223 cases of sport-related concussions, accurate clinical identification of a concussed athlete could be made with CNT (ImPACT) in most cases regardless of comparison to baseline or normed data. Schmidt et al (2012) were able to diagnose student athletes who had baseline CNT testing (ANAM) as being concussed with about equal accuracy in comparing postinjury scores to baseline data vs population norms.[4] However, Gardner et al[49] using CNTs (ImPACT and CogSport) found that the use of postinjury normative comparisons was inferior to the baseline model.

Most researchers and physicians agree that a reliable, accurate, and valid assessment of cognitive baseline function is helpful in better determining a student's postinjury cognitive deficits and rate of recovery, and some have identified specific concerns. One key consideration is that baseline CNTs are usually administered in a group setting. Moser et al[2] observed that athletes tested for baseline cognitive scores in group settings performed more poorly than athletes tested individually. This difference can be due to distraction in the group setting. It must also be appreciated that there is typically a very different level of motivation for students in routine pre-season baseline testing and postinjury testing in which they are seeking clearance for return to their sport. Echemendia et al[4] has noted that while testing an athlete individually is an ideal scenario, baseline testing in small groups of 3-5 individuals that are carefully monitored is sufficient. Concern also exists at times regarding possible intentionally poor effort on baseline testing. The term "sandbagging" has been used to describe athletes who intentionally underperform on a baseline test so that, if they were later to sustain a concussion, their postinjury test scores might appear more favorable in relation to their baseline.[23] However, research has indicated that only a small percentage of students who intentionally under-performed on ImPACT are able to avoid detection.[23,50]

Overall, availability of an accurate measure of baseline cognitive functioning is helpful for assessing recovery following a concussion, especially in students with above or below average cognitive function at baseline, developmental conditions such as attention-deficit hyperactivity disorder, learning disability, or premorbid psychiatric diagnosis.[23] It is the work of the neuropsychologist to consider the relevance of any baseline CNT or PnP data in the context of the full clinical picture of any student. Realistically, students are not capable of outperforming their actual levels of cognitive capability except when they have had some good luck in guessing on recognition memory tests. Therefore, the most common concern is not cases in which postinjury scores have not yet returned to an established baseline, but those in which postinjury scores are better than an existing baseline of questionable validity but perhaps not fully back to normal for that individual. The highest stakes decisions in interpreting postinjury test cognitive data for students are with respect to return to play in a contact sport where there is the inevitable risk of re-injury When there is any doubt about return to either an established or estimated baseline level of cognitive testing, the neuropsychologist should always err on the side of caution and never regard postinjury scores that are better than suspect baseline levels to provide evidence of full recovery.

Assessment of Validity. Numerous studies show that poor effort, response bias and/or malingering (in both children and adults) are not uncommon occurrences in the context of general neuropsychological evaluations and more specifically in neuropsychological evaluations for concussions and persistent postconcussive symptomatology.[51] Incorporating validity testing in a neuropsychological evaluation is therefore crucial for assessing these factors and providing context for test findings. If a patient is exaggerating symptomatology or exerting insufficient effort due to a variety of factors such as poor motivation, stress, other psychological factors, physical pain, lack of sleep, and/or feigning, proceeding with the collection of cognitive test results may be of very limited value.

In neuropsychological evaluations, performance validity is assessed along with symptom validity. *Performance validity tests* are embedded or stand-alone tests of cognitive function that are part of the neuropsychological evaluation.[51] Most of these cognitive tests of validity are designed to appear difficult at face value but are actually quite easy and can be performed reasonably well with very little effort or ability. Studies have shown that one's results on performance validity tests are unrelated to one's cognitive abilities, neurologic status or pain, except extreme cases, in both pediatric and adult populations.[52-55]

The practice and efficacy of incorporating validity testing in adult neuropsychological evaluations has been more extensively studied, but validity testing in pediatric populations has not been as thoroughly considered. Kirkwood et al.[56] stated that children are able to demonstrate deception by preschool age and reaffirmed that children can consistently pass validity tests using cutoffs that are established for adults.

Symptom validity tests allow differentiation between symptoms that are more likely neurologically based or non-neurologically based.[51] Araujo et al.[57] examined the relationship between suboptimal effort and PCS in children and adolescents who had sustained a concussion and found that those who exhibited suboptimal effort endorsed greater postconcussive symptoms. Furthermore, those who had suboptimal effort also performed lower on neuropsychological tests of attention and processing speed. Certain behavioral and psychological inventories also have integrated validity scales that can highlight tendencies to portray oneself in a more negative or pathological way or, conversely, to deny the presence of symptoms or problems. In considering such findings, however, it is important to evaluate the nature of such response patterns for each individual and whether the measures were normed on patients with physical symptoms and other bodily injuries of the kind often sustained by concussion patients.

Overall, the use of validity testing early and periodically in the assessment process can help avoid administration of

cognitive testing that will not prove meaningful and can guide the neuropsychological evaluation more in the direction of understanding motivation and psychological factors that may be more crucial in facilitating an individual's recovery.

Recommendations

Concussion Management

Recommendations from the neuropsychological evaluation of a concussion patient, like that of any other practitioner, should first address basic management considerations consistent with the patient's status in recovery and ability to handle stimulation and activity general. These should include sleep, physical exercise, video screen activity, light/noise exposure, and participation in more complex social situations.

Interdisciplinary Referrals

Results of the neuropsychological evaluation can also underscore needs the student may have to follow up with other members of the clinical team, including physicians for headache and pain management, psychiatry for medication evaluation and management of psychological symptoms such as anxiety and depression, psychotherapists for cognitive behavioral therapy and mindfulness to provide coping strategies and skills, physical therapy for vestibular and/or cervical evaluation or treatment or exercise rehab, occupational therapy or behavioral optometry for visual dysfunction, and speech pathology for cognitive rehabilitation.

Informing Academic Accommodations

For the middle or high school student in concussion recovery, recommendations focusing on the "return to learn" process may be the single most important area of focus for the neuropsychologist. As early as the 1980s, when the field of head trauma rehabilitation grew rapidly as survival rates for more severely injured patients increased due to advances in acute medical care, the literature reflected the need for educators to recognize the needs of TBI survivors.[58-61] Later work continued to outline the educational implications of TBI in general and learning problems of students with "post-concussional disorder".[62,63]

With rising public concern and professional awareness of the prevalence and risks of concussion injuries among adolescents and children early in recent years, however, particularly related to sports injuries, there has been renewed attention to the academic issues associated with concussions. Gioia and Collins,[64] in the CDC's *Heads Up* Tool Kit, were the first to present a systematic approach for educators to address the in-school management of students in concussion recovery. Their Acute Concussion Evaluation (ACE) Care Plan provided for monitoring symptoms and "red flag" indicators of worsening symptoms caused by overstimulation or cognitive overexertion and provided general advice for returning to school and everyday activities. It also outlined specific academic accommodations to be considered. The role of the school psychologist in advocating for the needs of recovering students has also been discussed.[65] The importance of individualized cognitive rest has been emphasized.[66] The rationale for specific academic accommodations, the roles of school personnel during recovery, and the integration of neurocognitive testing in school during the recovery process have also been discussed.[67]

Subsequent work has further delineated more programmatic approaches to management of students during concussion recovery. McAvoy[68] has emphasized the importance of a team approach with evolving roles for parents and school staff over time postinjury and stressed the relationship of symptoms and postinjury problems to accommodations. Kent and colleagues have outlined general stages of recovery with associated levels of activity and school accommodations.[69] Sady, Vaughan, and Gioia[70] emphasized the need for school concussion policies specifying the responsibilities of school staff and outlined a variety of practical and symptom-specific considerations, strategies, and accommodations, all within the context of the neurometabolic dysfunction that is the hallmark of concussion. Stewart et al[71] have reviewed academic accommodations and Master et al[69] have stressed the gradual transition that is most often effective in the "return to learn" process.

Position statements have further endorsed the needed for academic accommodations during recovery. Popoli et al[72] have outlined appropriate educational recommendations based on the length of a student's recovery time (Children's Hospital of Atlanta Concussion Consensus, 2013). The American Academy of Pediatrics has re-emphasized the relationship between the symptoms of concussion and academic implications, and the responsibilities of the family, medical and academic teams.[73] Key to working with the any concussed student early in recovery is the understanding that symptoms present in clear domains and largely reflect a disruption of the brain's normal metabolic activity which results in an energy crisis.[74] The eventual duration of symptoms cannot be known for a given individual with any certainty at first. Reducing cognitive demands and overstimulation, and finding a level of rest that is sufficient to allow symptoms to improve, are usually crucial in the early days to weeks. Students who are fortunate to recover from symptoms and cognitive limitations within days may require few if any accommodations. Most will recover within weeks and many of those will benefit from some accommodations. A minority, however, may require months or longer to recover during which time there may be significant challenges for them in maintaining academic progress without causing their own recovery to be complicated or stalled by cognitive overexertion or psychological stress. Furthermore, students with a history of multiple concussions, concussions occurring too closely together in time, and those with learning disabilities, ADHD, or prior anxiety or mood issues are at greater risk for recurrent concussions or prolonged recoveries.[3]

The Accommodation Process

The neuropsychological evaluation can contribute strongly to an individualized accommodation plan based on the student's presenting symptoms, cognitive test performance,

psychological assessment findings, and observations regarding changes in symptoms with cognitive exertion over the course of minutes to hours. Over the last decade, many middle and high school educators have become much more adept at providing accommodations during concussion recovery understanding that, unlike cases of developmental learning disabilities and ADD/ADHD, the accommodation needs for most students will evolve relatively quickly during recovery and expire once recovery is complete. A dynamic approach by the school team, starting with initial accommodation recommendations from the neuropsychologist and physician and flexibly applying them during phases of symptom flare-up and improvement, is typically best. Such an approach, however, requires considerable communication among the school nurse, guidance counselor, school psychologist, teachers, parents, and the student. Some schools have therefore adopted level systems ranging, for example, from red (out of school, resting at home, no academic work) to orange (attending school part-time and auditing classes with rest breaks as needed, no homework or tests) to yellow (attending full-time with self-paced homework, no tests) to green (full regular expectations, no accommodations).[69] Systems of this type can allow for more clarity of expectations on everyone's part, and adjustments can be made for a student within each level as recovery progresses. For students who have had particularly long or difficult recoveries and who have fallen much further behind in their work, some schools are able to facilitate their reintegration by involving them in transition programs designed to assist students who have had more extended absences and limitations due to medical or psychiatric hospitalizations.

Types and Sequence of Accommodations

Certain typical accommodations should be considered initially, with progression to other options depending on severity and duration of symptoms. Various authors have outlined typical academic accommodations for all clinicians and school staff to consider.[67,69,73,70] While every concussion is unique given factors including pre-existing conditions (learning disabilities, ADHD, migraine/headache problems, etc.), injury severity, number or recency of prior concussions, and specific symptom patterns, some of the more commonly prescribed accommodations and neuropsychological assessment findings typically relevant to each are as follows:

1 Consider the need for time out of school. In the first few days postinjury some students may do better to rest fully from classes and homework to allow symptoms to subside more rapidly. This is quite variable, however, as those more mildly affected may need no time off at all while the occasional case of more severe injury may require weeks of limited to no academic work. *Time out of school is more likely indicated in students with very high levels of initial presenting symptoms, those who have significant exacerbation with an attempt to attend even part-time, or those who become acutely more symptomatic with brief neuropsychological testing (computerized test battery alone or brief hybrid battery).*
2 Partial class attendance. In initial postinjury class attendance some students may be unable to tolerate the settings or cognitive demands of certain classes (eg video screens, noisier classrooms, smartboards, math, foreign language) or sustain attendance for a full day. Selective attendance may help maximize participation without driving symptoms too high. *Specific observations in the neuropsychological evaluation with respect to completion of computer-based tests or math computations can provide such evidence. Neuropsychological results indicating an ability to perform close to baseline on cognitive testing for short periods without significant symptom exacerbation would suggest the ability to benefit from some class participation. For some more severe cases, who are still more highly symptomatic along with more substantial levels of depression or anxiety indicated in testing, and who might otherwise be resting fully at home, partial attendance may be more productive on balance.*
3 Preferential classroom seating. Given cognitive limitations and interference from physical symptoms such as headaches and visual dysfunction during recovery, moving a student who may be normally seated further back in the classroom to assigned seating in the front may facilitate their ability to follow along. *Relevant neuropsychological findings include limited working memory span, slower processing speed in general, and/or deficits in new learning and retention of both auditory and visual information.*
4 Rest breaks are the most common and often most helpful in-school accommodation. Students should be allowed to leave class when symptoms flare up too much (typically beyond a 2-point increase on a 0-10 scale). The nurse's office is commonly suggested, which allows for staff assessment and monitoring, but in some cases students can be designated to use certain quiet areas in the school. *The need for breaks can be highlighted by exacerbation of symptoms during neuropsychological test performance.*
5 Limited/no video screen activity. The visual demands of work at a laptop, desktop, or tablet can be much more taxing than listening, writing by hand, or reading from paper for some students in recovery. This may relate to light sensitivity, inability to tolerate certain light wave frequencies, and/or visual scanning and focus demands when convergence insufficiency may be present. *Relevant neuropsychological findings include exacerbation of symptoms on assessment with CNT or with completion of other computer-administered inventories of executive or personality function.*
6 Limited homework load and extended deadlines for course assignments are essential accommodations for most students. This removes pressure for premature cognitive overexertion and allows students to complete work at a pace that is manageable within the constraints of their recovery. *In the neuropsychological evaluation, any needed stoppage of testing due to symptom*

exacerbation indicates this would be appropriate, as would failure to complete measures of scholastic work such as written math, reading comprehension, or essay writing within designated time limits.

7 Note taking support. Concussion-related disruption of vision (accommodative dysfunction or convergence insufficiency) can make class participation difficult due to problems repeatedly changing focus back and forth between the front of the room and notes on the student's desk. It may also be cognitively too challenging to listen effectively and take good notes simultaneously. Notes can be supplied or supplemented by either the teacher or another student. *Relevant neuropsychological findings may include reduced processing speed in general, minor inadvertent attentional lapses, headaches or eye strain induced by reading tasks, or slowness in brief timed essay composition.*

8 Record class lectures for later review. While it is not practical for a student to record all classes for later review, this may be helpful for specific classes or lectures. *Relevant neuropsychological test findings may include limited working memory span, and poor short-term memory/new learning, especially on auditory tasks such as story memory or word list learning.*

9 Postponement of tests and exams. Testing should not be attempted until a student has been able to attend classes regularly, feels well enough to tolerate the extra cognitive exertion involved in studying and test-taking, and has been able to adequately prepare. The typical consequences of premature test taking are uncharacteristically low scores and undue symptom exacerbation. *Relevant neuropsychological test findings include inability to complete assessment sessions without notable symptom flare-ups, or scores on such measures that are significantly below the student's estimated pre-injury performance level. Academic measures such as reading comprehension, written math, and essay composition may provide the most useful guidance.*

10 Extended time on timed testing. For those students who are still somewhat symptomatic but sufficiently recovered to resume taking tests and exams, extended time can help offset the effects of reduced processing speed and memory efficiency. *Relevant neuropsychological test scores include those on any timed measures. Findings of uncharacteristic attentional errors* (eg *misreading operational signs or incorrect carrying on math calculations) also indicate a need for additional testing time during which test responses can be reviewed for errors.*

11 Stop-the-clock testing breaks. When extended time alone is not sufficient due to symptom exacerbation caused by the more intensive cognitive effort of test-taking, supervised breaks that do not use up testing time can allow students the brief rest that may allow headaches, mental fogginess, visual discomfort, and other symptoms to subside enough for them to persevere and complete tests. *Relevant neuropsychological findings: when students can demonstrate the ability in the office assessment to similarly pace themselves in test completion for one hour or longer with breaks as needed and achieve test scores reasonably within their expected range.*

12 Staggering of tests and exams. When students who are getting better but still symptomatic resume testing, they may be quickly over-challenged by the demands of test clusters, such as during mid-year or final exams, or when faced with a backlog of tests. Such demands can become overwhelming if sufficient time is not allowed for recovery and preparation between these more intensive test sessions. In such cases students are often recommended to sit for no more than one test/exam per day; in some cases, a full day may be allowed between tests/exams. *For a student who has been able to complete individual tests, this need is largely determined by examining one's recovery time afterward, both with respect to level of symptom exacerbation and one's capacity to study additional material later the same day.*

Several other potential accommodations not listed here may also be very useful, but their application may be indicated more by information obtained in the clinical interview or observations reported from school attendance. These include accommodations for light or noise sensitivity, use of a smaller and quieter exam room, and tutorial support.

Conclusion

Neuropsychological contributions to the understanding and evaluation of mild TBI/concussion in younger patients have advanced impressively in recent years. As progress continues, many important issues lie ahead. Particularly for our children and adolescents, these include continuing to foster education and awareness of brain injury in our larger society, further development and refinement of approaches to assessment and academic accommodation, and gaining better understanding the potential long-term effects of multiple injuries during critical periods of development.

References

1. Iverson GL, Gaetz M, Lovell MR, Collins MW: Cumulative effects of concussion in amateur athletes. Brain Inj 18:433-443, 2004. https://doi.org/10.1080/02699050310001617352
2. Moser RS, Iverson GL, Echemendia RJ, et al: Neuropsychological evaluation in the diagnosis and management of sports-related concussion. Arch Clin Neuropsychol 22:909-916, 2007. https://doi.org/10.1016/j.acn.2007.09.004
3. Collins MW, Kontos AP, Reynolds E, et al: A comprehensive, targeted approach to the clinical care of athletes following sport-related concussion. Knee Surg Sports Traumatol Arthrosc 22:235-246, 2014
4. Echemendia RJ, Iverson GL, McCrea M, et al: Advances in neuropsychological assessment of sport-related concussion. Br J Sports Med 47:294-298, 2013. https://doi.org/10.1136/bjsports-2013-092186
5. McCrea M, Broshek DK, Barth JT: Sports concussion assessment and management: Future research directions. Brain Inj 29:276-282, 2015

6. Webbe FM, Zimmer A: History of neuropsychological study of sport-related concussion. Brain Inj 29:129-138, 2015. https://doi.org/10.3109/02699052.2014.937746
7. Ellis MJ, Leddy JJ, Willer B: Physiological, vestibulo-ocular and cervicogenic post-concussion disorders: an evidence-based classification system with directions for treatment. Brain Inj 29:238-248, 2015
8. Wang Y, Chan RCK, Deng Y. The role of psychology in the "Concussion Crisis." *Int Rev Psychiatry*. 15:341-349.
9. Iverson G: Predicting slow recovery from sport-related concussion: the new simple-complex distinction. Clin J Sport Med Off J Can Acad Sport Med 17:31-37, 2007. https://doi.org/10.1097/JSM.0b013e3180305e4d
10. Di Battista AP, Churchill N, Schweizer TA, et al: Blood biomarkers are associated with brain function and blood flow following sport concussion. J Neuroimmunol 319:1-8, 2018. https://doi.org/10.1016/j.jneuroim.2018.03.002
11. Daneshvar DH, Riley DO, Nowinski CJ, et al: Long term consequences: Effects on normal development profile after concussion. Phys Med Rehabil Clin N Am 22:683-700, 2011. https://doi.org/10.1016/j.pmr.2011.08.009
12. Browne GJ, Dimou S: Concussive head injury in children and adolescents. Aust Fam Physician 45:470, 2016
13. Sady MD, Vaughan CG, Gioia GA: Psychometric characteristics of the post-concussion symptom inventory in children and adolescents. Arch Clin Neuropsychol 29:348-363, 2014. https://doi.org/10.1093/arclin/acu014
14. Plourde V, Yeates KO, Brooks BL: Predictors of long-term psychosocial functioning and health-related quality of life in children and adolescents with prior concussions. J Int Neuropsychol Soc 24:540-548, 2018. https://doi.org/10.1017/S1355617718000061
15. McCrea M, Guskiewicz K, Randolph C, et al: Incidence, clinical course, and predictors of prolonged recovery time following sport-related concussion in high school and college athletes. J Int Neuropsychol Soc 19:22-33, 2013. https://doi.org/10.1017/S1355617712000872
16. Randolph C, McCrea M, Barr WB: Is neuropsychological testing useful in the management of sport-related concussion? J Athl Train 40:139-152, 2005
17. Resch JE, McCrea MA, Cullum CM: Computerized neurocognitive testing in the management of sport-related concussion: An update. Neuropsychol Rev 23:335-349, 2013. https://doi.org/10.1007/s11065-013-9242-5
18. Prince C, Bruhns ME: Evaluation and treatment of mild traumatic brain injury: The role of neuropsychology. Brain Sci 7:105, 2017. https://doi.org/10.3390/brainsci7080105
19. McCREA M, Iverson GL, McAllister TW, et al: An integrated review of recovery after mild traumatic brain injury (MTBI): Implications for clinical management. Clin Neuropsychol 23:1368-1390, 2009
20. Barth JT, Alves WM, Ryan TV, et al: Mild head injury in sports: Neuropsychological sequelae and recovery of function. In: Levin HS, Eisenberg HM, Benton LA (eds): *Mild Head Injury*, 1st ed., New York, NY: Oxford University Press, Inc; 1989
21. Gronwall DMA: Paced auditory serial-addition task: A measure of recovery from concussion. Percept Mot Skills 44:367-373, 1977
22. Strauss E, Sherman EM, Spreen O: A Compendium of Neuropsychological Tests: Administration, Norms, and Commentary. American Chemical Society, 2006
23. Iverson GL, Schatz P: Advanced topics in neuropsychological assessment following sport-related concussion. Brain Inj 29:263-275, 2015. https://doi.org/10.3109/02699052.2014.965214
24. Iverson GL, Lovell MR, Collins MW: Validity of ImPACT for measuring processing speed following sports-related concussion. J Clin Exp Neuropsychol 27:683-689, 2005. https://doi.org/10.1081/13803390490918435
25. Newman JB, Reesman JH, Vaughan CG, Gioia GA: Assessment of processing speed in children with mild TBI: A "First Look" at the validity of pediatric ImPACT. Clin Neuropsychol 27:779-793, 2013. https://doi.org/10.1080/13854046.2013.789552
26. Broglio SP, Ferrara MS, Macciocchi SN: Test-retest reliability of computerized concussion assessment programs. J Athl Train 42:509-5142007
27. Kontos AP, Sufrinko A, Womble M, Kegel N: Neuropsychological assessment following concussion: An evidence—based review of the role of neuropsychological assessment pre- and post-concussion. Curr Pain Headache Rep 20:38, 2016. https://doi.org/10.1007/s11916-016-0571-y
28. Davis GA, Purcell LK: The evaluation and management of acute concussion differs in young children. Br J Sports Med 48:98-101, 2014. https://doi.org/10.1136/bjsports-2012-092132
29. McCrory P, Meeuwisse W, Dvorak J, et al: Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. Br J Sports Med 51:838-847, 2017
30. Barr WB, McCrea M. *Diagnosis and* assessment of concussion. The handbook of sport neuropsychology; Springer Publisher, 2011.
31. Kirkwood MW, Peterson RL, Baker DA, Connery AK: Parent satisfaction with neuropsychological consultation after pediatric mild traumatic brain injury. Child Neuropsychol 23:273-283, 2017. https://doi.org/10.1080/09297049.2015.1130219
32. Brooks BL, Low TA, Daya H, Khan S, Mikrogianakis A, Barlow KM: Test or Rest? Computerized cognitive testing in the emergency department after pediatric mild traumatic brain injury does not delay symptom recovery. J Neurotrauma 33:2091-2096, 2016. https://doi.org/10.1089/neu.2015.4301
33. Crowe L, Collie A, Hearps S, et al: Cognitive and physical symptoms of concussive injury in children: a detailed longitudinal recovery study. Br J Sports Med 50:311-316, 2016. https://doi.org/10.1136/bjsports-2015-094663
34. Belanger HG, Vanderploeg RD: The neuropsychological impact of sports-related concussion: A meta-analysis. J Int Neuropsychol Soc 11:345-357, 2005. https://doi.org/10.1017/S1355617705050411
35. Iverson GL, Collins MW, Lovell MR: Predicting recovery time from concussion in high school football players. J Int Neuropsychol Soc 13:65, 2007
36. Nelson LD, Guskiewicz K, Marshall SW, et al: Multiple self-reported concussions are more prevalent in athletes with ADHD and learning disability. Clin J Sport Med Off J Can Acad Sport Med 26:120-127, 2016
37. Michael K, Yeates KO, Taylor HG: Management of pediatric mild traumatic brain injury: A neuropsychological review from injury through recovery. Clin Neuropsychol 22:769-8002008. https://doi.org/10.1080/13854040701543700
38. Brown NJ, Mannix RC, O'Brien MJ: Effect of cognitive activity level on duration of post-concussion symptoms. Pediatrics 133:e299-e3042014. https://doi.org/10.1542/peds.2013-2125
39. Riggio S, Jagoda A: Concussion and its neurobehavioural sequelae. Int Rev Psychiatry 28:579-586, 2016. https://doi.org/10.1080/09540261.2016.1220927
40. Losoi H, Silverberg ND, Wäljas M, et al: Recovery from mild traumatic brain injury in previously healthy adults. J Neurotrauma 33:766-776, 2015. https://doi.org/10.1089/neu.2015.4070
41. Novak Z, Aglipay M, Barrowman N, et al: Association of persistent postconcussion symptoms with pediatric quality of life. JAMA Pediatr 170:e162900, 2016. https://doi.org/10.1001/jamapediatrics.2016.2900.-e162900
42. Morgan CD, Zuckerman SL, Lee YM, et al: Predictors of postconcussion syndrome after sports-related concussion in young athletes: a matched case-control study. J Neurosurg Pediatr 15:589-598, 2015. https://doi.org/10.3171/2014.10.PEDS14356
43. Yeates KO, Taylor HG, Rusin J, et al: Premorbid child and family functioning as predictors of post-concussive symptoms in children with mild traumatic brain injuries. Int J Dev Neurosci 30:231-237, 2012. https://doi.org/10.1016/j.ijdevneu.2011.05.008
44. Silverberg ND, Iverson GL, McCrea M: Activity-related symptom exacerbations after pediatric concussion. JAMA Pediatr 170:946-953, 2016. https://doi.org/10.1001/jamapediatrics.2016.1187
45. Tator CH, Davis HS, Dufort PA, et al: Postconcussion syndrome: Demographics and predictors in 221 patients. J Neurosurg 125:1206-1216, 2016. https://doi.org/10.3171/2015.6.JNS15664
46. Zemek RL, Farion KJ, Sampson M, McGahern C: Prognosticators of persistent symptoms following pediatric concussion: A systematic review. JAMA Pediatr 167:259-265, 2013. https://doi.org/10.1001/2013.jamapediatrics.216

47. Guay JL, Lebretore BM, Main JM: The era of sport concussion: Evolution of knowledgepractice, and the role of psychology. Am Psychol 71:875-887, 2016. https://doi.org/10.1037/a0040430
48. Ponsford J, Cameron P, Fitzgerald M: Predictors of postconcussive symptoms 3 months after mild traumatic brain injury. Neuropsychology 26:304-3132012. https://doi.org/10.1037/a0027888
49. Gardner A, Kay-Lambkin F, Stanwell P, et al. A systematic review of diffusion tensor imaging findings in sports-related concussion.| Journal of Neurotrauma. https://www.liebertpub.com/doi/abs/10.1089/neu.2012.2628. Accessed March 29, 2019.
50. Schatz P, Glatts C: "Sandbagging" baseline test performance on ImPACT, without detection, is more difficult than it appears. Arch Clin Neuropsychol 28:236-244, 2013. https://doi.org/10.1093/arclin/act009
51. Connery AK, Peterson RL, Baker DA, Kirkwood MW: The impact of pediatric neuropsychological consultation in mild traumatic brain injury: a model for providing feedback after invalid performance. Clin Neuropsychol 30:579-598, 2016. https://doi.org/10.1080/13854046.2016.1177596
52. Alsalaheen B, Stockdale K, Pechumer D, Broglio SP: Validity of the immediate postconcussion assessment and cognitive testing (ImPACT). Sports Med 46:1487-1501, 2016. https://doi.org/10.1007/s40279-016-0532-y
53. Donders J: Performance on the test of memory malingering in a mixed pediatric sample. Child Neuropsychol 11:221-227, 2005. https://doi.org/10.1080/09297040490917298
54. Carone DA: Children with moderate/severe brain damage/dysfunction outperform adults with mild-to-no brain damage on the Medical Symptom Validity Test. Brain Inj 22:960-971, 2008. https://doi.org/10.1080/02699050802491297
55. Etherton JL, Bianchini KJ, Greve KW, Ciota MA: Test of Memory Malingering Performance is unaffected by laboratory-induced pain: implications for clinical use. Arch Clin Neuropsychol 20:375-384, 2005. https://doi.org/10.1016/j.acn.2004.09.007
56. Kirkwood MW, Peterson RL, Connery AK: Postconcussive symptom exaggeration after pediatric mild traumatic brain injury. Pediatrics 133:643-6502014. https://doi.org/10.1542/peds.2013-3195
57. Araujo GC, Antonini TN, Monahan K, et al: The relationship between suboptimal effort and post-concussion symptoms in children and adolescents with mild traumatic brain injury. Clin Neuropsychol 28:786-801, 2014. https://doi.org/10.1080/13854046.2014.896415
58. Cohen SB: Educational reintegration and programming for children with head injuries. J Head Trauma Rehabil 1:22-29, 1986. https://doi.org/10.1097/00001199-198612000-00007
59. Ewing-Cobbs L, Fletcher JM, Levin HS: Neuropsychological functions following closed head injury in infants and preschoolers. In: Presented at the: International Neuropsychology Meeting; 1986, 1986
60. Rosen CD, Gerring JP: Head trauma: educational reintegration. Coll Hill Press, 1986
61. Savage RC: Educational issues for the head-injured adolescent and young adult. J Head Trauma Rehabil 2:1-10, 1987
62. D'Amato RC, Rothlisberg BA: How education should respond to students with traumatic brain injury. J Learn Disabil 29:670-683, 1996. https://doi.org/10.1177/002221949602900611
63. Dykeman BF: School-based cognitive interventions for children with postconcussional disorder. J Instr Psychol 28:20, 2001. -20
64. Gioia GA, Collins MW. *Acute Concussion Evaluation (ACE): Pphysician/Clinician Office Version*; 2006.
65. Lewandowski LJ, Rieger B: The role of a school psychologist in concussion. J Appl Sch Psychol 25:95-110, 2009. https://doi.org/10.1080/15377900802484547
66. Parsons J, McLeod TCV, Gioia GA: Cognitive rest: The often neglected aspect of concussion management. Athl Ther Today 15:1-3, 2010. https://doi.org/10.1123/att.15.2.1
67. McGrath N: Supporting the student-athlete's return to the classroom after a sport-related concussion. J Athl Train 45:492-498, 2010
68. McAvoy K: Return to learning: Going back to school following a concussion. Communique 40(6), 2012
69. Master CL, Gioia GA, Leddy JJ, Grady MF: Importance of 'Return-to-Learn' in pediatric and adolescent concussion. Pediatr Ann 41:e180-e185, 2012. https://doi.org/10.3928/00904481-20120827-09
70. Sady MD, Vaughan CG, Gioia GA: School and the concussed youth — recommendations for concussion education and management. Phys Med Rehabil Clin N Am 22:701-719, 2011. https://doi.org/10.1016/j.pmr.2011.08.008
71. Stewart GW, McQueen-Borden E, Bell RA: Comprehensive assessment and management of athletes with sport concussion. Int J Sports Phys Ther 7:433-447, 2012
72. CHOA Concussion Consensus: Establishing a uniform policy for academic accommodations - David Michael Popoli, Thomas G. Burns, William P. Meehan, Andrew Reisner, 2014. https://journals.sagepub.com/doi/abs/10.1177/0009922813499070. Accessed March 30, 2019.
73. Halstead ME, McAvoy K, Devore CD, et al: Returning to learning following a concussion. Pediatrics 132:948-957, 2013. https://doi.org/10.1542/peds.2013-2867
74. Grady MF: Concussion in the adolescent athlete. Curr Probl Pediatr Adolesc Health Care 40:154-169, 2010. https://doi.org/10.1016/j.cppeds.2010.06.002