

Neuropsychological Assessment of Sport-Related Concussion

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KEYWORDS

- Neuropsychology • Concussion • mTBI • Sports
- Assessment • Management

Evaluation and management of sports-related concussion has received unprecedented attention in both the scientific community and lay media in recent years. Assessment of concussion can be a challenging endeavor for medical practitioners given the different factors associated with each individual injury. Traditionally, clinicians have had to rely on subjective reports of athletes to determine status regarding recovery. The use of neuropsychological testing provides an objective method in the evaluation and management of concussion, and has led to its increased popularity over the past decade. The purpose of this article is to review the utility of neuropsychological testing in the management of sports concussion. The discussion begins with a brief review of the history of neurocognitive testing in sports, followed by an examination of data supporting the reliability, validity, sensitivity, and prognostic value of using neurocognitive testing during the subacute period of recovery following sports concussion. A case study demonstrating the practical use of neurocognitive testing in sports-related concussion is also presented.

HISTORY OF NEUROPSYCHOLOGICAL TESTING

Before the 1980s most brain injury research focused on severe traumatic brain injury; neurologic and neurocognitive changes following mild traumatic brain injury (mTBI) were considered inconsequential. Barth and colleagues¹ conducted the first large scale research study of neuropsychological assessment of concussion in sports that laid the foundation for current management practices. This landmark study

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examined recovery from concussion in collegiate athletes using a neuropsychological test battery of paper/pencil tasks. Overall, it was found that athletes experienced a significant decline in neurocognitive functioning after injury when compared with preinjury baseline testing. Data returned to normal within 10 days after injury. A few years later, neuropsychological assessment of concussion was first used in professional sports with the Pittsburgh Steelers. This eventually led to league-wide concussion programs in the National Football League (NFL; 1993),² the National Hockey League (1996),³ and Major League Baseball (2004). Since then, neuropsychological testing has continued to accurately identify deficits in athletes who were otherwise asymptomatic.⁴⁻⁷ As a result, neuropsychological assessment has expanded understanding of concussion and currently plays an important role in the evaluation and management of sport-related concussion.⁸ However, use of traditional paper/pencil testing is neither practical nor economical for widespread use among the millions of athletes that experience concussion each year.⁹

To more greatly benefit concussed athletes at all levels and ages, computer-based neurocognitive testing has become increasingly common over the last decade, especially in organized sports. When compared with traditional neuropsychological testing, computer-based assessment has several advantages. For baseline testing, computerized assessment is efficient and economical because large numbers of athletes are able to be tested within a short period of time. Practice effects are minimal because computer-based testing allows for randomization of stimuli and multiple test versions improve reliability across multiple administrations. In addition, computer-based testing allows for more accurate measurement of reaction time to within one one-hundredth of a second, and increased validity of identifying subtle changes or deficits in cognitive speed. Computer-based testing also reduces administrator error and inter-rater reliability issues.¹⁰ Following each administration, data is easily stored and accessed in a computer database.¹¹ Despite the immediate availability of test scores, however, only qualified professionals trained in both neuropsychological assessment and traumatic brain injury should interpret the results. In fact, current legislation is being instituted in multiple states that would require athletes to be removed from play until they are evaluated by a physician or psychologist.

The main disadvantage with computer-based assessment is that the examiner typically cannot directly observe the athlete taking the test. Also, computer-based tests sample from selective neuropsychological domains rather than a global assessment of cognitive function. The measured domains, such as attention, working memory, visual motor speed, reaction time, and so forth, have been shown to be selectively affected by mild traumatic brain injury and are the focus of computer-based assessment. In cases of postconcussion syndrome or protracted recovery from sports concussion, more thorough neuropsychological assessment may be indicated. For the many previously stated reasons, however, computerized assessment for concussion is not only being used at the professional level but is currently used by approximately 350 universities and 2500 high schools. There are currently multiple computer-based neuropsychological batteries that have been developed to assess athletes following concussion. Examples of available programs include ImPACT, CogSport, and Headminder. Varying levels of psychometric data are available for these instruments, although all have been researched and used specifically for the management of sports concussion.¹²⁻¹⁵

Recent studies using functional MRI with adolescent athletes have confirmed that there is significant hyperactivation and disruption of brain physiology in even mild injuries that do not involve loss of consciousness.¹⁶ In general, standard structural brain imaging techniques, such as CT and MRI scans of the brain, are usually

unremarkable following concussion because it is a functional rather than structural injury.¹⁷

In conjunction with objective neuropsychological assessment, subjective reporting symptom reporting remains an important element in the evaluation of concussion. Headache is the most common physical symptom following concussion.¹⁸ Athletes who experience headaches accompanied by typical migraine type symptoms of nausea, vomiting, vision changes, and photophobia or phonophobia may experience a greater severity of symptoms and prolonged recovery. Mihalik and colleagues¹⁹ assessed the presentation of posttraumatic migraine via neurocognitive testing with 3 groups: a nonheadache control group, a headache group, and a group exhibiting posttraumatic migraine characteristics. Findings indicated that the posttraumatic migraine group demonstrated significantly lower neurocognitive functioning on all 4 composites areas (verbal memory, visual memory, visual motor speed, and reaction time) and reported significantly more symptoms than both the control group and headache group.¹⁹

In an effort to better understand symptom presentation following concussion, factor analysis was conducted on the Post-Concussion Symptom Scale,^{2,7} a 22-item Likert scale completed by the athlete following a concussion. Statistical analysis revealed 4 symptom clusters: physical/somatic, cognitive, emotional, and sleep-related difficulties.²⁰ Please refer to **Fig. 1**. These factors should be viewed both independently and reciprocally, and represent important domains for individually tailored interventions.

THE ROLE OF NEUROPSYCHOLOGICAL ASSESSMENT

Neuropsychological assessment has long been used following traumatic brain injury because it provides specific information regarding neurocognitive and neurobehavioral status of the examinee. Over the last 20 years it has become increasingly useful in the realm of sports concussion and has been deemed a cornerstone of concussion

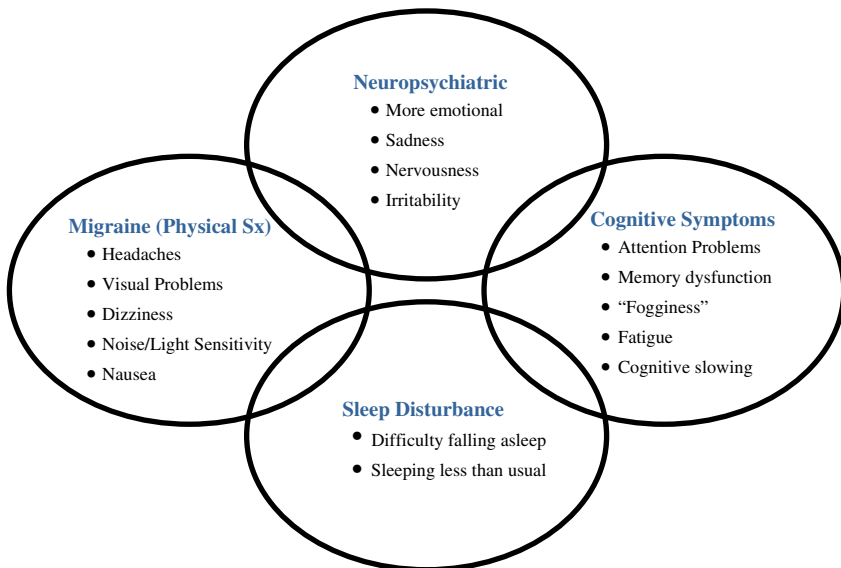


Fig. 1. Factor analysis of postconcussion symptom scale.

management by the Concussion in Sport (CIS) group at the International Symposia on Concussion in Sport.^{17,21,22} Furthermore, the recommendations of the CIS group's consensus statement call for the use of baseline neuropsychological testing whenever possible.²³ Recommendations for the use of objective neuropsychological assessment in the management of sports-related concussion can also be found in the position statement of the National Athletic Trainers Association.²² The recognition of objective neuropsychological assessment by groups comprised of varied medical professionals is an indication of its importance as an effective tool in the evaluation and management of sports-related concussion.

Clinical Utility of Neuropsychological Assessment

Neuropsychological assessment has become the preferred assessment tool for evaluating neurocognitive functioning following traumatic brain injury,²⁴ in part, because of its ability to detect even subtle cognitive deficits in concussed athletes.^{4,11} Several studies have used neuropsychological assessment, both traditional paper and pencil and computerized, to determine duration of recovery from concussion. The results of these studies, most of which have been conducted over the past decade, are summarized in **Table 1**.

An examination of data from **Table 1** reveals several clearly observable trends. First, a comparison between days until cognitive resolution and symptom resolution indicates an apparent discrepancy and tremendous variability across studies. Computerized neuropsychological assessment appears to be more sensitive to the subtleties of recovery, indicating that symptoms resolve before return to baseline neurocognitive functioning. Overall, it appears reasonable to suggest that objective

Authors	Sample Size	Population	Tests Used	Total Days Cognitive Resolution	Total Days Symptom Resolution
Pellman et al 2005 ⁵⁹	95	Pro (NFL)	Paper and pencil NP	1 d	1 d
McCrea et al 2003 ⁶⁰	94	College	SAC	>1 d	7 d
McCrea et al 2003 ⁶⁰	94	College	Paper and pencil NP	5–7 d	7 d
Echemendia 2001 ⁵	29	College	Paper and pencil NP	3 d	3 d
Guskiewicz et al 2003 ³⁷	94	College	Balance BESS	3–5 d	7 d
Blieberg et al 2005 ⁶¹	64	College	Computer	3–7 d	Did not evaluate
Iverson et al 2006 ⁴¹	30	High school	Computer	10 d	7 d
McClincy et al 2006 ⁶²	104	High school	Computer	14 d	7–10 d
Lovell, et al 2007 ⁶³	208	High school	Computer	26 d	17 d

Abbreviations: BESS, balance error scoring system; NP, neuropsychological testing; SAC, the standardized assessment of concussion.

neuropsychological testing is more sensitive to recovery than subjective symptom reporting. Every athlete, however, should have both full cognitive recovery and symptom resolution before returning to play. In addition, there is evidence indicating prolonged recovery times for younger athletes. This effect of age highlights the importance of considering individualized factors when evaluating and managing sports-related concussion.

Individualized Management

Neuropsychological assessment provides not only an objective measure of neurocognitive functioning following head injury and allows for an individualized approach to concussion management. Individual athletes vary significantly in neurocognitive ability before or after injury, so one must measure their individual differences.²⁵ Neuropsychological assessment has detected differences in neurocognitive performances based on several individual factors, including age, gender, and history of prior concussion.

Age

Several studies have used neurocognitive testing to demonstrate differences in child and adolescent athletes compared with adults. Field and colleagues²⁶ compared baseline and postconcussion neurocognitive functioning for high school and college athletes during recovery from concussion. Despite the higher rate of prior concussions for the college sample, high school athletes demonstrated longer overall recovery from in-study concussions. These findings suggest a more protracted recovery from concussion in high school athletes. Similar results have been found in comparisons between high school and professional football players.²⁷ Furthermore, evidence suggests that high school athletes who experienced a mild concussion, (ie, less than 15 minutes of on-field symptoms), required at least 7 days before full neurocognitive and symptom recovery was achieved.²⁸ Prolonged recovery in younger athletes is thought to be directly related to immature brain development, and possibly increased susceptibility to the neurometabolic changes associated with mTBI.^{29–33}

Gender

The increased participation of women and girls in organized athletics has raised the question of whether gender influences concussion incidence and severity. Recently, new evidence has suggested that a potential difference exists between the way men and women experience and recover from concussion. Colvin and colleagues³⁴ compared a large sample of male and female soccer players, adjusting for body mass index, and found that women had significantly more postconcussive symptoms as well as poorer performance on computer-based neuropsychological testing. Several other studies have found similarly poor postconcussion neurocognitive performance in women when compared with men.^{35,36} Although there appear to be gender differences in the severity of symptoms and neurocognitive functioning following concussion, the potential reasons for these differences remain unclear. There may be gender-specific differences in brain physiology or even neck strength that may contribute to these findings. Moreover, incidence of migraine is higher in women compared with men, and could potentially play a mediating role. Continued research in this area is needed to further clarify the complex factors involved in these apparent gender differences.

Prior concussion history

Identification of an athlete's concussion history is an important factor in determining whether the athlete can safely return to play. There is a growing body of evidence

suggesting detrimental physical and cognitive effects of multiple concussions. Although there is a paucity of prospective evidence, a recent retrospective study surveyed a sample of retired NFL athletes and found that those who had experienced 3 or more concussions were more likely to report symptoms of cognitive impairment and depression.³⁷ In a study examining multiple concussions in college football players, Collins and colleagues⁴ demonstrated long-term mild deficits in executive functioning and speed of information processing in athletes who sustained 2 or more concussions. In a more recent study, Colvin and colleagues³⁴ reported male and female high school soccer players with a history of at least 1 previous concussion performed significantly worse on computerized neuropsychological testing than those athletes who had no prior concussion history. Neurocognitive deficits in processing speed were also identified in male rugby players with a history of 3 or more concussions.³⁸ Other studies, however, have indicated no detrimental effects of concussion history on neurocognitive performance.^{39–41} As a result, there continues to be a lack of consensus regarding the effects of multiple concussions on neurocognitive performance, which is a topic of continued empirical investigation. It is hoped that studies such as these will help to clarify the significance of individualized factors, such as age, gender, and history of multiple concussion, and ultimately help to inform effective management strategies.

Psychometric Properties and Utility of Neuropsychological Testing

The primary purpose of neuropsychological testing following concussion is to assess for possible change in cognitive functioning. Typically, clinicians attempt to estimate decline in cognitive functioning attributable to head injury. This section will examine the psychometric properties and clinical utility of neuropsychological testing in sports-related concussion.

Reliability

Adequate reliability is critically important to neuropsychological tests, but perhaps even more so for those meant specifically to assess concussion. Assessments of neurocognitive functioning following sports-related concussion often occur in brief retest intervals because of the nature of return-to-play decision-making. Several studies have attempted to demonstrate reliability of computer-based neuropsychological measures of concussion, with test-retest reliabilities generally falling in the moderate range.^{42–44} Some methodological concerns have occurred in these prior studies, including the administration of multiple test batteries in the testing session, which increases the risk of interference effects and inclusion of invalid data in these analyses. In a well-controlled study examining ImPACT, Iverson and colleagues⁴⁵ looked at the psychometric properties by assessing a sample of 56 nonconcussed adolescents on 2 occasions. Results of the initial analysis were then compared with results from a group of 41 amateur athletes assessed within 72 hours of injury. Test-retest reliability coefficients for the 5 composite scores ranged from 0.65 to 0.86, which are comparable or higher than many traditional neuropsychological tests. Furthermore, the comparison of concussed and nonconcussed athletes demonstrated the sensitivity of ImPACT and allowed for the calculation of Reliable Change Indices (RCIs).⁴⁵ RCIs provide the clinician with increased confidence when determining whether or not follow-up assessments are discrepant from baseline. (The RCIs for ImPACT can be found in **Table 2**).

Overall, athletes with concussions are far more likely to have 2 or more declines exceeding reliable change across the 5 composites compared with healthy controls (63.4% versus 3.6%).⁴⁵

Composite	Declined	Improved
Verbal memory	9 points	9 points
Visual memory	14 points	14 points
Processing speed	3 points	7 points
Reaction time	0.06 s	0.06 s
Postconcussion scale	10 points	10 points

Data from Iverson GL, Lovell MR, Collins MW. Interpreting change on ImPACT following sports concussion. *Clin Neuropsychol* 2003;17:464.

Long-term test-retest reliability for ImPACT has also been established. Schatz⁴⁶ examined a sample of collegiate athletes by administering participants' baseline assessments 2 years apart. Intraclass correlation coefficients revealed adequate stability for the visual memory, processing speed, and reaction time composites, with slightly more variability on the verbal memory composite and symptom score (Table 3). However, using RCIs and regression-based methods, only a small percentage of participants' scores showed reliable or significant change on the composite scores (0%–6%) or symptom scale (5%–10%).

Validity

Studies of validity of neuropsychological measures of concussion have attempted to determine a given test's ability to measure their purported cognitive constructs. Schatz and Putz⁴⁷ examined concurrent validity of several computerized neurocognitive assessment tools (eg, ImPACT, HeadMiner, CogSport) using cross-validation. First, computerized measures were shown to demonstrate significant but moderate correlations with established neuropsychological measures (eg, Trail Making Tests, Digit Span Test). In addition, computerized assessments generally demonstrated moderate correlations with one another on processing speed and reaction time domains, but not on memory indices. These results indicate that the tests share some common variance on cognitive constructs, such as processing speed and reaction time.

Neuropsychological testing is both sensitive and specific in identifying concussion. Schatz and colleagues⁴⁸ examined performance on computerized neurocognitive testing, as well as on a subjective symptom scales, and found that 82% of subjects

Composite	Mean		ICC
	Time 1 (in seconds)	Time 2 (in seconds)	
Verbal memory	87.6	87.8	.459
Visual memory	75.6	78.1	.653
Processing speed	41.2	42.0	.742
Reaction time	0.54	0.53	.676
Symptom scale	9.3	9.8	.431

Abbreviation: ICC, intraclass correlation coefficient.

Data from Schatz P. Long-term test-retest reliability of baseline cognitive assessments using ImPACT. *Am J Sports Med* 2010;38:47–53.

in the concussion group and 89% of subjects in the control group were correctly classified according to discriminate function analysis. Furthermore, Iverson and Brooks⁴⁹ compared healthy adolescent males to high school football players who sustained a recent concussion using an algorithm that classifies neurocognitive performance based on composite percentile ranks. Findings indicated that the majority of normal subjects (73%) and the minority of concussed athletes (21%) were classified as “broadly normal.” In contrast, 56% of concussed athletes and only 8.5% of the normal subjects fell in the unusually low or extremely low classification ranges. Similar studies have demonstrated sensitivity exceeding 90% when computerized assessment measures were combined with a self-reporting measure and a brief traditional neuropsychological test battery.⁵⁰

Added Value

Several recent studies have also demonstrated the added value of computerized neurocognitive testing relative to the use of subjective symptoms in isolation. Traditionally, clinicians have relied heavily on the subjective self-reporting of symptoms when evaluating postconcussion functioning. However, the asymptomatic athletes performed significantly lower than uninjured controls on measures of neurocognitive functioning.⁶ Van Kampen and colleagues⁵¹ found 93% of a sample of concussed athletes had either abnormal neurocognitive test results or elevated symptoms when compared with baseline, and adding neurocognitive testing resulted in a net increase in sensitivity of 19%.⁵¹ When specific neurocognitive abilities (reaction time and memory) were examined 4 days following concussion in high school and college athletes, 11% of the concussed athletes had abnormal reaction time and 32% had abnormal memory compared with their baseline data.⁵² These studies show the added value of using neurocognitive testing in conjunction with symptom evaluation when determining recovery from concussion. The addition of neuropsychological testing provides a sensitive, objective assessment tool that helps clinicians make more accurate diagnostic and return-to-play decisions.

Prognostic Utility

Neuropsychological assessment may also assist with prognosis following concussion. Prognosis is important because it alerts the clinician to the severity of the injury. As a result, specific treatment recommendations can be made or implemented. For example, depending on the severity of deficits on neurocognitive testing, specific academic accommodations can be implemented (eg, untimed tests) before experiencing significant academic difficulty stemming from the injury.

To determine whether acute examination could predict recovery occurring within 10 days, Iverson⁵³ administered computerized neurocognitive testing to concussed high school athletes within 72 hours of injury. This prospective study indicated that more than half the sample (56%) required more than 10 days to completely recover. A closer examination of the composite scores indicated that concussions that required more than 10 days to recover from were more likely to result in multiple scores below the tenth percentile compared with normative data. In fact, high school athletes performed worse on 3 of 4 cognitive composite scores (visual memory, processing speed, and reaction time), and approximately 95% of these athletes required greater than 10 days to recover.⁵³ Additional research has further identified prognostic indicators of concussion based on symptoms and neuropsychological test patterns. Lau and colleagues⁵⁴ examined 177 concussed high school football players and discovered both subjective and objective prognostic indicators when evaluating athletes within an average of 2.23 days following concussion. Self-reported migraine

symptoms, perceived neurocognitive decline (eg, bradyphrenia), and decreased reaction time composite scores were most significant in predicting longer recovery times following concussion. Continued research addressing prognostic indicators may determine more accurate recovery times for acutely injured athletes.

CLINICAL EVALUATION

Existing evaluation and management techniques have been strongly influenced by the CIS group's consensus statements, which have suggested each athlete progress through standardized return-to-play guidelines.^{17,21} Specifically, McCrory and colleagues²¹ described 3 main components to be used with all athletes for concussion management: neuropsychological assessment, evaluation of subjective symptoms, and balance testing. These components are critical when making return-to-play decisions and should be considered in conjunction with internationally accepted return-to-play criteria outlined in the following list:

1. Athlete must be asymptomatic at rest.
2. Athlete must be asymptomatic with full physical and cognitive exertion.
3. Balance testing must be returned to baseline.
4. Neurocognitive testing must be returned to baseline.

Baseline Neurocognitive Testing

Ideally, the clinical evaluation begins with baseline testing before a concussive injury. Measuring an athlete's neurocognitive abilities before injury allows for more informed return-to-play decisions. Baseline testing is not required to successfully determine that an athlete has fully recovered because neuropsychological tests are constructed to compare injured athletes scores to healthy normal individuals of their same normative group (eg, age, gender). Despite this, baseline testing is preferred for a more accurate understanding of an athlete's premorbid neurocognitive status. It should be noted that baseline testing can be invalid for a multitude of reasons, including a distracting environment, not taking the test seriously, lack of full effort, confusion with instructions, learning disabilities, and attention-deficit/hyperactivity disorder. Thus, a thorough evaluation should address the presence of these issues.

Clinical Model

Following diagnosis (or suspicion) of a concussion, a clinician trained in neuropsychological testing evaluates the athlete. Subacute clinical evaluation of the concussed athlete should include a detailed clinical interview related to premorbid functioning; current injury; relevant patient history, including medical, social, psychiatric, school, developmental, cultural variables (eg, family environment); and behavioral observations.²⁷

Athletes should return to play based on a graduated progression through several steps. Overall, any athlete with remaining symptoms or abnormal neurocognitive test results should not be returned to play. Lovell⁵⁵ provided a framework from which to base decisions. Ideally, an athlete should undergo a neuropsychological evaluation within 72 hours of the concussion. If any neurocognitive deficits are present, follow-up neuropsychological testing is best completed 5 to 7 days later,⁵⁵ and subsequently at weekly or biweekly intervals to monitor and track recovery.

Testing a symptomatic athlete allows for prognostic estimates, as previously described, and provides data-based recommendations regarding academic considerations and potential return to physical conditioning. The brief (20–25 minute)

neurocognitive test may or may not temporarily exacerbate some symptoms. But the subjective information along with the objective test data helps formulate specific recommendations to expedite recovery (eg, removal from school or classroom accommodations for student athletes). However, if the athlete is severely symptomatic, it may not be necessary to test neurocognitive abilities because testing can significantly exacerbate symptoms. In these cases, cognitive and physical exertion should be eliminated or extremely limited and the athlete evaluated with computer testing after several days of recovery. In most instances, repeat testing every week or two is generally recommended and allows one to track the athlete's recovery process.

Once an athlete is asymptomatic at rest, a graded return to exertion is necessary to monitor any return of symptoms with increased heart rate and avoid severe exacerbation of symptoms. If symptoms return with exertion, modifications may be made to the athlete's cognitive or physical exertion. The athlete does not progress to the next level, but rather stays at an exertional level (both cognitive and physical exertion) that does not provoke symptoms. Thus, it is necessary to increase exertional levels from mild, then to moderate, then finally to heavy (or game pace exertion) over several days before any contact. In all cases, once the athlete is asymptomatic with heavy, noncontact exertion, a final neurocognitive test should be used to ensure that the athlete's abilities are at baseline levels before contact. If the athlete is asymptomatic, but neurocognitive testing has not returned to baseline levels, then the athlete should not be returned to play. Rather, if the athlete displays deficits on testing, an additional examination with repeat testing is recommended within 5 to 7 days. For athletes who continue to exhibit significant symptoms or test deficits despite rest, consideration should occur for more extensive medical intervention or more extensive neuropsychological testing.

Despite its documented value, neuropsychological assessment should not be used exclusively as the lone source of clinical information when treating sports concussions. Along with subjective symptoms and neurocognitive testing, a physical/vestibular examination should be included. Problems with balance occurs in up to 40% of concussed athletes.⁵⁶ Balance dysfunction can occur secondary to brain trauma or actual injury to the vestibular system. In either instance, a screening of postural sway with the athlete standing with feet together and eyes open and then eyes closed can identify grossly abnormal balance. Most athletes' dizziness or gait dysfunction resolves within a few weeks. However, recent research found vestibular rehabilitation significantly reduced dizziness, gait, and balance dysfunction in athletes.⁵⁷

When an athlete is unable to meet the return-to-play criteria previously described, the topic of retirement becomes an issue of concern, especially because multiple concussions may result in long-term neurocognitive deficits also previously described.^{4,56} Unfortunately, no specific cutoff has been established for retiring a player, and again, decisions should be made on an individual basis. However, 2 potential red flags for potential retirement include (1) lingering symptoms many weeks or months following the injury despite proper management and (2) if minimal biomechanical force is causing a reoccurrence of concussion-related symptoms.

CASE EXAMPLE

Patrick is a 15-year-old high school quarterback who sustained multiple concussions during the 2009 football season. The first injury occurred in mid September when he sustained a posterior helmet-to-turf impact after being tackled. In retrospect, he reported experiencing several acute symptoms, including vision changes, fatigue, vasovagal dizziness, headache, and general lethargy. Patrick denied these symptoms

at the time of the injury and continued to play. He continued to experience headaches 3 out of 7 days per week, vasovagal dizziness, fatigue, and cognitive difficulties through October 2009 when he unfortunately sustained another head injury while playing football. This second injury again involved the posterior aspect of his helmet striking the turf following a tackle, resulting in a significant exacerbation of previous symptoms.

Patrick completed the 2009 football season without reporting the symptoms of either head injury. He reported the injuries and symptoms following the 2009 season and was seen in clinic in mid November 2009. At the time of his initial clinic visit, Patrick was experiencing daily headaches, particularly at school, that he rated as a 7 out of 10 on a pain scale. He also continued to experience vasovagal dizziness, fatigue, photosensitivity, phonophobia, and moderate to severe cognitive difficulties that were resulting in decreased academic performance. A clinical interview revealed no prior history of concussion. There was a strong family history of migraine headaches on the maternal side, as well as a proclivity for carsickness. The physical evaluation revealed deficits during vestibular-ocular screening, particularly provocation of dizziness during gaze stability testing. Neurocognitive testing was accomplished using ImPACT, and revealed statistically significant deficits in memory (verbal and visual), processing speed, and reaction time when compared with baseline (see ImPACT data).

Overall, results of the initial evaluation indicated moderate levels of post concussion syndrome resulting from multiple head injuries sustained during the 2009 football season. Patrick's symptom presentation called for several treatments. First, removal from physical exertion and reduction of cognitive exertion via academic accommodations was indicated. Patrick was placed on half days of school and provided with 50% reduction of work, extra time on tests, elimination of tests when possible, and extensions on long-term assignments. Second, Patrick was referred for pharmacologic intervention with recommendation of prescription of amantadine, a neurostimulant empirically shown to be effective in improving cognitive functioning following head injury.⁵⁸ Finally, given his difficulty during vestibular ocular screening, Patrick was referred for a formal vestibular evaluation and subsequent vestibular physical therapy.

After approximately 1 month of compliance with treatment recommendations, Patrick returned to the clinic in mid December 2009, and demonstrated improvements in both physical symptoms and neurocognitive functioning, although neither returned to baseline. He was prescribed 200 mg of amantadine (100 mg in the morning and 100 mg at lunch) and completed 1 month of vestibular therapy. Headache frequency decreased to one time per week and severity decreased to a 1 out of 10 on a pain scale. Dramatic improvements in neurocognitive functioning were observed during ImPACT testing. Verbal and visual memory scores improved considerably, but remained slightly below baseline, and processing speed and reaction time composite scores were commensurate with baseline (see ImPACT data). At this point in recovery, it was recommended that Patrick remain on prescribed medication while returning to school full time and engaging in increased amounts of noncontact physical exertion during formal physical therapy to monitor heart rate.

Patrick returned to the clinic in mid January 2010 and reported a complete resolution of physical symptoms associated with concussion. He continued his prescribed dosage of 200 mg amantadine and Patrick was no longer experiencing headache, dizziness, or fatigue despite having returned to school full time (with academic accommodations) and engaging in moderate levels of noncontact physical exertion (running and weightlifting). ImPACT data at the time of this appointment indicated 3 out of 4 composite scores within reliable change of Patrick's baseline. The lone exception

was continued mild deficits in verbal memory. Because of his improved symptom presentation and near baseline neurocognitive functioning, it was recommended that Patrick be weaned off amantadine while continuing exertional physical therapy and remaining in school full-time with academic accommodations.

When he returned to clinic in February 2010, Patrick reported being completely asymptomatic from both a physical and cognitive standpoint. He had been weaned off amantadine for approximately 1 month, and continued to engage in high levels of physical exertion with no return of symptoms. In addition, academic performance returned to preinjury levels and there were no symptoms with cognitive exertion while at school. Furthermore, Patrick's neurocognitive performance on ImPACT returned to baseline. Because Patrick was completely asymptomatic with full physical exertion and demonstrated baseline neurocognitive functioning, it was determined that he met international return-to-play criteria and he was cleared for return to football. Patrick and his parents agreed to follow-up approximately 3 weeks into the next football season to be certain subtle symptoms or neurocognitive deficits did not return with contact.

This case illustrates several important issues to consider in the management of concussion. First and foremost, accurate identification of signs and symptoms on the sideline is a critical initial step in effective management. As was the case here, athletes are not always forthcoming when reporting symptoms of concussion. As a result, medical staff, athletic trainers, and coaches must be aware of subtle concussion signs and changes in mental status. Players exhibiting any sign or symptom of concussion should be removed from play and referred for medical follow-up. Athletes should never be permitted to return to the contest during which the injury took place. Second, this case highlights the potential for protracted recovery time in cases where a subsequent head injury is sustained before the first injury was completely resolved. In this case, Patrick's second head injury clearly exacerbated the unresolved first injury, and almost certainly resulted in prolonged recovery time. Finally, the use of neurocognitive assessment is a critical component in the identification and management of concussion. Computerized neurocognitive assessment tools, such as ImPACT, provide the clinician with important information for the planning of treatment recommendations and allow for progress monitoring during recovery. This information also offers the clinician increased certainty that neurocognitive deficits, which are often subtle, are completely resolved before returning an athlete to play.



ImPACT™ Clinical Report

High School Football QB

Exam Type	Baseline	Post-injury	Post-injury	Post-injury	Post-injury	Post-injury
Date Tested	08/13/2008	11/16/2009	11/30/2009	12/18/2009	01/11/2010	02/22/2010
Last Concussion	11/23/2008	09/11/2009	09/11/2009	09/11/2009	09/11/2009	09/11/2009
Exam Language	English	English	English	English	English	English
Test Version	4.5.805	4.5.805	4.5.805	4.5.805	4.5.805	4.5.805
Normative Comparison Group	M 14-15	M 14-15	M 14-15	M 14-15	M 14-15	M 14-15

Composite Scores *												
Memory composite (verbal)	91	68%	83	38%	77	18%	89	60%	83	38%	93	80%
Memory composite (visual)†	89	80%	73	36%	55	5%	83	69%	89	80%	89	80%
Visual motor speed composite	46.58	95%	29.05	19%	29.05	19%	47.33	96%	52.68	99%	53.25	99%
Reaction time composite	0.49	90%	0.78	1%	0.76	1%	0.44	97%	0.42	98%	0.45	96%
Impulse control composite	4		45		9		2		1		5	
Total Symptom Score	0		17		18		7		3		1	

SUMMARY

Neuropsychological assessment has long been used following traumatic brain injury because it provides specific information regarding neurocognitive and neurobehavioral status of the examinee. It has been deemed reliable, valid, and can be prognostic when used in the acute stages following concussion. Over the last 20 years it has become increasingly useful in the realm of sports concussion and has been deemed a cornerstone of concussion management by the CIS group at the International Symposia on Concussion in Sport.^{17,21,22} As a result, evaluation and management of sports-related concussion has received unprecedented attention at the professional and collegiate levels, as well as in high school and middle school. To more greatly benefit concussed athletes at all levels and ages, computer-based neurocognitive testing has become increasingly common as well as baseline testing before injury. Despite its proven value, neuropsychological assessment should be used as one tool in a full, individualized assessment of concussion.

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