The “Value Added” of Neurocognitive Testing After Sports-Related Concussion

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Background: Neurocognitive testing has been endorsed as a “cornerstone” of concussion management by recent Vienna and Prague meetings of the Concussion in Sport Group. Neurocognitive testing is important given the potential unreliability of athlete self-report after injury. Relying only on athletes’ reports of symptoms may result in premature return of athletes to contact sport, potentially exposing them to additional injury.

Hypothesis: Use of computer-based neurocognitive testing results in an increased capacity to detect postconcussive abnormalities after injury.

Study Design: Case control study; Level of evidence, 3.

Methods: High school and college athletes diagnosed with a concussion were tested 2 days after injury. Postinjury neurocognitive performance (Immediate Postconcussion Assessment and Cognitive Testing) and symptom (postconcussion symptom) scores were compared with preinjury (baseline) scores and with those of an age- and education-matched noninjured athlete control group. “Abnormal” test performance was determined statistically with Reliable Change Index scores.

Results: Sixty-four percent of concussed athletes reported a significant increase in symptoms, as judged by postconcussion symptom scores, compared with preinjury baseline at 2 days after injury. Eighty-three percent of the concussed sample demonstrated significantly poorer neurocognitive test results relative to their own baseline performance. The addition of neurocognitive testing resulted in a net increase in sensitivity of 19%. Ninety-three percent of the sample had either abnormal neurocognitive test results or a significant increase in symptoms, relative to their own baseline; 30% of a control group demonstrated either abnormalities in neurocognitive testing or elevated symptoms, as judged by postconcussion symptom scores. For the concussed group, use of symptom and neurocognitive test results resulted in an increased yield of 29% overreliance on symptoms alone. In contrast, 0% of the control group had both symptoms and abnormal neurocognitive testing.

Conclusion: Reliance on patients’ self-reported symptoms after concussion is likely to result in underdiagnosis of concussion and may result in premature return to play. Neurocognitive testing increases diagnostic accuracy when used in conjunction with self-reported symptoms.

Keywords: concussion; neurocognitive testing; neuropsychological testing; Immediate Postconcussion Assessment and Cognitive Testing (ImPACT)

Sports-related concussion is a transient neurologic condition that occurs as a result of traumatic biomechanical force.[1] Symptoms may include confusion, disorientation, memory loss, motor unsteadiness, dizziness, headache, or visual disturbances. These symptoms usually occur with no detectable pathologic changes, and traditional neurodiagnostic tests such as CT, MRI, and electroencephalogram are generally insensitive in measuring the subtle neurologic changes after injury.[17] Recent research has indicated that sports-related concussion is a very common injury and that a minimum of 1.5 million concussion injuries occur in American football in the United States alone.[2]

The diagnosis and management of sports-related concussion have traditionally relied heavily on an athlete’s self-report of symptoms, but these symptoms may not always be accurately reported to team medical personnel. However, as many clinicians have recognized, and recent research has suggested, an exclusive reliance on the athlete’s report of symptoms may result in potential exposure to additional injury.[15,18]

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Recent research has demonstrated that even in mildly concussed athletes, there can be a pronounced memory decline, lasting for at least 7 days after injury.[10,22] These data have led to a reexamination of previous return-to-play guidelines and a reconsideration of return-to-play standards that were heavily symptom based. More recently, neurocognitive testing has been endorsed as a "cornerstone" of concussion management by the Vienna Concussion in Sports Group. Specifically, neurocognitive testing has been identified as a helpful piece of additional information to assist in diagnosing and managing concussions.[1] This position was reaffirmed by a second international conference held in Prague in 2004.[25] The role of neurocognitive testing in the diagnosis and management of concussion has been emphasized because of the potential unreliability of athlete self-report of symptoms. The minimization of postconcussion symptoms (PCS) is a well-known phenomenon at all levels of competition.[7,18,19] An athlete's apparent fear of removal from a game or of losing his or her position on the team may tempt some athletes to deny or underreport postconcussive symptoms. Furthermore, prior research has suggested that premature return to play may be a particularly dangerous practice in children given a likely heightened degree of vulnerability in this group.[4,5,9]

Despite the widespread acceptance of neurocognitive testing in professional,[16,20] collegiate,[6,8,19] and high school sports,[22,23] few studies have been completed regarding the clinical utility of neurocognitive testing relative to player report of symptoms. In addition, although most concussion protocols espouse "return to baseline" on neurocognitive testing before return to sport activity,[2,18,21] this fails to take into account test error or "practice effects" as a result of multiple exposures to the test or test battery.

Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) is a computer-based neurocognitive test battery designed specifically for sports-related concussion. This is a widely used program, allowing completion of neurocognitive testing in an expeditious and standardized manner. The ImPACT test battery has undergone extensive validation through multiple studies and is currently used throughout professional and amateur sports.[11-14,22,23,31]

This study was designed to evaluate the individual and combined sensitivity and specificity of player symptom reporting, as judged by PCS score and neurocognitive testing in a group of high school and college athletes. Athletes were evaluated 2 days after concussion, and their test results were compared with the on-field diagnoses by a medical doctor or certified athletic trainer. The on-field diagnosis by medical staff has traditionally represented the "gold standard" for concussion diagnosis. We hypothesized that the use of computer-based neurocognitive testing (ImPACT) would result in an increased capacity to detect postconcussive abnormalities, compared with PCS alone, in a large group of athletes with diagnosed concussions.

MATERIALS AND METHODS

This study received approval from the University of Pittsburgh Institutional Review Board. All concussed athletes (N = 122) had undergone preseason baseline testing with ImPACT and had completed at least 1 follow-up evaluation within 2 days of injury. Athletes within the concussed sample were included from high schools and colleges within the states of Pennsylvania, Michigan, Illinois, Oregon, Maine, and California. This ongoing clinical program implements the use of baseline and postinjury neurocognitive testing to assist team medical staff in making return-to-play decisions after the occurrence of sports-related concussions.

All athletes in our clinical sample were included with the exception of athletes with a history of attention deficit disorder or a psychiatric disorder for which they were receiving medication. No athletes were included with a history of seizures or any other known neurologic disorder. To take into account the possible impact of prior concussions in the injured sample, a series of analyses was conducted to evaluate group differences between athletes with and without a history of prior concussion. There were no statistically significant differences in ImPACT test performance or in symptom reporting at either baseline or postconcussion with the exception of differences between the 2 groups at baseline with regard to the verbal memory composite score ($t = -2.72$, $P < .007$). However, the group with a history of past concussion actually performed better than the no concussion group.

For the purpose of comparison, a sample of 70 nonconcussed athletes composed a control group. This group underwent baseline testing followed by a second evaluation within 1 week of baseline testing to determine test-retest fluctuations. This group was employed in this study to allow a direct comparison of changes in ImPACT and PCS scores during 2 successive testing periods (as was the case with the concussed group). In addition, this control group made possible the completion of statistical analyses to evaluate the specificity of ImPACT testing and PCS scores.

For this study, concussion was defined as a "traumatically induced alteration in mental status with or without a loss of consciousness," based on the standard American Academy of Neurology nomenclature.[15] In addition to alteration of consciousness, athletes were diagnosed with concussion if they reported other typical symptoms of injury, such as headache, dizziness, balance dysfunction, or nausea, after a blow to the head or body. All injuries were diagnosed by a physician or certified athletic trainer who was present at the time of the injury.

The test battery used in this study was ImPACT.[24] The computer-based neurocognitive assessment tool includes a demographic questionnaire, symptom inventory, injury evaluation form, and a 20-minute neurocognitive test battery. The standardized demographic questionnaire requires the athlete to document relevant educational, sports participation, and personal medical history. This section also requires the athlete to report each prior concussion that had been formally diagnosed by a team physician or a certified athletic trainer. Also, ImPACT contains the 22-item PCS scale, which is also administered along with the test battery. The PCS scale evaluates common postconcussive symptoms (such as headache, nausea, dizziness, and trouble sleeping) as rated by the athlete on

TABLE 1
ImPACT Neurocognitive Test Battery[a]

Test Name	Neurocognitive Domain Measured
Word Memory	Verbal recognition memory (learning and retention)
Design Memory	Spatial recognition memory (learning and retention)
X's and O's	Visual working memory and cognitive speed
Symbol Match	Memory and visual motor speed
Color Match	Impulse inhibition and visual motor speed
Three Letters Memory	Verbal working memory and cognitive speed
Symptom Scale	Rating of individual self-reported symptoms
Composite Score	**Contributing Score**
Verbal memory	Averaged percentage correct scores for the Word Memory (learning and delayed), Symbol Match memory test, and Three Letters Memory test
Visual memory	Averaged percentage correct scores for the Design Memory (learning and delayed) and the X's and O's test
Reaction time	Mean time in milliseconds for the X's and O's (mean counted correct reaction time), Symbol Match (mean weighted reaction time for correct responses), and Color Match (mean reaction time for correct response)
Visual motor processing speed	X's and O's (mean correct distracters), Symbol Match (mean correct responses), and Three Letters Memory (number of correct numbers correctly counted)

[a]ImPACT, Immediate Postconcussion Assessment and Cognitive Testing.

a Likert scale from 0 (asymptomatic) to 6 (symptomatic) according to his or her condition at the moment of testing.

The ImPACT test battery evaluates multiple aspects of cognitive functioning and is relatively brief. The entire battery, including the demographic information and PCS scale, takes less than 25 minutes to administer, is automatically scored, and produces a 6-page report that is complete with age-referenced percentile scores for select indices. The ImPACT test battery is heavily oriented toward the evaluation of attention, visual scanning, and information processing, although it also evaluates visual memory, verbal memory, and visual motor speed. Multiple studies using the ImPACT test battery have indicated that it is both reliable and valid. For example, Iverson et al[13] found no significant practice effects in a sample of noninjured high school athletes tested twice within several days. With regard to validity studies, the ImPACT test battery has been found to correlate highly with the Symbol Digit Modalities Test, an often-used test of cognitive speed in research with athletes.[14] This test battery has also demonstrated good sensitivity and specificity in prior studies of young athletes, and ImPACT has the capability to discriminate even mildly concussed high school athletes.[26,27,31] It has also been found to correlate with athlete self-report of neurocognitive decline and "fogginess."[12]

Table 1 provides a listing of the individual ImPACT tests and a description of neurocognitive abilities assessed. From these 6 tests, 4 separate composite scores are generated: verbal memory, visual memory, visual motor speed, and reaction time. In addition, an impulse control composite score is calculated that serves as 1 indicator of test validity. These composite scores were constructed to measure the broad neurocognitive domains that their names suggest, and recent validity studies have indicated good convergence with more traditional neuropsychological tests.[14] Multiple composite scores were constructed to reflect the reality that athletes who have suffered a concussion may present with different neurocognitive deficits depending on the biomechanics of their injuries,[30] their ages,[9,28] and a variety of other factors. Therefore, no one score can be used to assess severity of injury.

The administration of the ImPACT test battery was supervised by a team of clinical neuropsychologists, athletic trainers, and/or physicians who were trained and supervised in the administration of the standardized inventory. The ImPACT test battery, including the PCS scale, was administered within 2 days of injury. All of the data obtained from the administration process were automatically generated within the ImPACT clinical report and used in the current analysis.

Significant declines in test scores after concussion and significant increases in symptom scores were determined by the application of Reliable Change Index (RCI) scores as described by Iverson et al[13] and presented in Figure 1. The use of RCI scores is an increasingly popular method

$SEM_1 = SD\sqrt{1 - r_{12}}$ Standard deviation from time 1 multiplied by the square root of 1 minus the test-retest coefficient.

$SEM_2 = SD\sqrt{1 - r_{12}}$ Standard deviation from time 2 multiplied by the square root of 1 minus the test-retest coefficient.

$S_{diff} = \sqrt{SEM_1^2 + SEM_2^2}$ Square root of the sum of the squared SEMs for each testing occasion.

Figure 1. Reliable Change Index score formula. SEM, standard error of the mean.

TABLE 2
Group Means and RCI Values for ImPACT Composite Scores[a]

ImPACT Composite Score	Concussed Group Baseline	Concussed Group at Follow-Up	RCI Value (.80) Confidence Interval
Verbal memory	85.7 (8.9)	76.0 (14.4)	8.75
Visual memory	74.0 (12.8)	64.3 (13.8)	13.55
Reaction time	0.57 (0.08)	0.64 (0.13)	0.06
Processing speed	36.0 (6.8)	32.7 (8.6)	4.98
Symptom report	6.8 (9.6)	25.6 (19.9)	9.18

[a]RCI, Reliable Change Index, ImPACT, Immediate Postconcussion Assessment and Cognitive Testing. Standard deviations are in parentheses.

to account for practice effect and other factors that can influence test scores over repeated testing.[3,10,27] The RCI scores allow a clinician to account for measurement error surrounding test-retest difference score and therefore adjust each score for practice effects secondary to multiple exposures to the particular test.

For this study, RCI indices were established for the verbal memory, visual memory, reaction time, visual motor processing speed, and PCS composite scores produced in the ImPACT report. An athlete's test performance was deemed to be reliably different relative to his or her own baseline if the difference between postconcussion and baseline scores on a given composite index of ImPACT was larger than the established RCI scores, as determined in previously published research by Iverson et al.[13] Iverson et al have used these RCI scores in researching the ImPACT test battery by testing 56 healthy "not concussed" athletes twice within a few days to examine their test-retest reliability, practice effect, and reliable change parameters and to ultimately determine the normal variability of testing. Whenever an athlete exceeds these normal variations, he or she is judged as abnormal on the test score in question. For example, because the established RCI value for verbal memory is 8.75, any decline on this index (relative to baseline) that exceeds this value is rated as significantly different. Because the verbal memory composite scores are expressed as integers, a score that has decreased by 9 points or more would be categorized as abnormal. Additional RCI values are provided in Table 2.

Postconcussion Evaluation

All the athletes in our study had taken a preinjury (baseline) test from which difference scores could be calculated after injury. Whenever an athlete experienced a concussion during the period 2001 to 2004, he or she was referred for evaluation, which involved completion of the ImPACT test and PCS score. Concussions were diagnosed on the basis of the criteria described earlier.

Statistical Analysis

Abnormal performance was determined by comparing the athlete's postinjury scores to his or her baseline performance. Deviations from baseline performance larger than the established RCI scores for the particular composite score were deemed to be abnormal. Statistical differences in concussion classification using symptoms and ImPACT test results were determined via χ^2 analyses. All statistical calculations were performed with the Statistical Package for the Social Sciences (SPSS Science Inc, Chicago, Ill).

RESULTS

Sample characteristics are displayed in Table 3 for both concussed and control groups. Ninety-seven of the 122 concussed athletes (80%) were high school students, and 25 (20%) were college students. The control group was composed of 50 (71%) high school and 20 college (29%) athletes. Mean education level for the collective sample was 10.2 years (range, 8-15 years). The concussed sample was largely male athletes (82%), whereas the control group consisted of more female than male athletes (54%). American football athletes composed a majority of the concussed sample (68%). Eleven percent were soccer athletes, 8% were basketball athletes, and the remaining 13% competed in ice hockey, wrestling, or lacrosse. For the control group, 50% were swimmers, 24% were soccer players, 17% were track athletes, and the remaining athletes participated in wrestling and lacrosse. With regard to concussion history, 76% of the concussed sample had no prior concussion history, and 24% had a past history of concussion. Fourteen percent of the concussed sample had a history of 1 prior injury. Eight percent of the sample had experienced 2 prior concussions, and only 2% had experienced 3 or more concussions. The control group had a slightly lower rate of concussion, with only 10% of the group having experienced a past concussion and none of the group having more than 1 concussion.

Based on their total PCS scores only, 64% of the athletes reported an increase in symptoms from their baseline that exceeded the RCI score. In contrast, only 9% of the control group reported a subjective increase in symptoms from baseline to their second evaluation ($\chi^2_1 = 55.4$, $P < .00000$). Eighty-three percent of the concussed sample demonstrated at least 1 ImPACT score that exceeded the RCI for that score, whereas 30% of the control group had 1 abnormal ImPACT score. Therefore, the addition of neurocognitive testing resulted in an increase in sensitivity from 64% to 83%, a net increase of 19% for the concussed group.

TABLE 3
Demographic Data of the Concussed and Nonconcussed Athlete Sample[a]

Variable	Concussed Subjects (N = 122)	Control Subjects (N = 70)
Mean (SD) age, y	16.6 (12-27)	17.3 (14-22)
Mean (SD) education, y	10.2 (8-15)	10.9 (8-16)
High school, %	80	71
College, %	20	29
Previous concussions, %		
0	76	90
1	14	10
2	8	0
3	2	0
Gender: man/woman, %	82	47
Sport, %		
American football	68.0	0
Soccer	11.0	24
Basketball	7.6	0
Swimmers	0	50
Track	0	17
Other	14.4	9
Time between injury to testing, d	2	3
On-field markers[b]		
Positive LOC	12.3%	NA
Retrograde amnesia	53.5%	NA
Anterograde amnesia	1.8%	NA
Confusion	17.8%	NA

[a]LOC, loss of conscious; NA, not applicable.
[b]Because of the natural difficulty of collecting on-field markers, some data were missing.

When either the symptom score or at least 1 neurocognitive test result was abnormal, 93% of concussed athletes were correctly identified as concussed when compared with the gold standard of on-field diagnosis. Whereas 30% of the control group did have 1 abnormal ImPACT score, no one (0%) in the control group had both abnormal neurocognitive performance and an increase in symptoms. Overall, the predictive value of having an abnormal PCS score was 93%, but the predictive value of not having an elevated symptom score was only 59%. If ImPACT was used in the absence of symptom data, the predictive value of having at least 1 abnormal neurocognitive test score was 83%, and the predictive value of a negative test result was 70%. However, when criteria for concussion classification were changed to requiring at least 1 abnormal ImPACT test and an abnormal PCS score, the predictive value of neurocognitive testing was 81%, and the predictive value of having a negative score was 83%.

DISCUSSION

Concussion has become a major public health issue because of the risk of both short- and long-term morbidity. Historically, return-to-play guidelines have relied heavily on the athletes' self-reports of symptoms. However, overreliance on athlete symptoms has recently been criticized based on the tendency of some athletes to underreport symptoms, presumably in an attempt to speed their return to the playing field.[18] We present data in this study that suggest reliance on symptoms alone is inadequate and is likely to lead to missed diagnosis of the injury in a significant number of athletes. We found that only 64% of our recently concussed sample reported a significant increase in symptoms on the PCS scale within 2 days of evaluation. Adding neurocognitive testing increased the number of athletes who were identified as being abnormal to 83%. However, if a significant increase in symptom self-report and a decline on neurocognitive testing were used as classificatory criteria, the "diagnostic yield" increased to 93% compared with the gold standard of on-field diagnosis. Furthermore, we found that although 93% of our concussed sample had either ImPACT or symptom scores that fell within the abnormal range compared to baseline level, none of the nonconcussed sample of athletes had both abnormal symptoms and abnormal ImPACT performance. These findings support previous studies that have indicated an imperfect agreement between self-reported symptoms and decreased neurocognitive test scores after concussion.[6,10,22]

This is the first study to formally evaluate the sensitivity and specificity of the ImPACT test when used in combination with athlete report of symptoms. Given these results, it is of concern that most return-to-play decisions after concussion have relied heavily on the athlete's self-report of symptoms. In fact, in many sports settings, return-to-play decisions have been based almost exclusively on the self-reported symptoms.[4,15] This study demonstrates that even athletes who report being symptom free may continue to exhibit neurocognitive deficits that they are either unaware of or are failing to report.

Recently, the Concussion in Sports Group[1,25] recommended the use of neurocognitive testing in conjunction with other diagnostic information such as symptoms. This current study provides support for this recommendation. Furthermore, our data suggest that if neurocognitive testing is unavailable, the treating physician should be cautious in returning athletes to play based on their self-report of symptoms. This study also provides preliminary support for the use of the ImPACT composite scores as diagnostic indicators, with a higher number of abnormal composite scores suggesting a more severe concussion. In this study, 2 abnormal ImPACT scores did not occur in any of the nonconcussed athletes and may provide a clear marker of injury. However, this is not to suggest that athletes with 1 abnormal ImPACT score are presumed to be normal. Clearly, further study of the individual and aggregate use of ImPACT scores to evaluate the recovery process is needed.

We recognize several limitations with this study. First, our approach used a rigorous statistical method for determination of significant change after concussion, rather than a clinical approach. Therefore, given the relatively conservative nature of RCI scores, it is possible that we may have failed to correctly classify milder concussions in the sample whose scores did not fall outside of the RCI scores. Second, our sample primarily consisted of male high school and collegiate football players, which limits generalizability to other groups. In contrast, our control group consisted of athletes from more traditionally noncontact sports such as swimming and track and field. Therefore, our concussed and control groups were not identical. However, it is important to note that our assessment of significant change after injury was based on whether the athletes differed relative to their own baseline scores rather than comparison with the control group. Therefore, differences between the concussed and control group with regard to the sport participated in and concussion history did not affect the classification of athletes with regard to whether their test performance was normal or abnormal. In the future, we hope to continue to investigate the relationship of neurocognitive performance and athletes' report of symptoms in other sport groups outside of football. In addition, because the study was conducted exclusively with nonprofessional athletes, our findings should not be generalized beyond those sports levels. Recent published studies of professional football athletes in the United States have suggested a quicker recovery rate and no significant effect of multiple injuries in this group when compared with younger nonprofessional athletes.[28,29] Therefore, the development of different RCI criteria based on age and level of competition may be useful, as recommended by the recent Prague conference.[25]

Based on the current study, we conclude that the use of neurocognitive testing (ImPACT) results in an increased sensitivity to detect postconcussion abnormalities. Therefore, we believe that neurocognitive assessment tools such as ImPACT provide "added value" to the more traditional assessment of symptoms.

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