The “Value Added” of Neurocognitive Testing Following Sport-Related Concussion

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ABSTRACT

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

Hypothesis: The use of computer-based neurocognitive testing results in an increased capacity to detect post-concussive abnormalities following injury.

Study design: Retrospective study to evaluate the sensitivity of the Post-Concussion Symptom Scale (PCS), neurocognitive testing, and the combination of symptom evaluation and cognitive testing in the diagnosis of sport-related concussion.

Methods: High school and college athletes diagnosed with a concussion were tested 2 days post injury. Post-injury neurocognitive performance and symptom scores were compared to pre-injury (baseline) and to an age and education matched non-injured athlete control group. “Abnormal” test performance was determined statistically by the application of Reliable Change Index scores (RCIs).

Results: Sixty four percent of concussed athletes reported a significant increase in symptoms compared to pre-injury baseline at two days post-injury. Eighty three percent of the concussed sample demonstrated significantly poorer neurocognitive test results relative to their own baseline performance. Therefore, 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. Utilization of both symptom and neurocognitive test results resulted in an increased yield of 29% over reliance on symptoms alone. In contrast, 0% of the control group had both symptoms and abnormal neurocognitive testing.

Conclusion: Reliance purely on a patient’s self-reported symptoms following concussion is likely to result in the under-diagnosis of concussion and may result in premature return to play. The addition of neurocognitive testing increases diagnostic accuracy.

Clinical Relevance: Athlete’s subjective symptoms are often not reliable in determining whether or not concussion has completely resolved. Neuropsychological testing provides
additional information to assist in the determination of concussion recovery and return to play.

**Keywords:** Concussion, neurocognitive testing, post concussion symptoms, mild traumatic brain injury, ImPACT.
INTRODUCTION

Sport-related concussion is a usually transient neurological condition that occurs as a result of traumatic biomechanical force. Symptoms may include confusion, disorientation, memory loss, motor unsteadiness, dizziness, headache, or visual disturbances. These problems occur with minimal or no detectable anatomic pathology. CT, MRI and EEG are generally insensitive to measure the subtle neural aspects of concussion. Recent research has indicated that a minimum of 1.5 million concussion injuries occur in American football in the USA alone.

The diagnosis and management of sports related concussion has traditionally relied heavily on an athlete’s self-report of symptoms. Often these symptoms go unrecognized by team medical personnel. As a result, the athlete may be returned to the field prematurely. However, as many clinicians have recognized and recent research has suggested, relying exclusively on the athlete’s report of symptoms may result in potential exposure to additional injury.

Recent research has demonstrated that even in mildly concussed athletes, there can be a pronounced memory decline, lasting for at least 7 days post injury. These data have lead to a recent re-examination 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 (CIS). Specifically, neurocognitive testing has been identified as a helpful piece of additional information to assist in diagnosing and managing concussions. This position has been reaffirmed by a second international conference held in Prague in 2004. The role of neurocognitive testing in the diagnosis and management of concussion has been emphasized due to the potential unreliability of athlete self-report of symptoms. The minimization of post concussion symptoms is a well known phenomenon at all levels of competition. An athlete’s apparent fear of removal from a game or of losing his/her position in the team may tempt some athletes to deny or under-report post-concussive symptoms, thus
exposing the athlete to potential further injury. 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.\textsuperscript{5,6,12}

Despite the nearly unanimous acceptance of neurocognitive testing in professional,\textsuperscript{21,25} collegiate\textsuperscript{8,11,22} and high school sports\textsuperscript{27,28}, few studies have been completed regarding the clinical utility of neurocognitive testing relative to player symptoms. In addition, while most concussion protocols espouse “return to baseline” prior to return to sport activity\textsuperscript{3,20,24} this fails to take into account test error or “practice effects” as a result of multiple exposures to the test or test battery.

\textbf{ImPACT} (Immediate Postconcussion Assessment and Cognitive Testing), is a computer based neurocognitive test battery designed specifically for sport-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 utilized throughout professional and amateur sports\textsuperscript{14,15}.

This study was designed to evaluate the individual and combined sensitivity and specificity of player symptom reporting and neurocognitive testing in a group of high school and college athletes. Athletes were evaluated two days post concussion and their test results were compared to the on the field diagnose 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 post-concussive abnormalities in a large group of athletes with diagnosed concussions.
METHODS and MATERIALS

This study received approval by the University of Pittsburgh Institutional Review Board. All concussed athletes (N=122) had undergone pre-season baseline testing with ImPACT and had completed at least one follow-up evaluation within two days of injury. Athletes within the concussed sample were included from high school and colleges within the states of Pennsylvania, Michigan, Illinois, Oregon, Maine and California. This ongoing clinical program implements the use of baseline and post injury neurocognitive testing to assist team medical staff in making return to-play decisions after the occurrence of sports-related concussions. In addition to the recently concussed group of athletes, a sample of 70 non-concussed athletes comprised a control group underwent baseline testing followed by a second evaluation within one week of baseline testing. This group provided the basis for comparison for the concussed group.

Concussion was defined as a “traumatically induced alteration in mental status that may or may not be accompanied by a loss of consciousness,” based on the standard American Academy of Neurology nomenclature (AAN)\(^2,18\). 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, following 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 utilized in this study was the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT).\(^30\) 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 required the athlete to report each prior concussion that had been formally diagnosed by a team physician or a certified athletic trainer. ImPACT also contains the 22-item Post-Concussion Symptom Scale which is also administered along with the test battery. The scale evaluates common symptoms related to concussion (such as headache, nausea, dizziness and trouble.
sleeping) and these were graded by the athlete from 0 (asymptomatic) to 6 (symptomatic) according to their 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 demonstraphic and symptom information takes under 25 minutes to administer, is automatically scored, and produces a 6-page report that is complete with age-referenced percentile scores for select indiciies. The test battery is heavily oriented towards the evaluation of attention, visual scanning and information processing, although it also evaluates visual memory, verbal memory, and visual-motor speed. Multiple studies utilizing the ImPACT test battery have indicated that it is both reliable and valid. For example, Iverson et al found no significant practice effects in a sample of non-injured 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 utilized test of cognitive speed in research with athletes. 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. ImPACT has also been found to correlate with athlete self-report of neurocognitive decline and “fogginess.”

Table 1 provides a listing of the individual ImPACT tests and a description of neurocognitive abilities assessed. From these six tests, four separate composite scores are generated: Verbal Memory, Visual Memory, Visual Motor Speed, and Reaction Time. In addition, an Impulse Control composite score is calculated which serves as one indicator of test validity.

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

Significant declines in test scores following concussion and significant increases in symptom scores were determined by the application of reliable change index scores (RCIs) as described by Iverson and presented in Figure 1. The use of RCIs is an increasingly popular method to account for practice effect and other factors that can influence test score over repeated testing. The RCIs 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. Iverson and his colleagues have utilized this approach to statistically determine change across more than one testing session.

For this study, RCI indices were established for the Verbal Memory, Visual Memory, Reaction Time, Visual Motor Processing Speed and Post-Concussion Symptom 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 post-concussion and baseline scores on a given composite index of ImPACT was larger than the established RCI score, as determined in previous published research by Iverson. Iverson has utilized these RCI scores in researching the ImPACT test battery by testing 56 healthy “not concussed” athletes twice within a few days to look at their test re-test reliability, practice effect and reliable change parameters. This study was able to 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, since the established RCI value for verbal memory is 8.75, any decline on this index (relative to baseline) that exceeds this value was rated as significantly different. Since the verbal memory composite scores are expressed as integers, a score of -9 or greater would be categorized as abnormal. Additional RCI values are provided below in Table 2.
Post-concussion Evaluation

All the athletes in our study had their own pre-injury baseline scores from which to calculate any change following injury. Whenever an athlete experienced a concussion during the period 2001-2004 he or she was referred for post-injury neurocognitive evaluation, which involved completion of the ImPACT test and Post-Concussion Symptom Scale. Concussions were diagnosed on the basis of the criteria described earlier in the manuscript.

Statistical Analysis

All data are expressed as the mean value or percentage of patients who fit the criteria for abnormal performance based on RCI scores. Abnormal performance was determined by comparing the athlete’s post-injury scores to his or her baseline performance. Scores larger than the established RCI score for the particular composite score were deemed to be abnormal. Statistical differences in concussion classification using symptoms and ImPACT test results were determined via Chi-Square analyses. All statistical calculations were performed with Statistical Package for the Social Sciences (SPSS).37

RESULTS:

Sample characteristics are displayed in Table 3 for both the 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 athletes (29%). Mean education level for the collective sample sample was 10.2 years (range=8 to 15 years). The concussed sample was largely male (82%), while the control group consisted of more females than males (54%). American football athletes comprised a majority of the concussed sample (68%). Eleven percent were soccer athletes, 9 percent basketball athletes, and the remaining 12 percent competed in ice hockey, wrestling or lacrosse. For the control group, 50% were swimmers, 24% soccer players, 12% track athletes and and the remaining athletes were
wrestlers and lacrosse athletes. With regard to concussion history, 77 percent of the
couced sample had no prior concussion history, while 12 percent had a history of one
prior injury. Eight percent of the sample had experienced 2 prior concussions and only 3
percent had experienced three or more concussions. The control group had a slightly
lower rate of concussion with only 9% of the group having experienced a past concussion
and none of the group having more than one concussion.

Based on their Post Concussion Symptom Scale only, 64% (see Figure 2) of the
athletes at the time of testing reported a significant increase in symptoms relative to their
own baseline. In contrast, only 9% of the control group reported a subjective increase in
symptoms from baseline to their second evaluation ($\chi^2$ (df=1) = 55.4, $p < .00000$). Eighty-three percent of the concussed sample demonstrated at least one score ImPACT
composite score while 30% of the control group had one abnormal score ($\chi^2$ (df=1) =
53.5, $p < .00000$. 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

When either the symptom score or at least one neurocognitive test result was
abnormal, 94% of concussed athletes were correctly identified compared to the gold
standard of on-field diagnosis. None (0%) of the control group had both abnormal
neurocognitive performance and an increase in symptoms. Overall, the predictive value
of having an abnormal symptom score was 93% but the predictive value of not having an
elevated symptom score was only 59%. If ImPACT was utilized in the absence of
symptom data, the predictive value of a having at least one abnormal neurocognitive test
score was 83% and the predictive value of a negative test was 70%. However, if the
criteria were changed to requiring both at least one abnormal ImPACT test and an
abnormal symptom 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 due to the risk of both short and long term morbidity. In particular, younger athletes have recently been identified as an “at risk” group. Prior return to play guidelines have primarily relied on athlete self-report of symptoms and has not focused specifically on younger athletes. However, over-reliance on athlete symptoms has recently been criticized based on the tendency of some athletes to under-report symptoms, presumably in an attempt to speed their return to the playing field. We present data in this study that suggests that reliance on symptoms alone is inadequate and is likely to lead to premature return to play in a significant number of athletes. We found only 64% of our recently concussed sample demonstrated a significant increase in symptoms within two days of evaluation. Adding neurocognitive testing increased the number of concussed athletes correctly identified to 83%. However, if both significant declines in symptom self-report and neurocognitive testing were utilized as classificatory criteria, the “diagnostic yield” increased to 93% compared to the Gold Standard. Although it could logically argued that some of the asymptomatic status within two days of injury, past studies with ImPACT have indicated that acute recovery form concussion in younger athletes is more likely to take one week or more. It is interesting to note that 93% of our concussed sample had ImPACT and symptom scores that fell within the abnormal range compared to baseline levels. In contrast, none of a non-concussed sample of athletes had both abnormal symptoms and abnormal ImPACT performance. These findings support previous studies, which have indicated an imperfect agreement between self-reported symptoms and decreased neurocognitive test scores following concussion.

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 some alarming that most return to play decisions following concussion have relied heavily on the athlete’s assessment of their symptoms. In fact, in many sports settings, return to play decisions have been based almost exclusively on the athlete’s self-
report of symptoms. This study demonstrates that even athletes who are symptom free  
may still have neurocognitive deficits that they are either unaware of or are choosing to  
ignore. When neurocognitive tests such as ImPACT, this study suggests that this  
information does have added value in evaluating the concussed athlete. In the absence of  
the availability of neurocognitive testing, our data suggest that the treating physician  
should be cautious and somewhat sceptical in returning athletes to play, particularly  
within several days of injury.

Recent sporting organizations have supported the use of neurocognitive testing as  
a “cornerstone” of concussion management. Most recently, the Concussion in Sports  
(CIS) group\(^{(2,31)}\) has recommended the use of neurocognitive testing, in conjunction with  
other diagnostic information such as symptoms. This current study provides support for  
this recommendation. 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, two abnormal  
ImPACT scores was highly unusual in non-concussed athletes and may provide a clear  
marker of injury. However, this is not to suggest that athletes with one 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.

We recognize several limitations with this study. First, our approach utilizes a  
statistical method for determination of significant change following 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  
our sample whose scores did not fall outside of the RCIs. However, in our opinion, the  
use of more rigorous criteria such as RCIs only strengthens the argument for using  
neurocognitive testing. 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 non-contact 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 was
based on whether or not the athletes differed relative to their own baseline score rather than using an absolute number. In the future, we hope to continue to investigate the relationship of neurocognitive performance and athletes’ report of symptoms in other sport groups. In addition, because the study was conducted exclusively with non-professional athletes, our findings should not be generalized beyond those sport 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 to younger non-professional athletes\textsuperscript{34,37}. Therefore, the development of different RCI criteria based on age and level of competition may be useful, as recommended by the recent Prague conference\textsuperscript{31}.

Based on the current study, we conclude that the use of neurocognitive testing (ImPACT) results in an increased sensitivity to detect post-concussion abnormalities. Therefore we believe that neurocognitive assessment tools such as ImPACT provide “added value” to the more traditional assessment of symptoms. This study also supports the recommendations of the recent Vienna and Prague concussion in Sports (CIS) group consensus statements\textsuperscript{2,31}.
REFERENCES


Figure 1. Reliable Change Index Score Formula

\[ \text{SEM}_1 = SD \sqrt{1 - r_{12}} \] Standard deviation from time 1 multiplied by the square root of 1 minus the test-retest coefficient.

\[ \text{SEM}_2 = SD \sqrt{1 - r_{12}} \] Standard deviation from time 2 multiplied by the square root of 1 minus the test-retest coefficient.

\[ S_{\text{diff}} = \sqrt{\text{SEM}_1^2 + \text{SEM}_2^2} \] Square root of the sum of the squared SEMs for each testing occasion.
<table>
<thead>
<tr>
<th>Test Name</th>
<th>Neurocognitive Domain Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word Memory</td>
<td>Verbal recognition memory (learning and retention)</td>
</tr>
<tr>
<td>Design Memory</td>
<td>Spatial recognition memory (learning and retention)</td>
</tr>
<tr>
<td>X’s and O’s</td>
<td>Visual working memory and cognitive speed</td>
</tr>
<tr>
<td>Symbol Match</td>
<td>Memory and visual-motor speed</td>
</tr>
<tr>
<td>Color Match</td>
<td>Impulse inhibition and visual-motor speed</td>
</tr>
<tr>
<td>Three letter memory</td>
<td>Verbal working memory and cognitive speed</td>
</tr>
<tr>
<td>Symptom</td>
<td>Rating of individual self-reported symptoms</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Composite Scores</th>
<th>Contributing Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal Memory</td>
<td>Word Memory (learning and delayed), Symbol Match memory score, Three letters memory score</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>Design Memory (learning and delayed), X’s and O’s Percent correct</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>X’s and O’s (average counted correct reaction time), Symbol Match (average weighted reaction time for correct responses), Color Match (average reaction time for correct response)</td>
</tr>
<tr>
<td>Visual Motor Processing Speed</td>
<td>X’s and O’s (average correct distracters), Symbol Match (average correct responses) Three Letters (number of correct numbers correctly Counted</td>
</tr>
</tbody>
</table>


Table 2. Group Means and RCI values for ImPACT Composite Scores

<table>
<thead>
<tr>
<th>ImPACT Composite Score</th>
<th>Concussed Group Baseline</th>
<th>Concussed Group at FU</th>
<th>RCI Value (.80) Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal Memory</td>
<td>85.7 (8.9)</td>
<td>76.0 (14.4)</td>
<td>8.75</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>74.0 (12.8)</td>
<td>64.3 (13.8)</td>
<td>13.55</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>.57 (.08)</td>
<td>.64 (.13)</td>
<td>.06</td>
</tr>
<tr>
<td>Processing Speed</td>
<td>36.0 (6.8)</td>
<td>32.7 (8.6)</td>
<td>4.98</td>
</tr>
<tr>
<td>Symptom Report</td>
<td>6.8 (9.6)</td>
<td>25.6 (19.9)</td>
<td>9.18</td>
</tr>
</tbody>
</table>
Table 3. Demographic data of the concussed and non-concussed athlete sample

<table>
<thead>
<tr>
<th>Variable</th>
<th>Concussed Subjects</th>
<th>Control Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>N=</td>
<td>122</td>
<td>70</td>
</tr>
<tr>
<td>Mean (SD) age (yrs)</td>
<td>16.6 (12-27)</td>
<td>17.3 (14-22)</td>
</tr>
<tr>
<td>Mean (SD) education (yrs)</td>
<td>10.2 (8-15)</td>
<td>10.9 (8-16)</td>
</tr>
<tr>
<td></td>
<td>Highschool 80%</td>
<td>72%</td>
</tr>
<tr>
<td></td>
<td>College 20%</td>
<td>28%</td>
</tr>
<tr>
<td>Previous concussions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>130 (76%)</td>
<td>90%</td>
</tr>
<tr>
<td>1</td>
<td>23 (14%)</td>
<td>10%</td>
</tr>
<tr>
<td>2</td>
<td>13 (8%)</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
<td>4 (2%)</td>
<td>0%</td>
</tr>
<tr>
<td>Gender: man/woman</td>
<td>82%</td>
<td>47%</td>
</tr>
<tr>
<td>Sport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>American Football</td>
<td>68.0%</td>
<td>0%</td>
</tr>
<tr>
<td>Soccer</td>
<td>11.0%</td>
<td>24%</td>
</tr>
<tr>
<td>Basketball</td>
<td>7.6%</td>
<td>0%</td>
</tr>
<tr>
<td>Swimmers</td>
<td>0%</td>
<td>50%</td>
</tr>
<tr>
<td>Track</td>
<td>0%</td>
<td>17%</td>
</tr>
<tr>
<td>Other</td>
<td>14.4%</td>
<td>9%</td>
</tr>
<tr>
<td>Time between injury to testing</td>
<td>2 days</td>
<td>3 days</td>
</tr>
<tr>
<td>(days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-field markers*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive LOC*</td>
<td>12.3%</td>
<td>NA</td>
</tr>
<tr>
<td>Retrograde Amnesia</td>
<td>53.5%</td>
<td>NA</td>
</tr>
<tr>
<td>Anterograde Amnesia</td>
<td>21.8%</td>
<td>NA</td>
</tr>
<tr>
<td>Confusion</td>
<td>17.8%</td>
<td>NA</td>
</tr>
</tbody>
</table>

*Because of the natural difficulty of collecting on-field markers, some data were missing.

*LOC=Loss of conscious
Figure 2. Classification rates of concussed and control athletes (expressed as percentages of athletes classified).

Number of athletes classified as abnormal using RCI cut-off scores.