Neurocognitive Performance of Concussed Athletes When Symptom Free

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Context: Concussed athletes may underreport concussion-related symptoms in order to expedite return to play. Whether neurocognitive impairments persist once concussion-related symptoms resolve has yet to be determined. Reliance on athlete-reported, postconcussion symptoms when making return-to-play decisions may expose athletes to subsequent injury if complete recovery has not occurred.

Objective: To evaluate the presence of neurocognitive decrements in concussed athletes no longer reporting concussion-related symptoms.

Design: Within-groups design.

Setting: University research laboratory.

Patients or Other Participants: Twenty-one National Collegiate Athletic Association Division I collegiate athletes (16 men, 5 women). Age = 19.81 ± 1.25 years, height = 180.95 ± 10.62 cm, mass = 93.66 ± 27.60 kg, and previous concussions = 1.76 ± 2.02.

Main Outcome Measure(s): The ImPACT concussion assessment test was administered to concussed athletes at baseline, when symptomatic (within 72 hours of injury), and when asymptomatic. Index scores of verbal memory, visual memory, visual-motor speed, reaction time, and concussion-related symptoms were recorded at each session. The Symptom Assessment Scale was administered daily after injury to establish when the athlete became asymptomatic.

Results: When assessed within 72 hours of concussion, 81% of the athletes showed deficits on at least 1 ImPACT variable. At the asymptomatic time point, 38% of the concussed athletes continued to demonstrate neurocognitive impairment on at least 1 ImPACT variable.

Conclusions: Neurocognitive decrements may persist when athletes no longer report concussion-related symptoms. The exclusive use of symptom reports in making a return-to-play decision is not advised. A multifaceted approach to concussion assessment that includes evaluation of a myriad of functions is warranted.

Key Words: concussion, symptoms, ImPACT, return to play

Key Points

- Some athletes with sport-related concussion continued to show cognitive deficits after symptom resolution.
- Self-reported symptoms should be considered in conjunction with the results of other assessment techniques.
- A multifaceted assessment should be used to support the clinical examination when completing a concussion evaluation and making a return-to-play decision.

Sport-related concussion is commonly evaluated with a clinical examination and the athlete’s report of postconcussion symptoms. These subjective evaluations are routinely supported by an objective neurocognitive assessment.1-5 The neurocognitive assessment is purported to provide the greatest amount of objective clinical information during the postconcussion evaluation.6 Although pencil-and-paper batteries traditionally have been administered to assess cognitive domains, improvements in technology have resulted in a shift toward computer-based tests.7 Among other benefits, computer platforms offer the advantage of standardized test administration and scoring and improved measurement precision.8 Results vary, but computer-based neurocognitive assessments appear to be as sensitive to concussion’s deleterious effects as their pencil-and-paper counterparts.9-11

Test administration protocols differ among clinical settings, but serial postconcussion assessments commonly are reported.1,12-13 Multiple postconcussion assessments allow for the accurate tracking of neurocognitive decrements and the subsequent recovery from concussion. This protocol, however, may result in practice effects that obscure deficits related to concussive injuries. For instance, Peterson et al12 found that healthy control subjects improved by 23% to 44% on some pencil-and-paper neurocognitive tests given on days 1, 2, 3, and 10. Practice effects also have been seen on some computerized test output scores when administered multiple times.14,15

Reducing practice effects in concussed athletes is critical in making an accurate return-to-play decision, and a number of methods to curtail their influence on postmorbid tests have been proposed. One group16 has suggested a dual baseline assessment in order to minimize practice effects associated with a single computer test. Although this recommendation may reduce practice effects, it may not be clinically feasible because it doubles baseline-test administration time. Another suggestion provided by an international body of concussion experts recommends no neurocognitive testing of simple concussions (ie, concussions without loss of consciousness and
with resolution of concussion-related symptoms within 7 to 10 days of injury\textsuperscript{17}). Finally, the National Athletic Trainers’ Association suggested that practice effects can be reduced by using self-reported symptom resolution as an indicator to begin neurocognitive testing.\textsuperscript{18} In the National Athletic Trainers’ Association model, postconcussion symptoms are tracked daily until resolution. Once the athlete no longer reports symptoms, a neurocognitive assessment is completed. In this manner, practice effects are minimized and testing is completed only when symptoms have resolved and return to exertion and play can be considered.\textsuperscript{18}

Recently, the practicality of eliminating or delaying neurocognitive testing in cases of “simple” concussion has been questioned. One group\textsuperscript{19} recommended self-reported symptoms be used to the exclusion of other measures, in large part because neurocognitive decrements have not been shown to persist beyond symptom resolution. In contrast, others\textsuperscript{5,20,21} suggested that neurocognitive testing should be implemented soon after the concussion diagnosis due to the potential for an athlete to underreport concussion-related symptoms in order to expedite return to play. Relying solely on concussion-related symptoms appears counterintuitive, because it removes objective data from the concussion assessment process. In addition, we are uncertain whether concussed athletes who no longer report postconcussion symptoms continue to show neurocognitive impairment related to their injuries. Therefore, our primary purpose was to retrospectively evaluate the incidence of neurocognitive impairment in athletes who had sustained concussions but no longer reported concussion-related symptoms.

**METHODS**

**Procedures**

The current retrospective analysis was conducted as part of an ongoing investigation into the effects of sport-related concussion. As part of the athletes’ clinical care, our laboratory administers baseline concussion assessments to all high-risk varsity athletes at our university. Before being examined, all athletes read and signed a consent form approved by the institutional review board, which also approved the study. Baseline assessments were completed during the preseason, when all athletes were healthy and free from injury. Our concussion battery includes the Symptom Assessment Scale (SAS) and the ImPACT (ImPACT Applications, Inc, Pittsburgh, PA) neurocognitive assessment for concussion. An athlete who sustained a physician-diagnosed concussion completed the full battery following the injury. During the self-reported symptomatic (SRS) period after injury, the athlete’s symptoms were monitored and recorded daily on the SAS. On the day the athlete self-reported being asymptomatic (SRA), the complete assessment battery was readministered.

To be included in the data analysis, the athlete had to meet the following criteria: (1) completed a baseline assessment on the ImPACT test and SAS before injury, (2) was diagnosed with a concussion and had a follow-up assessment completed within 72 hours of the injury, and (3) denied experiencing any symptoms at the SRA assessment point. After complete injury resolution, each athlete was classified as having sustained a simple or complex concussion based on the guidelines provided in the summary and agreement statement of the 2nd International Conference on Concussion in Sport.\textsuperscript{17} A simple concussion was characterized by no loss of consciousness at the time of injury and symptom resolution within 10 days of injury. A complex concussion was characterized by a loss of consciousness lasting longer than 1 minute at the time of injury or symptoms persisting beyond 10 days after injury.

**Instrumentation**

The ImPACT test is a computer-based assessment of cognitive functioning that has been described in detail elsewhere.\textsuperscript{22} The test consists of 6 assessment modules that are combined mathematically to produce 4 composite scores for verbal memory, visual memory, visual-motor speed, and reaction time. The computer test also includes an evaluation of concussion-related symptoms. On a 22-item symptom list, the athlete ranks each item for current severity on a Likert scale (0 to 6); the maximum total score is 132. The reliability of the ImPACT has been reported\textsuperscript{23} to range from .54 to .76.

The SAS was administered during the baseline evaluation and each day after the concussion diagnosis. The SAS contains 22 items (Table 1) similar to those listed on the ImPACT test. The severity and duration of symptoms within the previous 24 hours are ranked on a Likert scale (1 to 6). The duration scale is anchored with briefly and always, and the severity scale is anchored with not severe at all and as severe as possible. All assessments were completed in a controlled laboratory environment and in the presence of a trained test administrator; baseline assessments occurred in groups no larger than 3.

**Data Analysis**

Means and SDs were calculated for each ImPACT variable for all athletes included in the analysis for each assessment. Postconcussion cognitive scores were compared with preseason assessment results to determine changes in performance. Significant declines in performance were determined through automated calculations of the reliable change index (RCI) embedded in the ImPACT program.\textsuperscript{15} Use of the RCI has been supported for interpreting changes to cognitive functioning after concussion.\textsuperscript{24}

**RESULTS**

A total of 21 National Collegiate Athletic Association Division I collegiate athletes (16 men, 5 women) met the inclusion criteria. The athletes’ age = 19.81 ± 1.25 years, height = 180.95 ± 10.62 cm, mass = 93.66 ± 27.60 kg, and previous concussions = 1.76 ± 2.02. The sample consisted of athletes from American football (n = 16), cheerleading (n = 2), women’s soccer (n = 2), and equestrian events (n = 1).
Table 2. Results on the ImPACT Test and Symptom Assessment Scale for All Concussed Athletes (n = 21) at the Baseline, Self-Reported Symptomatic, and Self-Reported Asymptomatic Assessment Times (Mean ± SD)*

<table>
<thead>
<tr>
<th>All Athletes (n = 21)</th>
<th>Baseline</th>
<th>Self-Reported Symptomatic</th>
<th>Self-Reported Asymptomatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal memory</td>
<td>0.85 ± 0.12</td>
<td>0.78 ± 0.19</td>
<td>0.86 ± 0.12</td>
</tr>
<tr>
<td>Visual memory</td>
<td>0.73 ± 0.19</td>
<td>0.64 ± 0.14</td>
<td>0.75 ± 0.13</td>
</tr>
<tr>
<td>Visual-motor speed</td>
<td>37.13 ± 7.73</td>
<td>35.96 ± 10.40</td>
<td>40.04 ± 8.11</td>
</tr>
<tr>
<td>Reaction time</td>
<td>0.59 ± 0.11</td>
<td>0.66 ± 0.18</td>
<td>0.57 ± 0.09</td>
</tr>
<tr>
<td>Symptom score</td>
<td>3.76 ± 5.55</td>
<td>25.86 ± 20.45</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>Symptom Assessment Scale</td>
<td>8.43 ± 9.30</td>
<td>67.00 ± 43.14</td>
<td>0.00 ± 0.00</td>
</tr>
</tbody>
</table>

Simple concussions (n = 17)

| Verbal memory         | 0.84 ± 0.12 | 0.82 ± 0.16 | 0.87 ± 0.11 |
| Visual memory         | 0.73 ± 0.17 | 0.66 ± 0.11 | 0.75 ± 0.13 |
| Visual-motor speed    | 36.31 ± 8.28 | 38.98 ± 8.45 | 39.68 ± 7.67 |
| Reaction time          | 0.59 ± 0.09 | 0.62 ± 0.12 | 0.58 ± 0.08 |
| Symptom score          | 2.29 ± 2.39 | 23.12 ± 20.03 | 0.00 ± 0.00 |
| Symptom Assessment Scale | 6.12 ± 6.72 | 58.35 ± 40.24 | 0.00 ± 0.00 |

Complex concussions (n = 4)

| Verbal memory         | 0.86 ± 0.15 | 0.58 ± 0.25 | 0.82 ± 0.15 |
| Visual memory         | 0.73 ± 0.26 | 0.53 ± 0.23 | 0.77 ± 0.12 |
| Visual-motor speed    | 40.63 ± 3.56 | 23.14 ± 8.33 | 41.57 ± 10.97 |
| Reaction time          | 0.59 ± 0.17 | 0.80 ± 0.32 | 0.54 ± 0.11 |
| Symptom score          | 10.00 ± 10.52 | 37.50 ± 20.63 | 0.00 ± 0.00 |
| Symptom Assessment Scale | 18.25 ± 13.33 | 103.75 ± 39.30 | 0.00 ± 0.00 |

*Identification of simple (n = 17) and complex (n = 4) concussions was based on the findings of the 2nd International Conference on Concussion in Sport.17

Table 3. Results on the ImPACT Test and Symptom Assessment Scale for All Concussed Athletes When Evaluated at the Self-Reported Asymptomatic Assessment Point (Mean ± SD)*

<table>
<thead>
<tr>
<th>Athletes With Cognitive Impairment (n = 8)</th>
<th>Athletes Without Cognitive Impairment (n = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual memory</td>
<td>0.75 ± 0.14</td>
</tr>
<tr>
<td>Verbal memory</td>
<td>0.89 ± 0.13</td>
</tr>
<tr>
<td>Visual-motor speed</td>
<td>37.56 ± 10.03</td>
</tr>
<tr>
<td>Reaction time</td>
<td>0.63 ± 0.10</td>
</tr>
<tr>
<td>Symptom score</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>Symptom Assessment Scale</td>
<td>0.00 ± 0.00</td>
</tr>
</tbody>
</table>

*Identification of athletes with and without cognitive impairment was based on demonstrated impairment on 1 or more ImPACT variables at the self-reported asymptomatic assessment.

No athlete included in the analysis reported any learning disabilities during baseline testing.

The athletes completed the SRS follow-up assessment 1.24 ± 0.70 days after the concussion diagnosis. The SRA assessment was completed when the athlete no longer reported concussion-related symptoms or an average of 8.14 ± 6.48 days after the initial postconcussion assessment.

Based on the duration of symptoms and reports of loss of consciousness, 17 athletes (81%) were identified as having simple concussions and 4 (19%) as having complex concussions. Those sustaining simple concussions completed their SRA assessment 5.64 ± 2.74 days after the injury, whereas those with complex injuries completed the SRA assessment 18.75 ± 6.48 days postinjury.

Of all the concussed athletes included in the analysis, 15 (71%) were identified as impaired according to the RCI calculations on at least 1 ImPACT cognitive variable at the SRS assessment relative to baseline. An additional 2 athletes were identified as impaired on the ImPACT symptom inventory, for a total of 17 athletes (81%) identified as impaired on at least 1 cognitive or symptom variable. Impairment on specific variables included 7 athletes on verbal memory, 8 on visual memory, 5 on visual-motor speed, and 9 on reaction time. Descriptive statistics for the ImPACT test and the SAS are shown in Table 2.

At the SRA time point, no athlete reported any concussion-related symptoms on either the ImPACT symptom inventory or the SAS. The ImPACT RCI calculations identified 8 athletes (38%) with continued impairment on at least 1 cognitive variable relative to baseline, despite their no longer reporting any concussion-related symptoms. The asymptomatic group that continued to demonstrate cognitive impairment (n = 8) included 6 athletes with simple concussions and 2 athletes with complex concussions. Impairment on the specific variables included 1 athlete on verbal memory, 2 athletes on visual memory, 3 athletes on visual-motor speed, and 4 athletes on reaction time. Means and SDs on the ImPACT test showing some impairment or no impairment at the SRA assessment are available in Table 3.

When the athletes were evaluated for cognitive decline at the SRA based on concussion severity (simple versus complex concussions), 6 athletes with simple concussion (35%) continued to show cognitive impairment on 1 or more variables. Impairment on the specific cognitive variables included 1 ath-
complete on visual memory, 2 athletes on visual–motor speed, and 4 athletes on reaction time. Two athletes with complex concussions (50%) continued to show impairment on the ImPACT at the SRA time point, including 1 athlete for verbal memory and 1 athlete for visual memory.

**DISCUSSION**

We implemented a retrospective analysis to examine the incidence of ongoing cognitive impairment in athletes who had sustained concussions but who no longer reported concussion-related symptoms. A significant number of athletes (38%) continued to show impaired test performance relative to their baseline evaluation despite denying the presence of concussion-related symptoms. These data conflict with those of previous investigators, who reported no change in neurocognitive performance from baseline to asymptomatic athletes with concussion. These investigators reported the mean performance of asymptomatic athletes up to 5 days postinjury, whereas we evaluated the performance of individual athletes when they were symptomatic and then asymptomatic to ascertain the continuation of neurocognitive decrements after symptom resolution. Our findings suggest that individual athletes’ cognitive decrements may extend beyond symptom resolution, warranting a conservative approach to return-to-play decision making.

In contrast with previous recommendations, basing return-to-play decisions on concussion-related symptoms alone does not appear prudent. The summary and agreement statement from the 2nd International Conference on Concussion in Sport stated that neuropsychological screening is not necessary in athletes with simple concussions and a demanding exertion protocol can begin once the athlete reports being asymptomatic. Our findings suggest that 35% of athletes with simple concussions continued to demonstrate cognitive impairment while no longer reporting concussion-related symptoms. Thus, the asymptomatic athlete with a simple concussion may be returned to play with cognitive deficits and placed at risk for further injury. Neurocognitive testing is therefore warranted for all athletes with concussions and may provide clinicians with important information for return-to-play decisions. In addition, until more data are available, the distinction between simple and complex concussions should not be used to determine whether athletes may benefit from neurocognitive testing. A self-reported, concussion-related symptom inventory should remain a part of the assessment battery, but it should be used in conjunction with other assessment methods.

The clinical examination continues to be the gold standard of concussion assessment; however, information obtained from symptom reports, neurocognitive evaluations, and postural control assessments can and should be used to support those findings. Neurocognitive evaluations have proven to be sensitive to concussion and should serve as the cornerstone of the concussion assessment. Postural control decrements also have been clearly demonstrated in concussed athletes. An athlete’s self-report of concussion-related symptoms should be used as a guide for test administration. Regardless of the specific evaluative tools adopted for the battery, no test should be used alone for concussion evaluation, because the greatest sensitivity to the injury occurs when multiple evaluative measures are used collaboratively. The collective objective data should support the physical examination and should be used to avoid returning an athlete to play before the injury has resolved.

The risks associated with returning an athlete to play before full recovery from a concussion are unclear. For instance, concussion is known to have a deleterious effect on reaction time and decision making as measured through neurocognitive evaluations. If these cognitive attributes remain impaired when the athlete returns to play, the risk for injury resulting from delayed and/or errant on-field decision making exists. An early return to play also may occur within the window of increased susceptibility to recurrent injury that exists before complete neurometabolic resolution of the injury. Although rare, a premature return to play also may place the athlete at risk for catastrophic injury if he or she sustains a second concussive blow before the first concussion has resolved. The athlete’s risk of catastrophic brain injury secondary to premature return to play is controversial, but recommendations to limit postconcussion evaluations may result in an errant return-to-play decision.

The potential for serious injury warrants the further investigation of the interaction between symptom resolution and neurocognitive performance. The small number of complex concussions in this study makes deducing results for this group difficult. Large-scale investigations with groups containing an equal number of simple and complex concussions, as well as control subjects, are warranted. In addition, research investigating the incidence of concussed athletes underreporting their symptoms should be performed. Although we have no reason to suspect that our athletes underreported symptoms, high school athletes may not inform medical personnel of concussive injuries. The underreporting of the injury was attributed to not wanting to leave the game, fear of letting teammates down, or being unaware of the signs and symptoms associated with concussion.

Both experimental evidence and anecdotal reports suggest an underreporting of concussion symptoms may occur and may be related to similar issues. Our preliminary data suggest neurocognitive testing should be employed in all instances when making postconcussive return-to-play decisions. Some athletes with seemingly minor concussive injuries may continue to demonstrate cognitive impairment after symptom resolution. Regardless of the tools used for assessment, all athletes at high risk for concussion should receive a baseline evaluation on a battery of concussion assessment measures when free from injury and illness in the preseason. After concussion and before beginning an exertional return-to-play protocol, the athlete should no longer report any concussion-related symptoms at rest. Delaying postconcussive assessments until the athlete no longer reports symptoms will reduce the potential for practice effects, which may confound return-to-play decision making.

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