Tracking Neuropsychological Recovery Following Concussion in Sport

Grant L. Iverson
University of British Columbia & Riverview Hospital

Brian L. Brooks
University of Calgary & Riverview Hospital

Michael W. Collins & Mark R. Lovell
University of Pittsburgh Medical Center

Author Notes: This study was presented at the Second International Conference on Concussion in Sport, Prague, Czech Republic, November, 2004. The authors thank Michael Gaetz for his helpful comments on an earlier draft of this article, and Jennifer Bernardo for assistance with manuscript preparation. Please address correspondence to Grant Iverson, Ph.D., Department of Psychiatry, 2255 Wesbrook Mall, University of British Columbia, Vancouver, B.C. Canada, V6T 2A1. Additional information regarding ImPACT is available at www.impacttest.com.

Abstract

Primary Objective: The purpose of this study was to illustrate the serial use of computerized neuropsychological screening with ImPACT to monitor recovery in a clinical case series of injured athletes. Methods & Procedures: Amateur athletes with concussions (N = 30, average age = 16.1, SD = 2.1 years) underwent preseason testing and three post-concussion evaluations within the following intervals: 1-2 days, 3-7 days (M = 5.2 days), and 1-3 weeks (M = 10.3 days). The study selection criteria increased the probability of including athletes with slow recovery. Results: Repeated Measures ANOVAs revealed significant main effects for all five composite scores (verbal memory, visual memory, reaction time, processing speed, and total symptoms). In group analyses, performance decrements and symptoms relating to concussion appeared to largely resolve by 5 days post injury and fully resolve by 10 days. Athletes’ scores were examined individually using the reliable change methodology. At 1 day post injury, 90% had two or more reliable declines in performance or increases in symptom reporting. At 10 days, 37% were still showing two or more reliable changes from preseason levels. Conclusions: This study illustrates the importance of analyzing individual athletes’ test data because group analyses can obscure slow recovery in a substantial minority of athletes.

Key Words: Concussion, Mild Traumatic Brain Injury, Outcome, Sports

Introduction

There is no doubt that traditional and computerized neuropsychological tests are sensitive to cognitive decrements associated with concussions in sports in the initial hours and days post injury [1-11]. In a large prospective cohort study [12], 1,631 football players from 15 colleges completed preseason baseline testing during the 3 year study. Players with concussions (n = 94) and noninjured controls (n = 56) underwent assessment of symptoms, cognitive functioning, and postural stability immediately, 3 hours, and 1, 2, 3, 5, 7, and 90 days after injury. Based on group analyses, concussed athletes balance problems resolved within 3-5 days, self-reported postconcussion symptoms gradually resolved by day 7, and cognitive functioning improved
within 5-7 days. Notably, 91% of athletes returned to personal baseline levels of symptom reporting by 7 days.

The results from a six-year National Football League concussion study were recently published in a series of eight articles [13-20]. There were 650 players who experienced 887 concussions during the study period. The time taken to return to play was as follows: (1) day of injury = 56.0%, (2) 1-6 days = 35.9%, (3) 7-14 days = 6.5%, and (4) more than 14 days = 1.6% [13]. Athletes who returned to play in the same game had fewer and briefer signs and symptoms of concussion, and they had no significantly increased risk for a second injury either in the same game or during the season [20].

NFL players sustaining a concussion underwent baseline neuropsychological evaluations (N = 685) and then completed a second evaluation (N = 95) within a few days following their concussion (M = 1.4 days, SD = 1.3; [14]). Surprisingly, the players did not show a single statistically significant decrement on any neuropsychological test when seen in the first few days post injury. These results are inconsistent with studies in both collegiate and high school athletes, where cognitive decrements are more pronounced. It is possible that these results may indicate a selection bias (NFL athletes exhibit more rapid recovery) or that age and developmental factors may play a role in recovery from concussion. In fact, results from a recent study suggested that high school athletes might have slower recovery from concussive injury when compared to a matched collegiate sample [21].

Moreover, in the NFL study, athletes with a history of three or more concussions did not perform more poorly on neuropsychological testing than those with fewer than three [16]. This finding, too, appears mildly discrepant from studies with amateur athletes. Previous studies with high school and university athletes have suggested that three or more concussions are associated with small but measurable cumulative effects [22-24], and increased risk for future concussions [25,26].

It has become a fairly robust finding that athletes tend to recover in terms of perceived symptoms and cognitive test performance within 3-10 days [7,10,12,16,27,28]. Nonetheless, we know clinically that recovery in some athletes can be slow and extend well beyond this typical period. Moreover, there is gradually accumulating evidence that a history of three or more concussions is associated with long-term changes in neurophysiology [24], subjective symptoms [24,29], and neuropsychological test performance [29] in some athletes. Researchers have reported that athletes with three or more concussions are at increased risk for a future concussion [25], have worse onfield presentations of their next concussion [23], have greater acute changes in memory performance [29], and are more likely to have slowed recovery [25]. Clearly, concussions should be managed individually, like every other injury, with general trends and expectations used as a framework for considering the individual athlete’s unique symptoms, problems, and experiences.

Computerized neuropsychological testing increasingly is being used to monitor recovery from concussions in athletes [4,5,8,11,27,28,30]. The purpose of this study is to illustrate the clinical use of computerized neuropsychological testing for tracking recovery from concussion in a selected sample of 30 amateur athletes. Group and individual analyses are presented. This is not a prospective study. This should be considered a clinical case series.
Method

Participants
Participants were 30 amateur athletes who underwent baseline preseason neuropsychological screening. All athletes were seen three times during the acute recovery period following a concussion. Their average age was 16.1 years (SD = 2.1; Range = 12-21). Their average number of years of completed education was 10.0 (SD = 1.9). The breakdown of athletes by educational category was as follows: Junior High School = 17.2%, High School = 72.5%, and University = 10.3%. The vast majority of participants were young men (93.3%), and most were football players (87%). No athlete had a self-reported learning disability, received special education services, or repeated a grade. One athlete had self-reported ADHD (3.3%) and two indicated that they had received speech therapy services in the past (6.7%). Eight athletes reported that they had been treated by a physician for headaches in the past (26.7%), and six of them reported that these were migraine headaches (20%). The number of previous concussions in this sample was as follows: 0 = 73.3%, 1 = 13.3%, 2 = 6.7%, 3 = 3.3%, 4 = 0%, and 5 = 3.3%. At baseline testing, the athletes simply answered questions embedded in the computerized program. The accuracy of their answers cannot be verified.

Athletes were included in this study if (a) they underwent preseason testing, and (b) they completed three post-concussion evaluations within carefully defined time periods. Their first evaluation occurred one or two days post injury. Their second evaluation occurred between three and seven days post injury (M = 5.2, SD = 1.3), and their third evaluation occurred between one and three weeks post injury (M = 10.3 days, SD = 3.5).

Measure
Version 2.0 of ImPACT is a brief computer-administered neuropsychological test battery that consists of six individual test modules that measure aspects of cognitive functioning including attention, memory, reaction time, and processing speed. Each test module may contribute scores to multiple composite scores. Four composite scores were used for this study. In general, the test battery is designed to yield multiple types of information within a brief period of time. Each test module may contribute scores to multiple composite scores. The Verbal Memory composite score represents the average percent correct for a word recognition paradigm, a symbol number match task, and a letter memory task with an accompanying interference task. These tests are conceptually similar to traditional verbal learning (word list) tasks and the auditory consonant trigrams test (i.e., the Brown-Peterson short-term memory paradigm), although the information is presented visually on the computer, not auditorily by an examiner. The Visual Memory composite score is comprised of the average percent correct scores for two tasks; a recognition memory task that requires the discrimination of a series of abstract line drawings, and a memory task that requires the identification of a series of illuminated X’s or O’s after an intervening task (mouse clicking a number sequence from 25 to 1). The first test taps immediate and delayed memory for visual designs and the second test measures short-term spatial memory (with an interference task). The Reaction Time composite score represents the average response time (in milliseconds) on a choice reaction time, a go/no-go task, and the previously mentioned symbol match task (which is similar to a traditional digit symbol task). The Processing Speed composite represents the weighted average of three tasks that are done as interference tasks for the memory paradigms. In addition to the cognitive measures, ImPACT also contains a Post-Concussion
Symptom Scale that consists of 21 commonly reported symptoms (e.g. headache, dizziness, “fogginess”). The dependent measure is the total score derived from this 21-item scale. The reliability [31,32] and concurrent validity [33,34] of the cognitive composite scores and the Post-Concussion Symptom Scale [35-37], and the sensitivity of the battery to the acute effects of concussion [28,30,32,38,39] has been examined in a number of studies.

**Reliable Change Methodology**
The reliable change methodology allows the clinician to reduce the adverse impact of measurement error on test interpretation. To represent clinically significant improvement, the change score must be statistically reliable. However, the converse is not true; a statistically reliable change does not necessarily guarantee a clinically meaningful change. For example, if a patient demonstrated severely impaired memory performance 3 months after a severe traumatic brain injury, and then demonstrated statistically reliable improvement a few months later, yet the score was still very low (impaired), this change might not be interpreted as clinically meaningful improvement. In other words, there was real change for the better, but the patient was still quite impaired in this area of functioning.

We applied reliable change estimates from Iverson, Lovell, and Collins [32] based on a sample of 56 non-concussed adolescents and young adults who completed the ImPACT test battery on two occasions. These were calculated through a modification of the method proposed by Jacobson and Truax [40]. This methodology has been used extensively in clinical psychology [41-47], clinical neuropsychology [48-53], and sports neuropsychology [1,31,54]. The reliable change methodology allows the clinician to estimate measurement error surrounding test-retest difference scores. Specifically, the standard error of difference (S_{diff}) is used to create a confidence interval for the baseline-retest difference score. The steps for calculating the S_{diff} are provided below. Note that the test-retest reliability coefficient is used in these formulas to make them more relevant to the interpretation of change over time. Most researchers and test publishers use internal consistency reliability coefficients in their SEM formulas (of course, internal consistency reliability is almost always higher than test-retest, making the SEM smaller).

\[
SEM_1 = SD \sqrt{1 - r_{12}} \quad \text{Standard deviation from time 1 multiplied by the square root of 1 minus the test-retest coefficient.}
\]
\[
SEM_2 = SD \sqrt{1 - r_{12}} \quad \text{Standard deviation from time 2 multiplied by the square root of 1 minus the test-retest coefficient.}
\]
\[
S_{\text{diff}} = \sqrt{SEM_1^2 + SEM_2^2} \quad \text{Square root of the sum of the squared SEMs for each testing occasion.}
\]

There remains controversy regarding the reliable change methodology in general and which formulas to use in particular. This controversy has been ongoing in clinical psychology [46,55,56] and has recently occurred in neuropsychology [54,57,58]. The formula for the standard error of the difference has been known for many years, is reprinted in textbooks (e.g., [59]), and it is used by test publishers to examine differences between two scores, such as Verbal and Performance IQ scores [60]. Jacobson and Truax modified this formula and this set off formula-related confusion and controversy for many years. For several years, Iverson has encouraged the use of the original formula in neuropsychology research and practice when the
test-retest reliability and standard deviations are known [50-52,61]. The Jacobson and Truax formula uses the standard deviation from time one only. The purpose of this discussion is not to encourage controversy, but to simply explain our choice of the formula presented above. Moreover, we needed to use this formula to be consistent with the previously published reliable change estimates presented in Table 1.

Table 1. Quick Reference Reliable Change Estimates: 80% confidence Interval [32].

<table>
<thead>
<tr>
<th>Composite</th>
<th>Declined</th>
<th>Improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal Memory</td>
<td>9 points</td>
<td>9 points</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>14 points</td>
<td>14 points</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>.06 seconds</td>
<td>.06 seconds</td>
</tr>
<tr>
<td>Processing Speed</td>
<td>3 points</td>
<td>7 points</td>
</tr>
<tr>
<td>Post-Concussion Scale</td>
<td>10 points</td>
<td>10 points</td>
</tr>
</tbody>
</table>

Results

Descriptive statistics for the cognitive measures and symptom ratings are presented in Table 2. To evaluate for changes in cognitive functioning and postconcussion symptoms, Repeated Measures ANOVAs were used to determine if mean cognitive and symptom scores differed across the four assessments. Pairwise comparisons were based on estimated marginal means using the least significant difference method, which does not adjust for multiple comparisons. Therefore, the reader should have more confidence in pairwise results with alpha less than .01.

Table 2. ImPACT composite scores and postconcussion symptoms.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>Day 1</th>
<th>Day 5</th>
<th>Day 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal Memory</td>
<td>83.2</td>
<td>71.6</td>
<td>77.9</td>
<td>80.3</td>
</tr>
<tr>
<td></td>
<td>(7.7)</td>
<td>(15.0)</td>
<td>(9.9)</td>
<td>(10.5)</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>69.9</td>
<td>62.5</td>
<td>69.4</td>
<td>73.1</td>
</tr>
<tr>
<td></td>
<td>(14.4)</td>
<td>(13.6)</td>
<td>(14.6)</td>
<td>(13.3)</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>.58</td>
<td>.72</td>
<td>.65</td>
<td>.60</td>
</tr>
<tr>
<td></td>
<td>(.09)</td>
<td>(.16)</td>
<td>(.14)</td>
<td>(.11)</td>
</tr>
<tr>
<td>Processing Speed</td>
<td>38.3</td>
<td>29.7</td>
<td>34.8</td>
<td>37.0</td>
</tr>
<tr>
<td></td>
<td>(7.9)</td>
<td>(8.4)</td>
<td>(7.5)</td>
<td>(9.0)</td>
</tr>
<tr>
<td>Postconcussion Symptoms</td>
<td>7.2</td>
<td>26.6</td>
<td>8.8</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>(9.0)</td>
<td>(16.4)</td>
<td>(8.8)</td>
<td>(9.6)</td>
</tr>
</tbody>
</table>

Note: Baseline was preseason. Day 1 (1-2 days), Day 5 (3-7 days), and Day 10 (7-19 days) post injury.
For the verbal memory composite score, there was a significant main effect for time \([F(3, 87) = 9.0, p < .001, \text{epsilon}.89, \text{eta squared} = .24]\). This is a medium to large effect size; approximately 24% of the variability in verbal memory scores was related to the variability in the time of measurements.

Compared to baseline, verbal memory scores were significantly lower at 1 day \((p < .001, \text{Cohen’s d} = 1.0, \text{large effect size})\) and 5 days \((p < .03, \text{Cohen’s d} = .60, \text{medium effect})\), but not at 10 days post injury. There was a significant improvement from 1 day to 5 days post injury \((p < .03, \text{d} = .51, \text{medium effect})\).
For the visual memory composite score, there was a significant main effect for time \([F(3, 87) = 5.3 \ p < .001, \ \text{epsilon} > .94, \ \text{eta squared} = .16, \ \text{medium effect}]\). Compared to baseline, visual memory scores were significantly lower at 1 day post injury \((p < .02, \ d = .53, \ \text{medium effect size})\), but not at 5 or 10 days post injury. There was a significant improvement from 1 day to 5 days post injury \((p < .02, \ d = .49, \ \text{medium effect})\).

Figure 3. ImPACT processing speed composite score.

For the processing speed composite, there was a departure from the assumption of sphericity (i.e., Huyn-Feldt Epsilon = .68). There was an overall main effect for time \([F (2.0, 59.3) = 9.5, \ p < .001; \ \text{Huyn-Feldt adjusted F}]\). Eta squared was .25, a medium to large effect size. Compared to baseline, processing speed scores were significantly lower at 1 day post injury \((p < .001, \ d = 1.1, \ \text{large effect size})\), but not at 5 or 10 days post injury. There was a significant improvement from 1 day to 5 days post injury \((p < .001, \ d = .64, \ \text{medium effect})\).
For the reaction time composite score, there was a significant main effect for time \[ F(3, 87) = 5.3 \ p < .001, \text{ epsilon } > .96, \text{ eta squared } = .30, \text{ medium-large effect size} \]. Compared to baseline, reaction time scores were significantly slower at 1 day post injury \( p < .001, d = 1.2, \text{ large effect size} \) and at 5 days post injury \( p < .007, d = .61, \text{ medium effect} \), but not at 10 days post injury. There was a significant improvement from 1 day to 5 days post injury \( p < .02, d = .48, \text{ medium effect} \) and from 5 days to 10 days post injury \( p < .03, d = .4, \text{ medium effect} \).

Figure 5. ImPACT symptom score.
Table 3. Serial reliable change comparisons for individual athletes: Preseason – day 1, day 1 – day 5, day 5 – day 10.

<table>
<thead>
<tr>
<th>Subject</th>
<th>VM</th>
<th>VsM</th>
<th>PS</th>
<th>RT</th>
<th>Sy</th>
<th>VM</th>
<th>VsM</th>
<th>PS</th>
<th>RT</th>
<th>Sy</th>
<th>VM</th>
<th>VsM</th>
<th>PS</th>
<th>RT</th>
<th>Sy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>-</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>-</td>
<td>-</td>
<td>↑</td>
<td>-</td>
<td>↑</td>
<td>↑</td>
<td>-</td>
<td>-</td>
<td>−</td>
<td>-</td>
<td>↑</td>
</tr>
<tr>
<td>2.</td>
<td>↓</td>
<td>-</td>
<td>↓</td>
<td>↓</td>
<td>↑</td>
<td>↑</td>
<td>-</td>
<td>-</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>-</td>
<td>↑</td>
<td>-</td>
</tr>
<tr>
<td>3.</td>
<td>-</td>
<td>-</td>
<td>↑</td>
<td>↓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>↑</td>
<td>↑</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4.</td>
<td>-</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>-</td>
<td>-</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>↑</td>
</tr>
<tr>
<td>5.</td>
<td>↓</td>
<td>-</td>
<td>↓</td>
<td>↓</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>-</td>
<td>-</td>
<td>↓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6.</td>
<td>↓</td>
<td>↓</td>
<td>-</td>
<td>↓</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>-</td>
<td>-</td>
<td>↑</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7.</td>
<td>↓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>↑</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>↓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>↑</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10.</td>
<td>↓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11.</td>
<td>↓</td>
<td>↓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12.</td>
<td>↓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>16.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>17.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>18.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>19.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>21.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>22.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>23.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>26.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>27.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>28.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>29.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>30.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: VM = Verbal Memory, VsM = Visual Memory, PS = Processing Speed, RT = Reaction Time, Sy = Total Symptoms. “↓” = reliable worsening, “↑” = reliable improvement, and “-” = no reliable change. The direction of the arrow is standard. Thus, for the total symptoms scores, lower scores reflect fewer symptoms which reflects improvement (thus the arrow would go up).

For the symptom total score, there was a departure from the assumption of sphericity (i.e., Huyn-Feldt Epsilon = .83). There was an overall main effect for time \[F (2.5, 71.7) = 35.7, p < .001; Huyn-Feldt adjusted F]\. Eta squared was .55, a large effect size. Compared to baseline, there was a significant increase in symptoms at 1 day post injury \(p < .001, d = 1.5, \) very large effect size\), but not at 5 or 10 days post injury. There was a significant improvement in symptoms from day 1
to day 5 (p < .001, d = 1.4, very large effect) and from day 5 to day 10 (p < .05, d = .36, small-medium effect).

The reliable change methodology was used to examine the composite scores for every athlete across the assessment intervals. The reliable change difference scores presented in Table 1 were used. Scores from day 1 were compared to preseason, scores from day 5 were compared to day 1, and scores from day 10 were compared to day 5. These results are presented in Table 3.

The examination of scores derived from individual athletes reveals similar and different findings as compared to the group analyses. The number of athletes who showed statistically reliably worse performance or symptoms at day 1 compared to preseason was as follows: Verbal Memory = 60%, Visual Memory = 30%, Processing Speed = 67%, Reaction Time = 70%, and Total Symptoms = 73%. Nearly all athletes (27/30, 90%) had two or more statistically reliable changes at day 1. At the third assessment interval, approximately 10 days post injury, 37% of the athletes still had 2 or more composite scores that were reliably worse than their preseason scores.

Of the athletes with pre-existing headaches or two or more previous concussions, 50% had not recovered by the third assessment period (compared to 30% of athletes who did not have either of these pre-injury factors). This was not a statistically significant difference; however, given the small sample sizes power was low for this analysis.

Discussion

This should not be considered a prospective study on outcome from concussion in amateur athletes. Instead, this study was designed to illustrate the use of computerized neuropsychological testing to monitor recovery. The sample should not be considered representative of all concussed athletes. These individuals were selected from a database because they met specific inclusion criteria: (a) they underwent preseason testing, and (b) they completed three post-concussion evaluations within carefully defined time periods (1-2 days, 3-7 days, and 1-3 weeks). The selection criteria increased the probability that we would study athletes who were more seriously concussed, slow to recover, or both. This is because a percentage of athletes in the database did recover at the second evaluation period (3-7 days) and were not included in the current analysis.

With those caveats in mind, the group analyses showed the expected findings. Consistent with the literature, athletes performed worse on neuropsychological testing and reported a large number of symptoms at one day post injury, with improvement and resolution of these problems by 5-10 days post injury [7,12,16,27,28,62]. However, the group analyses obscured important individual differences in recovery patterns. The number of athletes who showed statistically reliably worse test performance or symptoms at day 1 compared to preseason was as follows: Verbal Memory = 60%, Visual Memory = 30%, Processing Speed = 67%, Reaction Time = 70%, and Total Symptoms = 73%. Nearly all athletes (27/30, 90%) had two or more statistically reliable changes at day 1. At the third assessment interval, approximately 10 days post injury, 37% of the athletes still had 2 or more composite scores that were reliably worse than their preseason scores. Two or more declines are rare in healthy young people tested twice, occurring
in less than 5% [32]. As seen in Figures 1-5, this subset of unrecovered athletes was obscured in
the group analyses.

When individual athletes’ scores are examined, a number of specific issues and patterns can be
identified. First, some athletes might perform poorly at preseason (e.g., #26; Verbal Memory = 79 and Visual Memory = 46). If this represents a bad day and unusually poor performance, this
will obviously complicate post-injury comparisons. Second, some athletes report a large number
of symptoms at preseason (e.g., #7 = 34, #16 = 21, and # 29 = 29). It is important to remember
that the Postconcussion Scale is comprised of symptoms that are also associated with depression,
anxiety, stress, sleep problems, and other problems. The Postconcussion Scale should be
considered a “state” measure, not a “trait” measure. Thus, athletes who report a large number
of symptoms at baseline who are later concussed should be compared to normative data for the test,
not their personal baseline scores. Third, some athletes appear to improve and recover very
quickly (e.g., #17 and #28). Fourth, some athletes appear to improve gradually (e.g., #20).
Finally, some athletes improve gradually but don’t fully recover within 3 weeks (e.g., #15 and
#16).

Although research regarding the recovery of concussed athletes has most often relied on the
analysis of group data, analyses of this type may obscure individual variations in recovery.
Therefore, it is important to evaluate individual recovery with regard to the number of athletes
who continue to demonstrate neurocognitive or neurobehavioral sequelae at various points
during the recovery process.

References

[1] Barr WB, McCrea M. Sensitivity and specificity of standardized neurocognitive testing
immediately following sports concussion. Journal of the International Neuropsychological

[2] Collins MW, Grindel SH, Lovell MR et al. Relationship between concussion and
neuropsychological performance in college football players. Journal of the American
Medical Association 1999;282:964-70.


neuropsychological test protocol for sports-related return-to-play decision-making. Archives

athletes: Preliminary results of a web-based neuropsychological test protocol. Journal of


[41] Hageman WJ, Arrindell WA. A further refinement of the reliable change (RC) index by improving the pre-post difference score: introducing RCID. Behavior Research and Therapy 1993;31:693-700.


