The Relationship of Athlete-Reported Concussion Symptoms and Objective Measures of Neurocognitive Function and Postural Control

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Objective: Concussed athlete evaluations often include symptoms, balance, and neurocognitive assessments. We sought to identify the relationship between subjective symptom reports and objective clinical measures.

Design: A retrospective assessment.

Setting: A research laboratory.

Patients: Concussed collegiate-level athletes (N = 32, 19.7 years) evaluated pre- and postinjury (less than 48 hours).

Intervention: Each athlete completed an inventory of concussion-related symptoms, the NeuroCom Sensory Organization Test (SOT), and ImPACT neurocognitive assessment. Spearman correlations between balance symptoms and SOT scores and cognitive symptoms and ImPACT scores were completed.

Main Outcome Measures: Symptoms related to balance and cognitive deficits, SOT composite balance and visual, vestibular, and somatosensory ratios, and ImPACT output scores.

Results: Significant Spearman correlations were noted between reports of “dizziness” and the SOT composite balance ($r_s = -0.55$) and vestibular ratio ($r_s = -0.50$). Similarly, “balance problems” were significantly correlated with composite balance ($r_s = -0.52$) and the somatosensory ($r_s = -0.41$), visual ($r_s = -0.39$), and vestibular ratios ($r_s = -0.57$). The cognitive symptom of “feeling mentally foggy” and ImPACT variables of reaction time ($r_s = 0.36$) and “difficulty concentrating” and verbal memory score ($r_s = -0.41$) were significantly related. Finally, reports of “difficultly remembering” were significantly related to the verbal memory score ($r_s = -0.48$) and reaction time ($r_s = 0.36$).

Conclusions: These findings indicate self-report symptoms are associated with athlete deficits in postural control and cognitive function. The moderate relationship between the symptom reports and the objective measures warrants the continued use of all measures. A reduction in the number of symptoms concussed athletes respond to may be justified to reduce redundancy.

Key Words: sport concussion, symptoms, balance, cognitive function (Clin J Sport Med 2009;19:377–382)

INTRODUCTION

Concussion has been described as a diffuse injury affecting many areas of the brain. A wide variety of outcomes are associated with concussion and have been linked to a previous injury history, the location and magnitude of impact, age, and sex. Medical organizations therefore have recommended a battery of tests be used to assist the clinician in diagnosing and managing athletes suspected of sustaining a concussion. Although assessments for a number of domains have been implemented, tests of cognitive functioning, postural control, and self-report concussion-related symptoms have all been shown to be negatively affected after a concussion.

The cognitive assessment has been described as the cornerstone of the concussion assessment battery, and countless tests have been used to evaluate various aspects of cognitive functioning. The areas of information processing, planning, memory, and switching mental set are generally considered the most important. Pencil-and-paper-based examinations have traditionally been implemented to evaluate these domains, but computer-based testing has recently become widely adopted. In collegiate athletes who have completed a baseline evaluation, computer tests indicate a return to normal functioning approximately 7 days post-injury. Professional and high school athletes also recover quickly, although the timing may vary.

Deficits to balance after concussion have been noted for some time, but the quantification of postural control is a recent addition to the concussion assessment battery. Some have suggested that this assessment tool is more sensitive to postconcussion decrements than traditional pencil and paper tests. Field-based tests such as the Balance Error Scoring System have broad applicability, but the Sensory Organization Test appears to provide the clinician the best information on balance function. Functional recovery of postural control in most athletes follows a similar pattern as that of neurocognitive function with restoration ranging from 3 to 5 days.

The largest effects of concussion are associated with increased symptom reports leading clinicians to adopt this
tool as the primary evaluative technique for concussion assessment.10 An abundant number of symptom scales are available in the literature, many of which have been endorsed by various organizations.6,9 An inherent limitation with these tools, however, is the well-documented underreporting of symptoms by injured athletes.16 Regardless, each list contains symptoms that typically fall into the somatic (eg, dizziness), neuropsychiatric (eg, irritability), and cognitive (eg, difficulty concentrating) categories.17 Symptom resolution varies based on injury severity, but in most, concussed young adults recover in a few days after injury.7

Implementing a multifaceted approach to concussion management provides the clinician unique information from a variety of domains.18,19 In many settings, however, not all assessment tools are used in the evaluative process. With athlete-reported symptoms serving as the primary assessment tool, often in absence of a neurocognitive or postural evaluation, the validity of self-report symptoms to accurately reflect postural control and cognitive function is not clear. Therefore, the purpose of this investigation was to evaluate the relationship between self-report concussion-related symptoms and cognitive and postural control functioning in concussed athletes. Specifically, we hypothesize that postconcussion symptom reports of “dizziness” and “balance difficulties” will be accurately reflected in decreased postural control. We also predict that “feeling in a fog,” “difficulty concentrating,” and “difficulty remembering” will mimic decreased cognitive performance.

METHODS

As part of an ongoing investigation of concussion’s effect on postural control, neurocognitive functioning, and self-report symptoms, all athletes (eg, American football, soccer, gymnastics, and cheerleading) at our university at high risk for concussion received a baseline evaluation before the competitive season. The baseline evaluation consisted of the NeuroCom Sensory Organization Test (SOT) and the ImPACT neurocognitive assessment. Athletes also completed the Post-concussion Symptom Scale, a self-report inventory of concussion-related symptoms20 that is embedded within the ImPACT software. All baseline neurocognitive tests were completed in small groups (less than 5) and balance testing was completed individually. The operational definition of concussion was adopted from the American Academy of Neurology.21 In the event an athlete sustained a concussion during sport participation, the on-field diagnosis was made by a certified athletic trainer, confirmed by the team physician, and a follow-up assessment was completed within 48 hours. The follow-up assessment was the same assessment battery as the baseline evaluation with both neurocognitive and balance testing occurring individually. Each athlete provided written informed consent before testing.

As previously described,22 the ImPACT neurocognitive assessment is a computer-based evaluative tool that uses 6 modules to generate 5 composite scores. The composite scores include verbal memory, visual memory, processing speed, and reaction time. The Post-concussion Symptom Scale includes a list of symptoms commonly associated with concussion. Participants indicate the presence or absence of each symptom from the time of injury or within the 24 hours before testing. If the athlete indicated he or she has experienced the symptom, then the symptom severity was graded on a 1- to 6-point Likert scale. The ImPACT has been widely adopted for use in a number of interscholastic, collegiate, and professional settings.12,23 The sensitivity to cognitive decline after concussion appears to be high.18,24 Time to complete the ImPACT was approximately 20 minutes.

The SOT is a computer-driven postural control assessment that implements 6 balance conditions that challenge or remove components of the balance mechanism (eg, visual and/or somatosensory). The test generates 4 output scores, including a composite balance score and ratio scores for the somatosensory, visual, and vestibular components of balance. The SOT has been adopted at the collegiate level15,25 and shows moderate sensitivity to postural control changes after injury.18 Time to complete the SOT was approximately 20 minutes.

Data Analysis

Data from 36 concussed athletes were collected; however, not all athletes were included in all analyses. For example, some did not complete the SOT or ImPACT examinations at baseline or follow up because of time constraints or exacerbation of symptoms.

Multiple Spearman rank correlation coefficients were calculated between symptom reports and the baseline to postconcussion change scores (ie, follow up minus baseline) on the SOT and ImPACT variables. Change scores were imputed to account for individual performance variation known to occur with this type of testing. Likert scores for the balance symptoms of “dizziness” and “balance problems” were correlated to the SOT change scores for composite balance, visual ratio, vestibular ratio, and somatosensory ratio. Separate Spearman rank correlation coefficients analyses were completed for the cognitive symptoms of “feeling mentally foggy,” “difficulty concentrating,” and “difficulty remembering” with the change scores of the ImPACT output variables of verbal memory, visual memory, processing speed, and reaction time. All analyses were completed using SPSS Version 16.0 (Chicago, Illinois) and significance was noted as $P < 0.05$.

RESULTS

Of the 36 athletes whose data were included in this investigation, 32 were included in the final analysis: 23 football, 5 cheerleading, 3 soccer, and 1 equestrian athlete. Athletes completed baseline assessments from 2004 to 2005 and postinjury evaluations were completed through 2006. Consistent with previous investigations,26 data from 4 athletes were removed based on invalid baseline performance as indicated by the ImPACT test.22 Of the athletes included in the analyses, 75.0% (n = 24) were male and all athletes had a mean (standard deviation) age of 19.7 (1.2) years, height of 179.8 (11.9) cm, and body mass of 89.9 (27.9) kg. Sixteen of the athletes reported previously sustaining a concussion with a mean of 1.1 (1.8) injuries. Among all athletes, 59.4% (n = 19) reported experiencing at least 1 symptom of interest.
during postinjury testing (Table 1). The athletes may have reported other symptoms not evaluated for this investigation.

Data from 26 athletes were included in the assessment of symptoms and postural control. SOT data from the remaining 6 athletes were excluded because of missing baseline or follow-up assessments. Of those included in the analyses, 46.2% (n = 12) of the athletes endorsed 1 or more symptoms related to postural control and 19.2% (n = 5) were identified as having a clinically significant change in postural control.27 Three (11.5%) of these athletes reported balance-related symptoms and showed significant postural control declines. The SOT scores of those reporting and not reporting any postural control-related symptoms are found in Table 2. Spearman correlation calculations between the self-report balance symptom of “dizziness” and “balance problems” and the SOT variables of composite balance and the visual, vestibular, and somatosensory ratios are presented in Table 3. Significant correlations were noted between the symptom of “dizziness” and the vestibular ratio and “balance problems” and composite balance, somatosensory ratio, visual ratio, and the vestibular ratio change scores.

Data from all 32 athletes were included in the assessment of symptoms and cognitive functioning. Cognitive-related symptoms were endorsed by 59.4% (n = 19) of the athletes with 68.8% (n = 22) showing significant declines in cognitive function.22 Fourteen (43.4%) of these athletes endorsed cognitive functioning symptoms and demonstrated significant declines on the ImPACT battery.

The ImPACT scores of those reporting and not reporting any memory-related symptoms are found in Table 2. The correlation calculations between the cognitive symptoms and ImPACT output scores can be found in Table 3. Significant correlations were noted between the symptom of “feeling mentally foggy” and the ImPACT change score for reaction time; “difficulty concentrating” and the composite verbal memory score; and “difficulty remembering” and composite verbal memory score and reaction time.

Of the athletes completing all aspects of the assessment battery (n = 26), 19 (73.1%) showed significant declines on the objective balance or cognitive assessments and 17 (65.4%) reported postinjury balance or cognitive symptoms. When all aspects of the assessment battery were combined, 23 of the athletes (88.5%) declined in objective and/or subjective measures.

Once it established that significant relationships were present between changes in postural control and balance-related symptoms and changes in cognitive functioning and memory symptoms, a secondary analysis correlating balance and cognitive symptoms was performed. The analyses indicated significant relationships between self-report “balance problems” and “feeling mentally foggy” (r = 0.59; P < 0.00), “difficulty concentrating” (r = 0.67; P < 0.00), and “difficulty remembering” (r = 0.58; P < 0.00). In addition, reports of “dizziness” were significantly correlated with “feeling mentally foggy” (r = 0.55; P < 0.00), “difficulty concentrating” (r = 0.66; P < 0.00), and “difficulty remembering” (r = 0.55; P < 0.00).

**DISCUSSION**

The results of this study are the first to show athlete reports of concussion-related symptoms are associated with objective clinical measures of postural control and cognitive functioning. Specifically, moderate relationships were noted between the balance-related symptoms of “dizziness” and “balance problems” and an objective measure of postural control. Furthermore, the cognitive symptoms of “feeling mentally foggy,” “difficulty concentrating,” and “difficulty remembering” were correlated with a number of variables generated by a common clinical measure of neurocognitive functioning. With exception to the reaction time correlations, the negative relationships of these correlations suggest that as the athlete reports of symptom severity increase, their performance on the clinical tests declines in a similar manner. Positive correlations with reaction time indicate longer (ie, worse) responses as more severe symptoms are reported.

The strongest correlations between athlete reports of balance-related symptoms and the objective balance test were centered around the vestibular ratio and the composite balance scores. Other investigations have shown complaints of “dizziness” to be commonly associated with vestibular pathology28 and suppressed vestibular functioning has been previously demonstrated in concussed athletes.13,15 It stands to reason that those with impaired vestibular performance resulting from concussion would be unable to maintain their overall balance and therefore have suppressed composite balance scores. These individuals would likely report general balance problems in the form of both “dizziness” and “balance problems” asked on the symptom inventory.

Correlations between athlete reports of cognitive symptoms and the suppressed performance on the clinical neurocognitive assessment appear to be centered on reaction time and verbal memory. These cognitive variables are commonly affected by concussion29–31 and have a logical relationship to the athletes’ symptom reports. That is, athletes who reported “difficulty concentrating” and “difficulty remembering” are likely to have an impaired ability focus on the word list and recall the words in both the short-term and long-term memory portions of the ImPACT. Furthermore, “mental fogginess” may account for delays in reaction time at the time of recall. It is unclear, however, why the ImPACT test variables of visual memory and processing speed were not correlated. It is beyond the scope of this investigation to

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**TABLE 1. Athlete Distribution of Symptom Reports Related to Postural Control and Memory**

<table>
<thead>
<tr>
<th>Likert Ranking</th>
<th>0*</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance problems</td>
<td>0.75 (1.24)</td>
<td>21</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Dizziness</td>
<td>0.75 (1.41)</td>
<td>23</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Feeling mentally foggy</td>
<td>1.62 (1.86)</td>
<td>16</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>1.09 (1.33)</td>
<td>15</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Difficulty remembering</td>
<td>0.53 (0.98)</td>
<td>23</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
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</tbody>
</table>

*Zero indicates the athlete did not endorse the symptom. Items are not mutually exclusive.
elucidate the anatomic source of the dysfunction, but it is reasonable to believe that outcome variability associated with concussion may have resulted in those domains not being affected in this cohort.

These are the first data to link objective measures of balance and subjective reports of balance difficulties in concussed athletes. The lack of strong significant relationships between balance-related symptoms and various measures of postural control suggests that only some of the concussed athletes were able to accurately identify their postinjury impairments, the athletes were unwilling to report the deficits, or the balance assessment was not sensitive to the concussion-related decrements in postural control. In general, symptom reports did not mimic the findings on objective clinical measures because those reporting balance-related symptoms (46%) exceeded those showing impaired postural control (19%). This disparity may be explained by the low sensitivity (57%) of the SOT established using reliable change indices. Other investigators have used a 1 standard deviation cutoff to determine significant change over the baseline evaluation. Using a 1 standard deviation change criteria, 57.7% (n = 15) of our sample would have been identified as having a significant decline in postural control after the concussion. The 1 standard deviation criteria results in a tighter link between athletes’ reports and clinical findings but a 10% difference between those reporting changes in postural control and what is demonstrated using objective measures remains. It is therefore possible that concussed athletes are not aware of their postural control changes or they may have reason to suppress these changes to expedite return to play. The continued inclusion of postural control-related symptoms is warranted as a guide for implementing objective balance tests, but further work is needed to develop more sensitive cut scores when interpreting SOT variables and educating athletes on the severity of concussion and the risks of returning to play too soon.

The relation between athlete reports of memory-related symptoms and impaired cognitive functioning was more closely linked than the postural control counterparts. This difference is likely explained by the copious research used in developing cognitive assessments relative to postural control assessments. Ultimately, the cognitive tests produce a higher sensitivity to concussion’s deleterious effects than the balance assessments implemented here and elsewhere. Regardless, it has often been speculated that some athletes will minimize their reporting of concussion-related symptoms making the use of objective measures a necessity. The results presented here suggest that 10% of those with a diagnosed concussion may suppress their cognitive symptoms or may not be aware of minor changes in cognitive functioning. Regardless, the moderate strength of the correlations for both the balance and cognitive assessment suggests that a large portion of the variance remains unaccounted.

The findings from this investigation also suggest some redundancy is inherent in the symptoms athletes are asked to report after injury. Specifically, the balance-related symptoms both correlate to portions of the SOT test and the memory-related symptoms all correlate with the ImPACT measures of reaction time and/or verbal memory. Some reports suggest that removing items from the symptom list that provide little clinical information or are redundant with other items will improve their efficacy. For example, Piland recommends the removal of “difficulty remembering” by suggesting it provides

### TABLE 2. Mean Scores (Standard Deviation) on the NeuroCom Sensory Organization Test of Those Endorsing Balance Symptoms and the ImPACT for Those Endorsing Memory Symptoms

<table>
<thead>
<tr>
<th>Mean Stability</th>
<th>Somatosensory Ratio</th>
<th>Visual Ratio</th>
<th>Vestibular Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes (n = 11)</td>
<td>77.09 (14.24)</td>
<td>95.78 (3.47)</td>
<td>88.00 (12.13)</td>
</tr>
<tr>
<td>No (n = 17)</td>
<td>81.35 (9.77)</td>
<td>95.49 (4.26)</td>
<td>90.09 (11.16)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Memory Composite–Verbal</th>
<th>Memory Composite–Visual</th>
<th>Visual Motor Speed</th>
<th>Reaction Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes (n = 19)</td>
<td>81.58 (10.10)</td>
<td>67.21 (10.81)</td>
<td>37.56 (7.62)</td>
</tr>
<tr>
<td>No (n = 13)</td>
<td>87.46 (10.00)</td>
<td>71.77 (13.36)</td>
<td>37.34 (7.76)</td>
</tr>
</tbody>
</table>

### TABLE 3. Spearman Correlation Coefficients (P Value) Balance-Related Symptoms and Sensory Organization Test (SOT) Variables and Cognitive Symptoms with ImPACT Variables

<table>
<thead>
<tr>
<th>SOT–Composite Balance</th>
<th>SOT–Somatosensory Ratio</th>
<th>SOT–Visual Ratio</th>
<th>SOT–Vestibular Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance problems</td>
<td>–0.52 (&lt;0.00)*</td>
<td>–0.41 (0.03)*</td>
<td>–0.39 (0.04)*</td>
</tr>
<tr>
<td>Dizziness</td>
<td>–0.55 (&lt;0.00)*</td>
<td>–0.26 (0.17)</td>
<td>–0.35 (0.06)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ImPACT–Verbal Memory</th>
<th>ImPACT–Visual Memory</th>
<th>ImPACT–Visual Motor Speed</th>
<th>ImPACT–Reaction Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeling mentally foggy</td>
<td>–0.13 (0.44)</td>
<td>–0.28 (0.10)</td>
<td>–0.17 (0.33)</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>–0.41 (0.01)*</td>
<td>–0.07 (0.68)</td>
<td>–0.15 (0.37)</td>
</tr>
<tr>
<td>Difficulty remembering</td>
<td>–0.48 (&lt;0.00)*</td>
<td>–0.11 (0.53)</td>
<td>–0.32 (0.05)</td>
</tr>
</tbody>
</table>

*Significance at P < 0.05.
similar information to the symptom of “difficulty concentrating.” Our results find these 2 symptoms correlate nearly equally with the ImPACT verbal memory score, but “difficulty remembering” also correlates with the reaction time measure in addition to the verbal memory score. Thus, the removal of the “difficulty concentrating” symptom may be more appropriate than “difficulty remembering.” In a follow-up investigation, Piland merged “balance problems” with “dizziness” to validate their shorter symptom scale.33 Our results would support the opposite response because all variables generated by the SOT correlated with “balance problems” but not with “dizziness.” Differing results between our investigation and those reported previously in this article may be accounted for by differences in cohort size and demographics or differences in the symptom instrument and instructions used when administering them.

Finally, it has been suggested that concussion-related cognitive and postural deficits are associated34 and the finding of a strong correlations between athlete reports of balance and cognitive symptoms supports this proposal. Additionally, these findings support the notion that concussion may not be diffuse injury in which multiple areas may be influenced,1 but rather an injury that affects a shared mechanism influencing both motor and cognitive functions. The inability to identify the specific cerebral anatomy affected by the injuries included in this study makes this conclusion speculative. Future research evaluating functional performance of the brain may be able to elucidate this hypothesis.

The significant correlations found between athlete reports of concussion-related symptoms and objective measures of postural control and neurocognitive function clarify the athlete’s ability to accurately identify concussion-related impairments. The large portion of unexplained variance, however, warrants caution when interpreting these results. We cannot assume that all athletes reported the presence of all concussion-related symptoms or the full extent of the symptoms they are reporting. Furthermore, the strength of the symptoms that were reported is a subjective measure that may be influenced by a number of personal or social factors.35 This necessitates the continued use of both the subjective symptom reports and the objective clinical measures used here for the purposes of assessing athletes suspected of sustaining a concussion.

The results of this investigation further bolster the use of a multifaceted approach to concussion management. Clinicians relying solely on the symptom inventory are cautioned that not all athletes are able or willing to accurately report the number and magnitude of symptoms observable by other measures. This is highlighted by the 10% of our sample that was unable or unwilling to provide accurate reports of balance or cognitive impairments that were evident when evaluated by objective tests. As such, concussive injuries necessitate an individualized management approach that includes a baseline and postinjury evaluation with a multifaceted approach that combines both subjective reports of concussion-related symptoms and objective measures of balance and cognitive function. In combination, the sports medicine practitioner has access to the most sensitive information for making the concussion diagnosis. For example, computer-based neurocognitive testing alone only identified 63% of concussed individuals as impaired.18 When combined with postconcussion symptoms, however, the sensitivity is bolstered to over 82%17 with similar results when postural control measures are combined with symptom reports. The complete battery of assessment tools, however, can accurately identify over 90% of concussed athletes.18

REFERENCES


