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Do Postconcussive Symptoms Discriminate Injury Severity in Pediatric Mild Traumatic Brain Injury?

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Abstract

Objectives—To assess whether postconcussive symptoms (PCS) can be used to discriminate injury severity among children with mild traumatic brain injury (TBI).

Participants—One hundred eighty-six children with mild TBI, divided into high and low injury severity depending on whether the injury was associated with a loss of consciousness (LOC), and a comparison group of 99 children with orthopedic injuries (OI), all aged 8 to 15 years at the time of injury.

Main Measures—Parent-rated frequency and severity of PCS at initial assessment within 2 weeks postinjury and again at 3 and 12 months postinjury.

Results—Ratings of PCS obtained at the initial and 3-month assessments differentiated children with mild TBI from OI, although only ratings at the initial assessment discriminated among all 3 groups. Somatic PCS accounted for most of the discriminatory power.

Conclusions—Overall, the accuracy of group classification was relatively modest, with a large proportion of misclassifications of children in the mild-TBI groups. Although children with mild TBI have more PCS than children with OI, PCS do not permit sufficiently accurate discrimination of mild TBI and injury severity to warrant diagnostic decisions at this time.

Keywords

brain injuries; child; postconcussion symptoms

Each year in the United States, approximately 1.4 million people suffer from a traumatic brain injury (TBI); about one-third of those injuries occur in children,[1] making it one of the

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leading causes of childhood morbidity and mortality.[2] Injuries can be divided by severity into mild, moderate, and severe cases. Mild TBI accounts for approximately 80% to 90% of all TBIs.[3] Although long-term neurocognitive deficits are rare following mild TBI, children with mild TBI are more likely to display significant and persistent postconcussive symptoms (PCS) than children with other types of injuries.[4–6] *Postconcussive symptoms* can be defined as cognitive, behavioral, emotional, or somatic symptoms that are more frequent or severe than those reported by children with injuries not involving the head. Complaints most often reported include headaches, dizziness, poor concentration or memory, and moodiness. Although PCS resolve within several weeks in many cases, they can persist for months and sometimes years following injury.[5–7]

Many researchers posit that the onset, persistence, and severity of PCS are linked to injury severity.[4,8] Research on children with mild TBI demonstrates both indirect and direct links between injury severity and PCS. Glasgow Coma Scale (GCS) scores, assumed to reflect the brain's response to trauma, correlate with the number of PCS present at 6 weeks postinjury.[4] In children with more serious TBI, severity of TBI (ie, moderate and severe) accounts for unique variance in cognitive-somatic and emotional-behavioral symptoms across the first year postinjury.[9] In addition, children with more severe mild TBI, as defined by a greater number of clinical features displayed (eg, loss of consciousness [LOC], GCS < 15, number of acute symptoms of concussion), demonstrate a higher likelihood of evidencing more acute and persisting PCS than those with less severe mild TBI.[7]

Studies involving neuroimaging have provided more direct evidence of a connection between the extent of brain injury and PCS in children with mild TBI. In one study, increases in PCS from preinjury baseline to 3 months postinjury were related to both neuropsychological test impairment and smaller white matter volumes.[6] Another study using single-photon emission computed tomography to analyze regional patterns of blood flow showed that hypoperfusion in the temporal lobe was common in children with mild TBI, and these perfusion abnormalities were more common in individuals with more severe mild TBI.[10] Most importantly, children with mild TBI displaying medial temporal hypoperfusion were more likely to show persistent PCS than those without these abnormalities.[10,11] Diffusion tensor imaging of the corpus callosum revealed that adolescents with mild TBI displayed less white matter integrity than controls and that a measure of white matter diffusion was significantly correlated with PCS severity.[8]

Together, these findings suggest that elevated PCS can be attributed, in part, to actual changes in brain structure or function. These findings also suggest that differences in injury severity exist among children with mild TBI and that those differences correlate with PCS. Therefore, it may be possible to classify the severity of mild TBI through the assessment of PCS. Ponsford et al[12] explored this notion in adults with mild TBI by using stepwise discriminant function analysis. At 1 week postinjury, 5 symptoms explained 39.8% of the variance between the mild-TBI group and controls and correctly classified 80.3% of cases: headaches, dizziness, irritability, fatigue, and sleeping difficultly. These results suggest that in the first few weeks following injury, somatic symptoms are best at discriminating individuals with mild TBI from controls. Although the study did not address the classification of injury severity from PCS, it provided the first step toward that goal by showing that certain specific PCS differentiate individuals with mild TBI from those with injuries not involving the head.

Assessment of PCS after mild TBI may be related to injury severity and become an integral part of decision rules determining further assessment and intervention. The goal of the present study was to determine whether we could identify clusters of PCS that discriminate children with mild TBI of varying severity. Existing findings show that somatic and

cognitive PCS discriminate children with mild TBI from those with injuries not involving the head and that measures of injury severity are associated with PCS within mild-TBI samples.[7,13] Follow up of children with mild TBI also suggests that somatic PCS peak within the first few weeks and quickly resolve, whereas cognitive symptoms increase several months after injury and resolve more slowly.[7,9,13,14] However, past studies have not determined the clinical utility of different types of PCS in relation to the presence and severity of mild TBI at different points after injury. The purpose of this study was to investigate this issue by comparing children with more and less severe mild TBI with each other and with a non-head-injured control group on both composite and individual measures of somatic and cognitive PCS at 3 times postinjury. We hypothesized that somatic symptoms would discriminate among groups shortly after injury, whereas cognitive symptoms would discriminate groups at later times postinjury. Because research also suggests that only a subset of PCS show increase following mild TBI,[6] we further hypothesized that individual items representing discrete symptoms would display better discriminatory power and classification than composite scores representing symptom dimensions.

METHODS

Participants

Participants were recruited from the Emergency Departments at Nationwide Children's Hospital in Columbus, Ohio and Rainbow Babies and Children's Hospital in Cleveland, Ohio. All children aged from 8 to 15 years who presented for evaluation of blunt-head trauma or orthopedic injury (OI) were screened to determine whether they met the criteria for participation.

Children were considered to have mild TBI if their injury was associated with any of the following: an observed LOC; a GCS score of 13 or 14; or 2 or more acute signs or symptoms of concussion as noted by Emergency Department personnel. Acute symptoms included posttraumatic amnesia, vomiting, nausea, headache, diplopia, dizziness, disorientation, or any other indications of mental status change (ie, dazed, foggy, slow to respond, lethargic, confused, sleepy). Children were not eligible if they demonstrated an LOC lasting more than 30 minutes, any GCS score of less than 13, any delayed neurological deterioration (ie, a decline in GCS score to below 13 following admission or any emergent neurosurgical intervention), or any medical contraindication to magnetic resonance imaging (MRI). Children were not required to have undergone a computed tomographic scan to be eligible to participate. Children who had an acute computed tomographic scan were not excluded from the study if they demonstrated intracranial lesions or skull fractures, as long as they did not require neurosurgical intervention.

Children with OI were eligible to participate if they presented with fractures to the upper or lower extremities with an Abbreviated Injury Severity[15] score no higher than 3. Children were not eligible if they displayed any evidence of a head trauma or symptoms of concussion.

General exclusion criteria applying to both groups included any associated injury with an Abbreviated Injury Severity score greater than 3; any surgical interventions; previous head injury requiring medical treatment; history of severe psychiatric illness resulting in hospitalization; premorbid neurological disorders or mental retardation; hypoxia, hypertension, or shock during or following the injury; injury resulting from child abuse or assault; or injuries that would interfere with neuropsychological testing (eg, fracture of preferred upper extremity).

Sample size and characteristics

Among children eligible to participate and approached for the study, 186 (48%) of those with mild TBI and 99 (35%) of those with OI agreed to enroll. Participants and nonparticipants did not differ significantly in age, gender, or ethnic-racial minority status; they also did not differ in census tract measures of socioeconomic status, that is, mean family income, percentage of minority heads of household, and percentage of households below the poverty line. All 285 families completed the initial visit, 268 (94%) completed the 3-month assessment (178 or 96% of the mild-TBI group and 90 or 91% of the OI group), and 253 (89%) completed the 12-month follow-up (169 or 91% of the mild-TBI group and 84 or 85% of the OI group). The proportion of children who completed all follow-up assessments did not differ by group. Children who completed all follow-up assessments did not differ from those who did not do so in age, sex, preinjury symptoms, or early postinjury PCS, but they were less likely to be of minority ethnic status and were of higher socioeconomic status.

The presence of LOC was used to divide the mild-TBI group by severity, consistent with multiple-grading schemes for concussion.[16–18] Of the 186 children with mild TBI, 74 (40%) experienced LOC and 112 (60%) did not. Children with mild TBI with LOC had higher mean Injury Severity Scores[19] than those without LOC or the OI group (Table 1). The groups did not differ on age, gender, ethnic-racial minority status, or SES.

Procedure

Children who met all inclusion and/or exclusion criteria and whose parents agreed to participate were scheduled for an initial assessment that typically occurred within 2 weeks of their injury (M = 11.35 days, SD = 3.42). The assessments included ratings of PCS. Participants completed follow-up assessments at 3 and 12 months postinjury. Institutional review board approval and informed parental consent and child assent were obtained before participation.

Postconcussive symptoms

Parents completed ratings of PCS using the Health Behavior Inventory (HBI; Yeates et al, 1999), a 50-item self-report inventory rating of the frequency of occurrence of PCS using a 4-point Likert-type scale (*never* to *often)*. The HBI was developed from previous research on children with moderate and severe TBI,[9,20] as well as mild TBI.[6,21] Factor analyses of the HBI yield cognitive and somatic factors that are robust across raters and time.[22] For this study, both individual items comprising the somatic and cognitive scales as well as summary scores representing the cognitive and somatic factors were used in analyses. Both the cognitive and somatic summary scores demonstrated high internal consistency among the entire study sample across raters and assessment occasions (Cronbach α = 0.85–0.94).

Data analysis

Chi-square and independent samples t tests (or Wilcoxon rank sum tests for data determined to be nonnormally distributed) were used to test for group differences on demographic factors and indices of injury severity. Fisher linear discriminant function analyses were used to identify clusters of variables that best discriminated group members, specifically, children with OI, those with mild TBI without LOC, and those with mild TBI with LOC. Six discriminant function analyses were conducted to capture all possible combinations of timing of assessment (acute postinjury vs 3-month vs 12-month) and symptom measures (individual items vs summary scores). Only discriminant function analyses with at least 1 function that significantly discriminated between groups as measured by Wilks Λ were further evaluated. For any analysis that identified 1 or more significant discriminant

functions, post hoc pairwise comparisons were conducted on discriminant scores produced by the functions to determine which groups were successfully differentiated.

Of the 285 families who completed the initial visit, 8 parents did not complete at least 1 item on the HBI. At the 3-month follow-up, 4 parents did not complete at least 1 item on the HBI. Of the 253 families who returned for the 12-month follow-up, 4 parents did not complete at least 1 item on the HBI. Individuals' missing data at any given assessment were excluded from that specific analysis. The analyses presented here are based on all children who had complete data at each of the assessments.

RESULTS

Of the 6 discriminant function analyses, 4 yielded functions that significantly differentiated groups (Table 2). Regardless of whether individual items or summary scores were used, initial and 3-month ratings significantly discriminated among groups whereas the 12-month ratings did not. Post hoc pairwise comparisons of discriminant scores revealed that only the analysis using ratings of individual items at the initial assessment discriminated among all 3 groups (Table 3). Ratings of individual items at 3 months postinjury differentiated both groups of children with mild TBI from those with OI, but did not discriminate between the two mild-TBI groups. The same was true when summary scores of ratings from the initial assessment were used. Discriminant scores produced from summary scores at 3 months postinjury discriminated only between the mild-TBI group without LOC and OI group. For all analyses, positive discriminant scores were associated with mild TBI.

Examination of the structure matrices, which reflects the correlations between individual items or summary scores and discriminant scores, revealed a strong relation with somatic symptoms. When ratings from the initial assessment were used, the somatic symptoms of headaches, dizziness, and feeling the room spinning were most strongly correlated with discriminant scores (r = 0.85, 0.51, and 0.35, respectively). Similarly, the summary scores for somatic symptoms were more positively correlated with discriminant scores than the summary scores for cognitive symptoms (r = 1.0 and 0.41, respectively). Children with mild TBI, particularly those who experienced an LOC, displayed higher discriminant scores than children with OI; therefore, the positive correlation between somatic symptoms and discriminant scores indicates that within 2 weeks of injury, the frequency and severity of somatic symptoms differentiates children with mild TBI from those with OI.

When ratings at 3 months postinjury were used, both cognitive and somatic symptoms were related to the discriminant scores. The four individual items that most strongly correlated with discriminant scores at 3 months were headaches, being forgetful, having difficulty in concentrating, and tiring easily (r = 0.68, 0.41, 0.41, and 0.36, respectively). The summary score for somatic symptoms correlated more highly with discriminant scores than the summary score for cognitive symptoms, although both represent large effects (r = 0.99 and 0.52, respectively). The positive correlation between PCS and discriminant scores suggests that somatic and cognitive symptoms at 3 months postinjury differentiate children with mild TBI from those with OI.

Overall, classification of groups using discriminant scores and prior probabilities ranged from poor to fair. Analyses using individual items to produce discriminant scores yielded slightly better classification rates (56.8%–60.3%) than those derived from summary scores (44.6%–47.3%). When high- and low-severity mild-TBI groups were combined (collapsing all children with mild TBI into 1 group), percentage correct classification was between 70.0% and 77.6% when using individual items and between 61.1% and 64.8% when using

summary scores. Sensitivity and specificity values are displayed in Table 4. Errors in classification resulted largely from misclassification of children with mild TBI.

DISCUSSION

The study findings indicate that PCS did not consistently discriminate between children with high- and low-severity mild TBI at different times postinjury. Post hoc analyses revealed that only ratings of individual items from the initial assessment discriminated the high- and low-severity mild-TBI groups. In all other instances, the discriminant scores only differentiated between children with mild TBI and OI. Furthermore, classification accuracy was relatively modest, even for discriminating children with mild TBI from those with OI. At best, only 78% of cases were correctly classified as either mild TBI or OI when ratings of individual items from the initial assessment were used. These results represent a significant improvement on chance classification, but the error rate suggests that PCS ratings cannot be used alone to make diagnostic decisions.

In almost all cases, somatic symptoms showed the strongest correlation with discriminant scores. Somatic symptoms were associated with all functions that discriminated children with mild TBI from the OI group, occurring more frequently and severely in the mild-TBI groups. Moreover, headaches, dizziness, and feelings of the room spinning were among the most discriminating symptoms. In addition, analysis of ratings from the initial assessment suggests that these symptoms discriminated children with mild TBI who sustained an LOC from those without an LOC. Although cognitive symptoms discriminated among groups less successfully than somatic symptoms, both types of PCS correlated with discriminant scores at 3 months postinjury. This finding is consistent with data indicating that cognitive symptoms may increase several months after mild TBI.[13]

As predicted, discriminant scores derived from individual items displayed better discriminatory power and classification than those produced from summary scores. For instance, discriminant scores based on individual item ratings at the initial assessment discriminated significantly among all 3 groups, but none of the discriminant scores based on summary scores did so. Furthermore, when summary scores were used, sensitivity to detect children with mild TBI who sustained an LOC was substantially lower than when individual items were used. As noted earlier, the symptom summary scores (ie, cognitive and somatic) were based on strong, reliable factors.[22] Thus, it is somewhat surprising that the summary scores did not perform as well as individual items. A possible explanation for the better results obtained with individual items is that the differential weighting of items applied in this approach enhances the accuracy of group classification.

Thus, the results suggest that only a subset of PCS have discriminatory power in determining injury severity following mild TBI. Two symptoms in particular consistently emerged as strong discriminators, headaches and dizziness. Previous research has documented the increased prevalence of these symptoms in individuals with mild TBI, and the incidence of these symptoms correlates with later ratings of PCS.[23] Headaches are reportedly common following mild TBI, with estimates ranging from 50% to 80%.[24] Analysis of post-concussion headache in high school athletes revealed that those individuals experiencing headaches also experienced a greater number of PCS.[25,26] Furthermore, individuals experiencing migraine headaches following head injury are more likely to display longer recovery times and more complex concussions.[27] Studies have not yet demonstrated a link between injury severity and postural stability deficits, which may be reflected in subjective symptoms of dizziness. Deficits in postural stability have been documented in both adult and child samples, and postconcussion headache has been linked to deficits in balance.[28–30] However, it is unclear whether deficits in postural stability can

differentiate mild TBI on the basis of injury severity. Recent evidence shows that the acute presence of headaches and postural stability deficits predict postconcussion disorders 3 months postinjury,[31] suggesting a link between these symptoms and persistent problems. Furthermore, the worsening of headaches can be used as part of a decision rule to determine the need for neuroimaging following injury.[32]

The ability to classify severity of a mild TBI from early PCS presentation would be beneficial to clinical care and research. Neuroimaging or neuropsychological evaluation is uncommon following mild TBI unless indications suggest that the injury is complicated. At present, GCS is the primary tool used to determine injury severity, although it is clear that this tool coarsely separates individuals with TBI and cannot differentiate levels of impairment.[33] In other words, a clinical need exists for a valid and useful decision rule for diagnosing mild TBI. On the basis of the evidence documented here, early PCS may be a part of such a model. Unfortunately, any attempt at diagnostic classification derived from the current results would have poor sensitivity. Many children with mild TBI with LOC would be misclassified as low-severity mild TBI or even OI. Classification accuracy needs to be increased before PCS can be used clinically to diagnose mild TBI. One possible way to increase discriminatory power is to conduct a more thorough evaluation of the best discriminating symptoms, in this case, headaches and dizziness. Extensive assessment of headaches should include history, family history, and questions regarding type, chronicity, and severity. Postural stability can be quickly and easily assessed by using various techniques designed to assess central and peripheral deficits.[28] In the future, we intend to include more detailed assessments of both headache and postural stability in our research in an attempt to improve discriminatory power.

The primary limitation of the study was the inability to include all PCS from the HBI. The sample size was too small to include all 50 variables, so only the cognitive and somatic items and summary scores were used. Although emotional and behavioral symptoms did not cluster together in robust factors,[22] specific emotional or behavioral symptoms might increase the accuracy of group classification. Another limitation of the study is the use of LOC as an indicator of injury severity. Although many studies have used LOC as an indicator of injury severity, it is only an indirect indicator of brain abnormalities. As part of the present study, children with mild TBI also underwent MRI of the brain. About 18% of the children with mild TBI displayed neuroimaging abnormalities felt to be trauma-related. When children with and without abnormalities were compared with children with OI in analyses parallel to those presented here, very similar results were found. However, the subgroup of children with MRI abnormalities was small in size (n = 32) and differed from the other groups in ethnicity and cognitive ability,[34] making the results more difficult to interpret. Given the similarity of the findings, only the results using LOC to index injury severity were reported here.

To summarize, the current findings indicate that PCS are able to discriminate between children with mild TBI and OI with modest accuracy. Somatic symptoms appear to have the strongest discriminatory power. Although ratings obtained shortly after injury were able to discriminate between mild-TBI groups as a function of severity, overall classification was relatively poor. Therefore, further refinement of PCS-based measures is needed before relying on PCS to differentiate mild TBI from injuries not involving the head and particularly to differentiate among mild TBIs of varying degrees of severity.

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TABLE 1

Demographic and injury characteristics of children with mild traumatic brain injury with and without loss of consciousness and children with orthopedic injuries

Variable	Mild TBI + LOC (*n* = 74)	Mild TBI, no LOC (*n* = 112)	OI (*n* = 99)
Age at injury, *M* (SD)	12.15 (2.20)	11.83 (2.23)	11.76 (2.23)
Sex (Male)	77%	67%	65%
Race (white)	70%	71%	65%
SES, *M* (SD)	0.15 (0.97)	−0.02 (0.87)	−0.09 (1.15)
Injury severity score[a]	6.58 (5.23)	3.33 (3.49)	3.25 (1.52)

Abbreviations: LOC, loss of consciousness; OI, orthopedic injuries; SES, socioeconomic status (a standardized Z-score composite of maternal education, median family income for census tract, and the Duncan occupational status index); TBI, traumatic brain injury.

[a] $P < .01$.

TABLE 2

Wilks Λ values for all discriminant functions

	Functions 1 & 2		Function 2	
Analysis	**Wilks Λ**	**χ^2 (df)**	**Wilks Λ**	**χ^2 (df)**
Items				
Initial assessment	0.59	139.58 (42)[a]	0.91	24.08 (20)
3-mo assessment	0.79	58.15 (42)[b]	0.92	20.92 (20)
12-mo assessment	0.82	47.48 (42)	0.93	16.21 (20)
Summary scores				
Initial assessment	0.88	34.86 (4)[a]	0.99	1.48 (1)
3-mo assessment	0.96	10.62 (4)[b]	0.99	2.63 (1)
12-mo assessment	0.99	2.33 (4)	0.99	0.68 (1)

Abbreviation:df, degrees of freedom.

[a] $P < .005$.

[b] $P < .05$.

TABLE 3

Post hoc pairwise comparisons of discriminant scores

	Group		
	Mild TBI + LOC	**Mild TBI, no LOC**	**OI**
Items			
Initial assessment[a]	0.79	0.35	−0.97
3-mo assessment[b]	0.38	0.21	−0.55
Summary scores			
Initial assessment[b]	0.37	0.18	−0.48
3-mo assessment[c]	0.06	0.16	−0.24

Abbreviations: LOC, loss of consciousness; OI, orthopedic injuries; TBI, traumatic brain injury.

[a] Mild TBI + LOC > mild TBI—No LOC > OI.

[b] Both mild TBI groups > OI.

[c] Mild TBI—No LOC > OI.

TABLE 4

Classification results

	Sensitivity			Specificity
	Mild TBI + LOC	Mild TBI, no LOC	All-mild TBI	OI
Items				
Initial assessment	43.1%	51.9%	75.0%	82.5%
3-mo assessment	35.7%	61.3%	71.6%	68.2%
Summary scores				
Initial assessment	9.7%	50.0%	58.9%	72.2%
3-mo assessment	5.7%	61.3%	68.2%	58.0%

Abbreviations: LOC, loss of consciousness; OI, orthopedic injuries; TBI, traumatic brain injury.