

# Persistent Postconcussion Symptoms After Injury

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abstract

**OBJECTIVES:** We examined whether preinjury, demographic, and family factors influenced vulnerability to postconcussion symptoms (PCSs) persisting the year after mild traumatic brain injury (mTBI).

**METHODS:** Children with mTBI ( $n = 119$ ), complicated mild traumatic brain injury (cmTBI) ( $n = 110$ ), or orthopedic injury (OI) ( $n = 118$ ), recruited from emergency departments, were enrolled in a prospective, longitudinal cohort study. Caregivers completed retrospective surveys to characterize preinjury demographic, child, and family characteristics. PCSs were assessed using a validated rating scale. With multivariable general linear models adjusted for preinjury symptoms, we examined predictors of PCSs 3, 6, and 12 months after injury in children ages 4 to 8, 9 to 12, and 13 to 15 years at injury. With logistic regression, we examined predictors of chronic PCSs 1 year after traumatic brain injury.

**RESULTS:** Postinjury somatic, emotional, cognitive, and fatigue PCSs were similar in the mTBI and cmTBI groups and significantly elevated compared with the OI group. PCS trajectories varied with age and sex. Adolescents had elevated PCSs that improved; young children had lower initial symptoms and less change. Despite similar preinjury PCSs, girls had elevated symptoms across all time points compared with boys. PCS vulnerability factors included female sex, adolescence, preinjury mood problems, lower income, and family discord. Social capital was a protective factor. PCSs persisted in 25% to 31% of the traumatic brain injury group and 18% of the OI group at 1 year postinjury. The odds of chronic PCSs were almost twice as high in girls as in boys and were >4 times higher in young children with cmTBI than in those with mTBI.

**CONCLUSIONS:** A significant minority of children with mTBI and OI have PCSs that persisted 1 year after injury.



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**WHAT'S KNOWN ON THIS SUBJECT:** After mild traumatic brain injury (mTBI), ~15% to 30% of children have postconcussion symptoms (PCSs) for several months. There is little consensus regarding which injury-related, child demographic, preinjury, and family factors confer vulnerability to or protect against PCSs persisting during the first year.

**WHAT THIS STUDY ADDS:** Vulnerability factors used to predict PCSs persisting during the year after uncomplicated mTBI (25%), complicated mTBI (31%), or orthopedic injury (18%) included preinjury affective problems, female sex, adolescence, and family stresses. Girls had twice the odds of having chronic PCS compared with boys.

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Postconcussion symptoms (PCSs) are cognitive, physical, and affective symptoms, such as difficulty concentrating, headache, and irritability, that occur in ~30% children with mild traumatic brain injury (mTBI) seen in the emergency department (ED). Although PCSs resolve in many children with mTBI within 1 week to 1 month,<sup>1,2</sup> symptoms persist for  $\geq 1$  month in 11% to 30% and negatively impact functioning at home and school.<sup>2-5</sup> PCSs or “concussionlike symptoms” are relatively nonspecific and are endorsed after traumatic brain injury (TBI), to a lesser extent by children experiencing bodily injuries,<sup>3,6-8</sup> and by some children without injuries.<sup>9</sup> Even in children whose PCSs resolve, persistent reductions in health-related quality of life, particularly in physical or academic areas, are documented in children who are managed up to 1 year after injury.<sup>10,11</sup>

The literature is inconsistent regarding injury and noninjury factors that may place children at high risk for prolonged PCSs. Greater injury severity and positive computed tomography (CT) scan findings are often used to predict acute PCSs; however, preinjury characteristics of the child and family, including increasing age, female sex, poorer preinjury child adjustment, and family dysfunction, may be used to predict more chronic PCSs.<sup>2,5,12-15</sup> Persistent PCSs have a major impact on both health care and school systems. With 1 million to 2 million US children sustaining a concussion from just sport and recreation participation annually,<sup>16</sup> it is essential to identify injury and noninjury factors that either promote or hinder recovery from mTBI.

To address gaps in the literature, we examined parent ratings of PCSs in a prospective, longitudinal cohort study of recovery from pediatric mTBI relative to an orthopedic injury (OI) comparison group. We

hypothesized that elevated parent ratings of PCSs during the first year after a mTBI would be associated with vulnerability factors of greater injury severity (including loss of consciousness and the presence of neuroimaging abnormalities), demographic variables (including older age and female sex), preinjury child factors (including learning and psychological health difficulties), and family circumstances (including poverty and poorer family functioning). Social capital, or a family’s connectedness to the community, was expected to buffer the effects of injury on PCSs.

## METHODS

Participants were children ages 4 to 15 years who sustained a mTBI or OI and were recruited from the ED at 2 level 1 pediatric trauma centers (Children’s Memorial Hermann Hospital and the University of Texas Health Science Center at Houston [Houston, TX] and Primary Children’s Hospital [Salt Lake City, UT]) as part of a larger cohort study from January 2013 through September 2015. Recruitment was sequential and stratified by age at injury (4–5, 6–11, and 12–15 years), type of injury, and TBI severity. Children with severe psychiatric disorders or developmental delay were excluded because of difficulty assessing the impact of injury on outcomes. Institutional review board approval was received from each institution. Parents provided consent. Children  $\geq 8$  years of age provided assent.

## Definitions

TBI severity was based on the lowest ED Glasgow Coma Scale (GCS) score.<sup>17</sup> mTBI was defined on the basis of the World Health Organization<sup>18</sup> and Centers for Disease Control and Prevention<sup>19</sup> criteria of a GCS score of 13 to 15 on presentation for health care with 1 or more of the following: confusion or

disorientation, loss of consciousness for  $\leq 30$  minutes, posttraumatic amnesia for  $< 24$  hours, the presence or absence of a skull fracture, and/or other transient neurologic abnormalities. Complicated mild traumatic brain injury (cmTBI) met the above criteria but included an intracranial contusion or hemorrhage diagnosed by using a CT scan.<sup>20</sup> CT imaging in the ED was performed for clinical indication only. Those in an OI comparison group sustained an extremity fracture but no head injury. The Abbreviated Injury Scale<sup>21</sup> score and Injury Severity Score were assigned by trauma registrars.

## Procedure

Parents or legal guardians completed a survey as soon as possible after injury to characterize preinjury family structure, sociodemographic, and child characteristics. Follow-up surveys were scheduled for 3, 6, and 12 months after injury. English-speaking families completed surveys either online or by telephone interview; Spanish-speaking families completed telephone interviews with bilingual study coordinators.

## Child and Family Measures

### *Child Behavior Checklist*

We used the attention-deficit/hyperactivity disorder (ADHD), affective disorder, and anxiety disorder scales yielding t scores normed for age and sex; higher scores indicate more problems.<sup>22</sup> The Child Behavior Checklist (CBCL) has excellent test-retest reliability ( $r = 0.7-0.8$ ) and internal consistency ( $\alpha = 0.90-0.94$ ) at 1 year.

### *Postconcussion Symptom Inventory–Parent*

The Postconcussion Symptom Inventory–Parent (PCSI-P) scale is a validated parent-report measure used to provide a total score and physical, cognitive, emotional, and fatigue subscores.<sup>23</sup> It has 20 developmentally appropriate items

that are used to discriminate children who are concussed from those who are uninjured ages 5 to 15 years; we extended the age range to include 4-year-olds for consistency with other survey measures. A global question asked to what degree the child acted differently than before the injury. The PCSI-P total score has favorable internal consistency ( $\alpha = 0.94$ ). Higher scores indicate more symptoms.

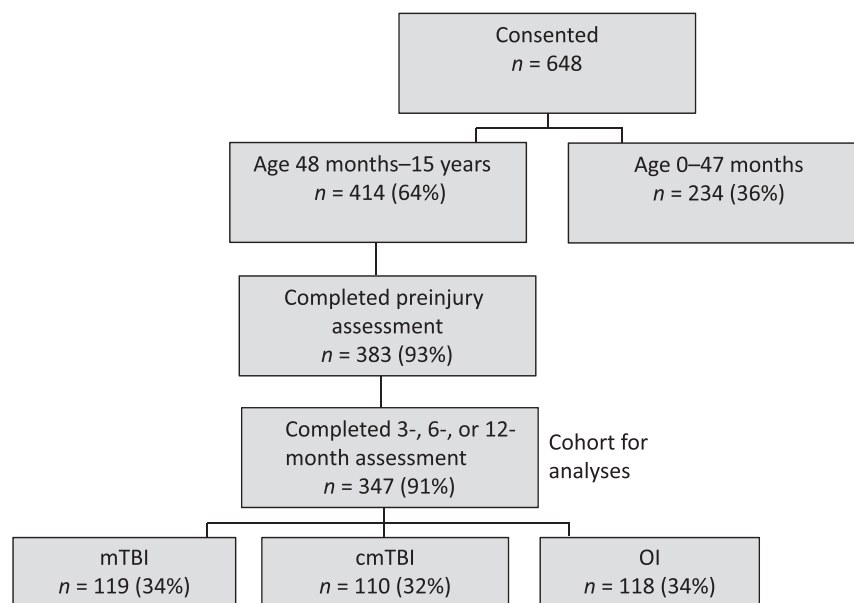
The presence or absence of PCSs was dichotomized on the basis of the *International Classification of Diseases, 10th Revision (ICD-10)* criterion of at least 1 symptom being present (or, for follow-up, increasing relative to preinjury) in at least 3 of the following areas: cognitive, emotional, somatic, and sleep and/or fatigue.

#### Family Environment Covariates

Preinjury family function was assessed by using the McMaster Family Assessment Device (FAD)–General Functioning Scale.<sup>24</sup> The FAD has 12 items scored 1 to 4; higher scores represent worse functioning. The Social Capital Index is used to measure perceptions of personal, family, neighborhood, and spiritual community support; higher total scores indicate greater support.<sup>25</sup> Families self-reported race, ethnicity, and income by family size; we calculated income relative to the poverty level using federal norms.

#### Statistical Approach

All children with outcomes available at preinjury and at least 1 follow-up time point were included in the analysis. Generalized linear mixed models, in which maximum likelihood estimation is used to incorporate all available outcome data, were fit with an unstructured covariance matrix and empirical estimates of the SE for model parameters for PCSI-P total scores and subscores by using SAS PROC MIXED (SAS Institute, Inc, Cary,



**FIGURE 1**  
Flow diagram of cohort recruitment.

NC). Potentially clinically important covariates were selected a priori, including the 3-way and 2-way interactions between injury group, time, and age (4–8, 9–12, and 13–15 years). Additional candidate covariates, including enrollment site, injury factors (previous concussion and loss of consciousness), child characteristics (sex; race and/or ethnicity; preinjury learning, behavioral, or developmental delay; and preinjury CBCL scores), and parent and/or family factors (respondent education, poverty level, preferred language, FAD score, social capital) were initially screened in a model controlled for preinjury PCSI-P score, injury group, time, and injury group by time interaction. To develop the final reported longitudinal models, a full model that included all candidate covariates with  $P < .20$  in initial screening, and these 4 factors, was iteratively reduced by removing variables (excluding preinjury PCSI-P score and main effects of injury and time) with  $P > .1$ . To identify predictors of chronic PCSs (yes or no) at the 1-year follow-up, multivariable logistic regression models were constructed by using an analogous

approach. In all analyses, we used a significance level of .05.

## RESULTS

### Study Population

Of the 414 children who consented to participate, 383 (93%) completed the initial survey in which we assessed retrospective ratings of preinjury PCSs and child and family functioning. The final cohort contained 347 (91%) children completing at least 1 postinjury assessment: 119 children with mTBI, 110 with cmTBI, and 118 with OI (Fig 1). In Supplemental Table 5, we compare key variables for children who did and did not have complete data; retention was lower in Hispanic children from the Houston site. Most families (76%) completed surveys online and had an English language preference (90%). The injury groups did not differ significantly on age, sex, race, or parental employment; however, parent income and education were lower in the mTBI group. Preinjury child psychological health and PCS estimates did not differ significantly across groups (Tables 1 and 2) or by sex.

**TABLE 1** Child, Family, and Injury Characteristics by Injury Group

	mTBI (N = 119)	cmTBI (N = 110)	OI (N = 118)	P <sup>a</sup>
<b>Child and family characteristics</b>				
Enrollment site Texas (versus Utah), <i>n</i> (%)	50 (42)	44 (40)	52 (44)	.82
Prefer to complete surveys online, <i>n</i> (%)	82 (69)	93 (85)	90 (76)	.02
Preferred language Spanish (versus English), <i>n</i> (%)	14 (12)	4 (4)	15 (13)	.04
Age at injury, <i>y</i> , mean (SD)	10.3 (3.7)	10.5 (3.5)	9.7 (3.7)	.16
Child sex female, <i>n</i> (%)	44 (37)	33 (30)	44 (37)	.43
Child race, <i>n</i> (%)				.14
American Indian or Alaskan native	2 (2)	0 (0)	0 (0)	
Asian American	1 (1)	5 (5)	2 (2)	
African American	11 (9)	4 (4)	6 (5)	
Native Hawaiian or other Pacific Islander	1 (1)	0 (0)	0 (0)	
White	90 (76)	93 (85)	95 (82)	
Multiracial	13 (11)	7 (6)	13 (11)	
Child ethnicity Hispanic or Latino, <i>n</i> (%)	31 (26)	17 (16)	33 (28)	.06
Married parents, <i>n</i> (%)	85 (73)	90 (83)	83 (72)	.11
Either caregiver currently employed, <i>n</i> (%)	112 (94)	105 (95)	106 (90)	.21
Respondent education, <i>n</i> (%)				.001
Less than high school	18 (15)	7 (6)	16 (14)	
High school	29 (24)	16 (15)	14 (12)	
Vocational and/or some college	36 (30)	59 (54)	42 (36)	
Bachelor's degree or more	36 (30)	28 (25)	46 (39)	
Income at or below poverty level, <i>n</i> (%)	37 (34)	11 (11)	21 (19)	<.001
Insurance type, <i>n</i> (%)				.29
None	9 (8)	10 (9)	5 (4)	
Medicaid and/or CHIP	43 (36)	31 (28)	33 (28)	
Commercial, private, and/or military	67 (56)	68 (62)	80 (68)	
Previous concussion with ED or doctor visit, <i>n</i> (%)	10 (8)	8 (7)	5 (4)	.41
Developmental, learning, or behavioral problem, <i>n</i> (%)	17 (14)	13 (12)	9 (8)	.26
CBCL affective <i>t</i> score, mean (SD)	55.3 (7.5)	54.4 (6.6)	54.2 (6.0)	.38
CBCL anxiety <i>t</i> score, mean (SD)	53.5 (6.2)	53.8 (6.6)	53.7 (5.4)	.95
CBCL ADHD <i>t</i> score, mean (SD)	55.0 (7.2)	53.5 (5.7)	53.8 (6.0)	.16
FAD general functioning scale, mean (SD)	1.5 (0.5)	1.5 (0.4)	1.5 (0.5)	.66
Social Capital Index, mean (SD)	3.5 (1.1)	3.6 (1.0)	3.7 (1.0)	.44
<b>Injury characteristics</b>				
Injury mechanism, <i>n</i> (%)				<.001
Pedestrian or bicycle	21 (18)	15 (14)	4 (3)	
Motorized vehicle	30 (25)	24 (22)	11 (9)	
Fall	44 (37)	54 (49)	83 (70)	
Struck by or against	12 (10)	10 (9)	6 (5)	
Organized sport	10 (8)	4 (4)	12 (10)	
Other	2 (2)	3 (3)	2 (2)	
Loss of consciousness (yes), <i>n</i> (%)	45 (38)	49 (45)	0 (0)	<.001
ED GCS (lowest postresuscitation), median (Q1, Q3)	15 (15, 15)	15 (14, 15)	—	.09
Maximum AIS excluding head, median (Q1, Q3)	1 (0, 2)	1 (0, 1)	2 (2, 2)	<.001
ISS score, median (Q1, Q3)	5 (1, 10)	10 (9, 16)	4 (4, 5)	<.001
Head imaging in ED (CT), <i>n</i> (%)	104 (87)	110 (100)	—	<.001
Injuries seen on brain imaging, <i>n</i> (%)				
Skull fracture	27 (23)	74 (67)	—	<.001
Cortical contusion	0 (0)	32 (29)	—	—
Hemorrhage	0 (0)	97 (88)	—	—
Admission type, <i>n</i> (%)				<.001
ED and/or observation only	53 (45)	5 (5)	78 (66)	
Hospital but not PICU	50 (42)	51 (46)	39 (33)	
PICU	16 (13)	54 (49)	1 (1)	
Hospital LOS, <i>d</i> , median (Q1, Q3)	2 (1, 4)	2 (2, 3)	2 (1, 3)	.80

AIS, Abbreviated Injury Scale; CHIP, Children's Health Insurance Program; ISS, Injury Severity Score; Q1, first quartile; Q3, third quartile; —, not applicable.

<sup>a</sup> *P* values reflect tests of association with injury group, specifically the  $\chi^2$  test for categorical variables, analysis of variance for continuous variables summarized by using the mean, and the Kruskal-Wallis test for continuous variables summarized by using the median.

**TABLE 2** Unadjusted PCSI-P Outcomes and *ICD-10* Concussion Criteria

Injury Group	PCSI Cluster and Total Scores					PCSI Global Outcome	<i>ICD-10</i>
	Somatic	Emotional	Cognitive	Fatigue	Total	Act Differently	Concussion Criteria <sup>a</sup>
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	n (%)	n (%)
<b>mTBI</b>							
Preinjury	2.1 (4.6)	1.6 (3.4)	2.0 (4.6)	0.5 (1.4)	6.1 (12.1)	—	26 (22)
Month 3	3.7 (6.1)	3.1 (4.6)	2.9 (4.8)	1.6 (3.1)	11.3 (15.7)	54 (48)	35 (31)
Month 6	3.4 (5.6)	3.6 (4.6)	3.1 (5.2)	1.5 (2.9)	11.5 (16.0)	44 (40)	41 (37)
Month 12	3.2 (5.7)	2.5 (4.4)	2.5 (4.6)	1.0 (2.3)	9.3 (13.8)	40 (39)	25 (25)
<b>cmTBI</b>							
Preinjury	1.4 (3.5)	1.4 (3.0)	1.0 (2.9)	0.7 (2.2)	4.4 (9.8)	—	17 (15)
Month 3	4.0 (6.7)	3.4 (5.4)	2.7 (5.2)	1.8 (3.2)	12.0 (18.2)	67 (64)	38 (37)
Month 6	2.9 (4.7)	4.0 (5.0)	2.8 (4.5)	1.6 (2.8)	11.3 (15.2)	48 (47)	38 (37)
Month 12	2.5 (5.0)	2.9 (4.5)	2.3 (4.1)	1.3 (3.1)	9.0 (14.7)	45 (46)	30 (31)
<b>OI</b>							
Preinjury	1.8 (3.8)	1.3 (2.8)	1.1 (3.4)	0.5 (1.7)	4.7 (9.8)	—	20 (17)
Month 3	1.4 (3.5)	1.9 (3.1)	0.9 (2.1)	0.7 (1.8)	4.9 (8.2)	38 (36)	17 (16)
Month 6	1.6 (3.5)	2.0 (3.1)	1.4 (2.9)	0.7 (1.8)	5.7 (9.2)	21 (19)	23 (21)
Month 12	1.3 (3.0)	1.3 (2.9)	0.8 (2.2)	0.6 (1.4)	4.0 (7.4)	23 (21)	19 (18)

—, not applicable.

<sup>a</sup> Preinjury: 1 symptom in at least 3 clusters; postinjury: ≥1 new or elevated postinjury symptom in at least 3 clusters.

Injury mechanism differed, with the youngest age group sustaining the mildest injuries, primarily from falls. Loss of consciousness was reported in 11% of younger and 33% to 41% of older children.

## Outcomes

### *Injury Group and Time Since Injury*

Before injury, 18% of children had symptoms that were consistent with *ICD-10* concussion diagnostic criteria (Table 2). Figure 2 includes the unadjusted PCSI-P group means from preinjury through the 12-month follow-up. Children were similar at baseline except for slightly higher cognitive scores seen in children with mTBI. Children with TBI had elevated scores at all follow-up time points that did not return to baseline. Table 3 includes multivariable model results across the 3 time points that were adjusted for preinjury PCSI-P ratings. Children with cmTBI (6 points) and mTBI (3.5 points) had higher adjusted scores compared with those with OI on the total postinjury PCSI-P and all subscales; however, those with mTBI and cmTBI did not differ significantly from each other.

Time from injury was important. Emotional and cognitive symptoms increased from 3 to 6 months but then fell at 12 months. Total, somatic, and fatigue symptoms resolved differently over time depending on age; 4- to 8-year-olds had lower scores at 3 months than older children, which either did not change or increased across follow-up (Fig 3). Older children had higher total and somatic scores than the 4- to 8-year-old group at 3 months, but their symptoms decreased over time. Adolescents had the highest fatigue symptoms, which had decreased by 1 year after injury.

### *Demographic, Child, and Family Predictors of PCSs*

Girls had higher unadjusted postinjury symptoms than boys in all areas of the PCSI-P despite similar preinjury PCSs (Fig 4). In the adjusted analysis, total scores remained 3.4 points higher for girls than for boys across the follow-up.

Preexisting affective problems, as measured by using the CBCL, were associated with elevated PCSs. Preinjury CBCL affective, anxiety, and ADHD scores were significantly associated with postinjury PCSs

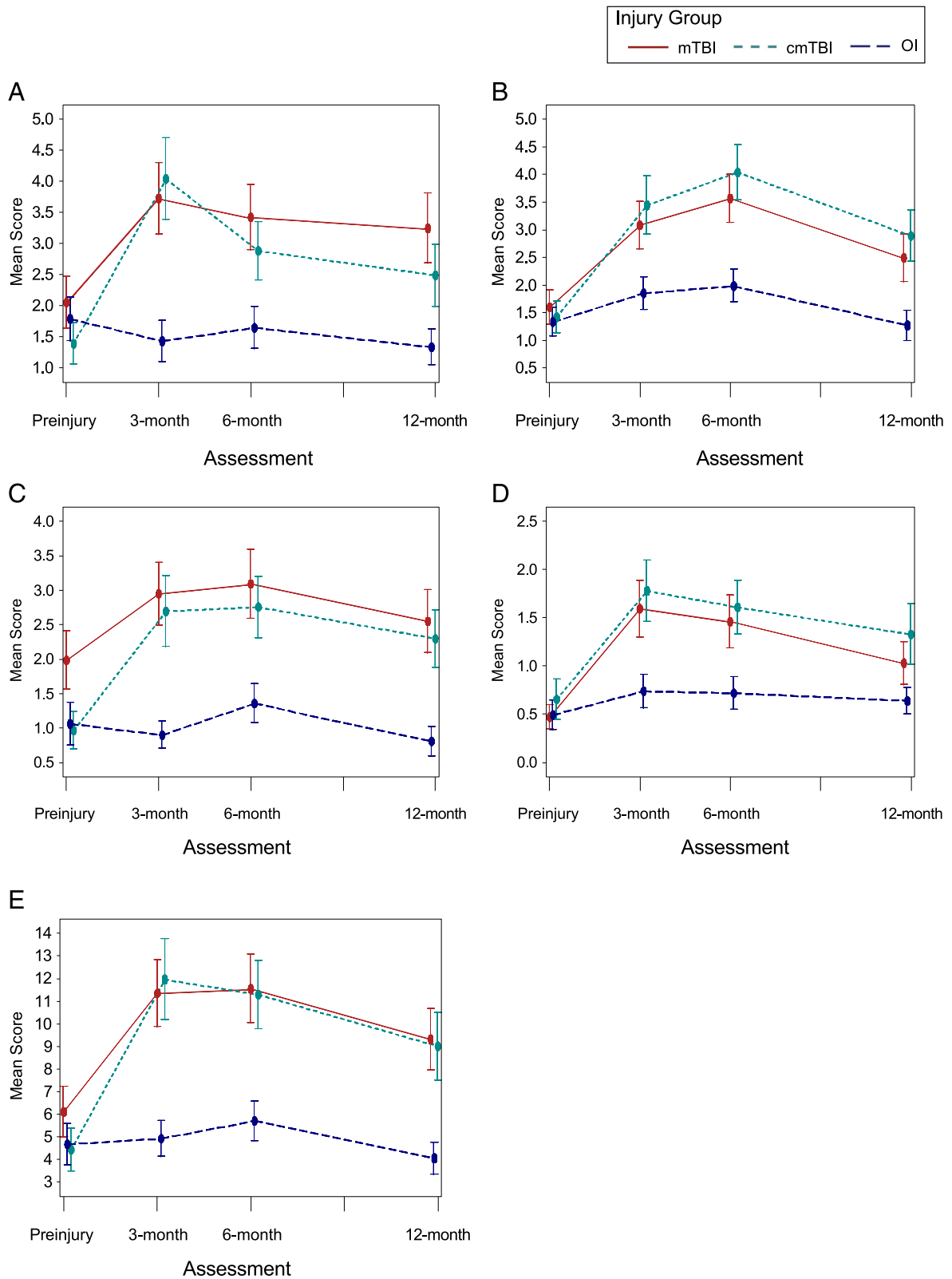
in univariable analyses. Only the affective score remained significant in multivariable analyses.

Family characteristics, including lower income, were associated with higher symptom burden; poorer family functioning predicted greater emotional and cognitive symptoms. Hispanic ethnicity was protective for emotional symptoms; Spanish language preference was protective for both total and somatic symptoms. Higher social capital was associated with lower symptom burden.

### *PCSSs 12 Months After Injury*

Despite significant improvement in PCSI-P scores over time, the PCSI-P global outcome question revealed that 21%, 39%, and 46% of the OI, mTBI, and cmTBI groups, respectively, continued to act differently 1 year after injury (Table 2). Most changes were mild to moderate; however, 3%, 8%, and 10% of the groups, respectively, showed significant to major differences.

Chronic postinjury concussion symptoms, defined as ≥1 symptom increasing in at least 3 areas relative to preinjury at 12 months postinjury, were identified in 18%, 25%, and



**FIGURE 2**

Unadjusted longitudinal PCSI-P total and subscore means ( $\pm$  SE) by injury group. Despite similar preinjury ratings, both the mTBI and cmTBI groups showed increases in all PCSI-P scores at the 3-month time point relative to the OI group that persisted across the follow-up. A, Somatic. B, Emotional. C, Cognitive. D, Fatigue. E, PCSI total.



**TABLE 3** Multivariable Model Results for PCSI-P Outcomes

	Somatic (N = 315)		Emotional <sup>a</sup> (N = 313)		Cognitive <sup>b</sup> (N = 314)		Fatigue (N = 323)		Total <sup>c</sup> (N = 315)	
	Coefficient (SE)	P	Coefficient (SE)	P	Coefficient (SE)	P	Coefficient (SE)	P	Coefficient (SE)	P
Preinjury rating of outcome	0.46 (0.13)	<.001	0.40 (0.07)	<.001	0.31 (0.08)	<.001	0.34 (0.14)	.02	0.45 (0.08)	<.001
Injury severity, time										
Injury severity (versus OI)		.001		<.001		<.001		.003		<.001
mTBI	1.23 (0.41)		0.88 (0.34)		0.96 (0.31)		0.45 (0.20)		3.52 (1.03)	
cmTBI	1.67 (0.51)		1.67 (0.42)		1.67 (0.39)		0.85 (0.27)		5.97 (1.42)	
Figure 2						.01	Figure 2		Figure 2	
Time from injury (versus 3 mo)		.02		<.001		<.001		.008		<.001
6 mo			0.54 (0.22)		0.22 (0.21)					
12 mo			-0.55 (0.22)		-0.38 (0.21)					
Demographics										
Age at injury	Figure 2	.34	—	—	—	—	Figure 2	.02	Figure 2	.62
Age by time interaction	Figure 2	.003	—	—	—	—	Figure 2	.01	Figure 2	.02
Female sex	1.17 (0.42)	.006	0.94 (0.36)	.01	0.84 (0.33)	.01	0.61 (0.23)	.008	3.43 (1.19)	.004
Spanish preferred language	-1.44 (0.58)	.01	—	—	—	—	-0.51 (0.27)	.06	-4.03 (1.36)	.003
Preexisting problems										
CBCL affective problems score	0.11 (0.04)	.002	0.10 (0.03)	.002	0.08 (0.04)	.06	0.09 (0.02)	<.001	0.38 (0.10)	<.001
Family environment										
Income relative to poverty level	-0.29 (0.09)	.002	-0.21 (0.09)	.02	-0.18 (0.07)	.01	-0.17 (0.05)	<.001	-0.80 (0.25)	.002
FAD family function	—	—	1.55 (0.44)	<.001	0.86 (0.43)	.046	—	—	2.89 (1.30)	.03
Social capital	-0.68 (0.23)	.004	-0.54 (0.20)	.006	-0.56 (0.19)	.003	—	—	-1.78 (0.66)	.008

—, variable not included in the final model for the outcome.

<sup>a</sup> The emotional outcome model also included race ( $P = .001$ ); Hispanic participants had a lower score on average than non-Hispanic white participants (effect estimate  $-1.48 \pm 0.58$ ).

<sup>b</sup> The cognitive outcome model also included the CBCL ADHD score ( $P = .09$ ) and previous diagnosis of learning, behavioral, or developmental delay ( $P = .08$ ).

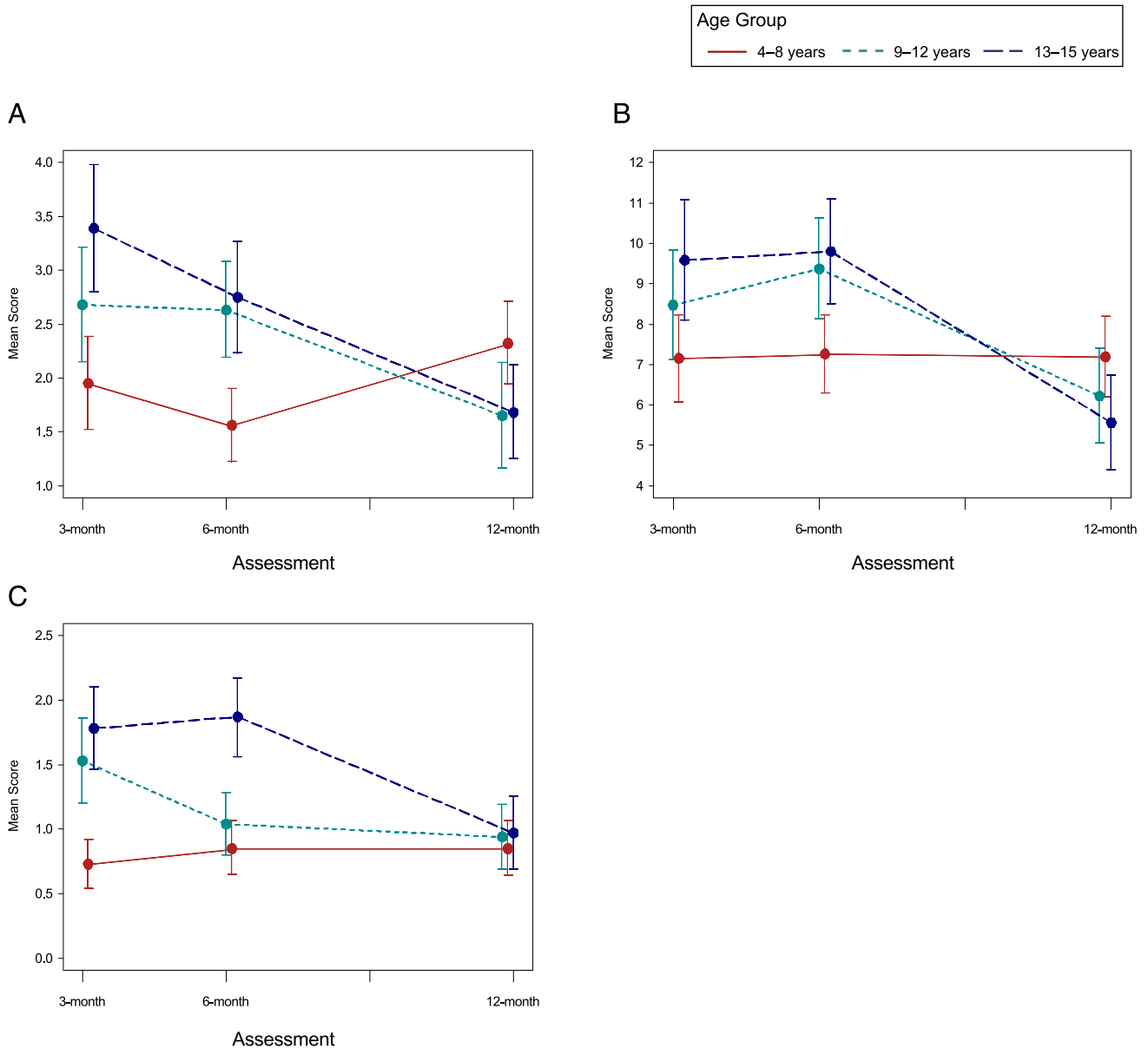
<sup>c</sup> Example interpretation of the total outcome model effect estimates: the total PCSI outcome was higher, on average, for those with mTBI (3.5 points) and cmTBI (6.0 points) compared with those with an OI in the year after an injury. The effect of age at injury differed by time (Fig 2). Total scores were 3.4 points higher for girls than boys, on average, and 4.0 points lower for those with Spanish as a preferred language. Higher preinjury affective problems, lower income, poorer family function, and lower social capital were all associated with increased total PCSI scores.

31% of children with OI, mTBI, and cmTBI, respectively (Table 2). In a multivariable model adjusted for preinjury PCSs, the odds of chronic PCSs were higher for girls and children with poorer family function and lower social capital. The odds of chronic PCSs were increased in 4- to 8-year-olds with cmTBI relative to both those with mTBI and OI but not for older children with mTBI or cmTBI relative to those with OI (Table 4).

## DISCUSSION

In the current study, we examined injury characteristics as well as demographic, preinjury, and family predictors of persistent PCSs during the first year after TBI in a broadly generalizable cohort of children. Key findings include the striking persistence of PCSs, particularly in girls; the differences in PCS trajectories by age; and the strong association of preinjury PCS and psychological health symptoms with persistent PCSs. Different characteristics of the family environment influenced PCSs and served as either protective or vulnerability factors. One year after injury, parents rated >40% of children with TBI as acting differently than before the injury, and 25% to 31% had postinjury symptoms meeting concussion diagnostic criteria. Our results converge with findings in other longitudinal studies in which researchers recruited children from EDs and reported ~20% to 30% of children with new or reemerging symptoms persisting at 3 or 12 months after injury.<sup>2,3,6</sup>

The high rate of chronic concussion symptoms is of concern because of the strong relation between persisting PCSs and reduced health-related quality of life.<sup>10-12,26</sup> PCSs vary over time; physical effects occur immediately after injury, cognitive symptoms occur throughout, and emotional symptoms develop later.<sup>27</sup>



**FIGURE 3**

Interactions between age and time for PCSI-P scores. Least squares means ( $\pm 1$  SE) for somatic, fatigue, and total scores, assuming average values of preinjury scores and other covariates, are shown. Children 4 to 8 years old had the lowest scores at 3 months and less change over time; 9- to 15-year-olds had higher initial total and somatic scores, and adolescents had the highest fatigue symptoms that decreased over time. A, Somatic. B, PCSI total. C, Fatigue.

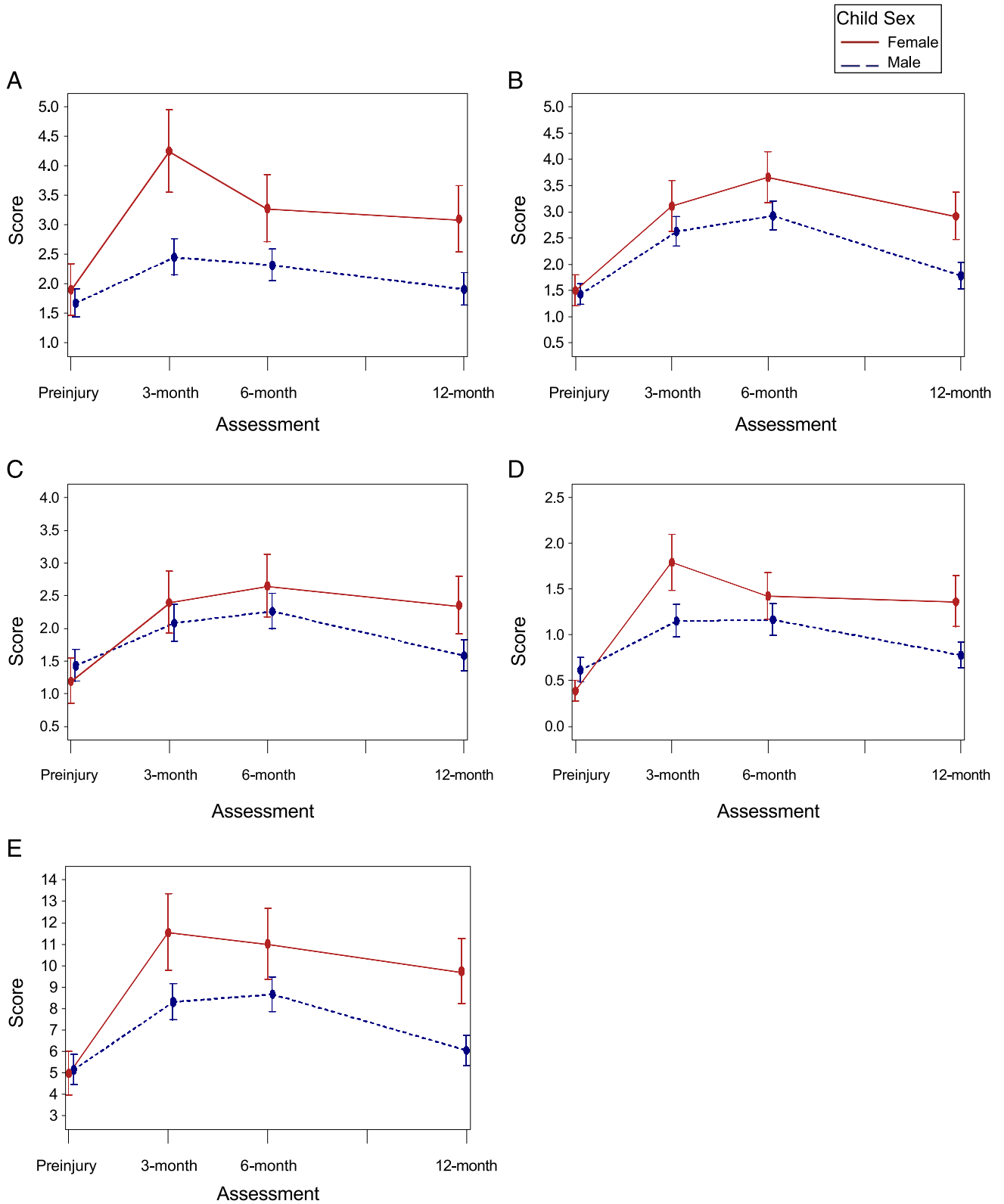
Persisting cognitive and emotional PCSs likely contribute to reduced school functioning<sup>10</sup> and changes in psychological health.<sup>28</sup> Little is known about how psychological characteristics, such as negative attributions, or physiologic changes in stress response and neural systems contribute to PCSs.<sup>29–32</sup> Recently, structural imaging revealed associations of brain network

abnormalities in children with persistent PCSs after mTBI that improved with aerobic training.<sup>29</sup> This reveals both neural changes after injury and their potential response to interventions.

The nonspecific nature of PCSs is underscored by the substantial rates of PCSs in children with no brain injury. Before injury, 18% of our sample met *ICD-10* criteria for

a concussion diagnosis; 1 year after injury, 18% of those in the OI group had postinjury-onset PCSs. Yeates et al<sup>6</sup> also found that children with mTBI and OI had a comparable rate of PCSs of moderate severity across the first year after injury. It is becoming increasingly clear that there is a general effect of injury on PCSs as well as on neurocognitive outcomes in children with mTBI





**FIGURE 4** Influence of child sex on longitudinal PCSI-P scores (means  $\pm$  1 SE). Girls had higher unadjusted postinjury total and subscale PCSI-P symptoms than boys despite similar preinjury PCSs. A, Somatic. B, Emotional. C, Cognitive. D, Fatigue. E, PCSI total.

**TABLE 4** Logistic Regression Results for Chronic Postinjury Concussion Symptoms at 12 Months After Injury (*N* = 300)

	Adjusted Odds Ratio (95% CI)	<i>P</i>
Preinjury concussion <sup>a</sup>	1.92 (0.93–3.96)	.08
Injury severity by age at injury, <i>y</i>		.04
4–8 <sup>b</sup>		
mTBI versus OI	1.57 (0.41–5.99)	
cmTBI versus OI	7.01 (2.10–23.4)	
9–12		
mTBI versus OI	0.60 (0.17–2.04)	
cmTBI versus OI	1.03 (0.31–3.40)	
13–15		
mTBI versus OI	2.60 (0.69–9.83)	
cmTBI versus OI	1.37 (0.33–5.66)	
Female (versus male) sex	1.94 (1.05–3.59)	.04
Family function (1-point increase)	2.42 (1.23–4.74)	.01
Social capital (1-point increase)	0.66 (0.50–0.88)	.01

One or more symptoms increased relative to preinjury at the 12-mo follow-up in at least 3 of the following areas: cognitive, emotional, somatic, and sleep and/or fatigue. CI, confidence interval.

<sup>a</sup> One or more symptoms at preinjury in at least 3 of the following areas: cognitive, emotional, somatic, and sleep and/or fatigue.

<sup>b</sup> In children 4 to 8 y old, having a cmTBI was associated with increased odds of chronic concussion relative to mTBI (odds ratio 4.47; 95% confidence interval 1.38–14.5).

and OI.<sup>33</sup> The development of next-generation PCS measures will help better discriminate symptom profiles in children with brain versus bodily injuries.<sup>29–32,34</sup>

Girls were almost twice as likely as boys to have persistent PCSs. Despite similar preinjury PCSs and psychological health symptoms, girls developed more elevated postinjury PCSs than boys in all areas that did not resolve. Elevated PCSs have been reported in girls recruited from both ED and sport samples.<sup>3,9,12,13,35,36</sup> However, the basis for sex differences and their relation with age at injury is unknown. In sport-related concussion samples, girls report more symptoms before and after a concussive event and have a slower recovery trajectory than do boys.<sup>35</sup> These samples contain predominantly postpubertal girls, which has raised the possibility that altered hypothalamic-pituitary-gonadal axis or other physiologic sex-linked differences may contribute to female vulnerability to PCSs.<sup>35,37</sup> Although this mechanism may help in explaining symptom burden in pubertal and postpubertal girls, girls in our sample had elevated PCSs irrespective of age. PCSs are

also related to psychological health problems that may occur more frequently in girls than in boys, including anxiety and posttraumatic stress symptoms.<sup>38,39</sup>

Adolescents and young children had different PCS patterns across the first year after injury. Similar to previous studies, adolescence was a susceptibility factor for total PCSs<sup>3,12,14,40,41</sup> and somatic and fatigue problems. This symptom elevation may be due to higher injury severity because more adolescents had a loss of consciousness and higher-velocity injuries. Although adolescents had more PCSs, their symptoms tended to improve over time. Children in the 4- to 8-year-old group tended to have a lower symptom burden at 3 months, but their symptoms did not improve over time. The odds of chronic PCSs were >4 times higher in children 4 to 8 years old with cmTBI than in those with mTBI and were 7 times higher than in the OI group.

Assessment of functioning before injury is necessary to dissociate postinjury from preexisting symptoms.<sup>2,9,12</sup> Preinjury PCS predicted persistent postinjury PCSs across time points. Similarly,

preinjury CBCL affective problem scores predicted elevated postinjury somatic, emotional, and fatigue PCSI scores. The preinjury PCSI-P total score was strongly related to each CBCL score, indicating that these measures share variance related to preinjury adjustment. Although the affective problems score had the most consistent relation with PCSs, a variety of preinjury psychological health issues may influence persistent PCSs.

Family factors exerted independent effects on PCSs, with low income and less adaptive family functioning being associated with greater PCS burden. Hispanic ethnicity and/or preference for Spanish language usage were protective factors for emotional, somatic, and total symptoms. Hispanic ethnicity has been associated with health disparities<sup>42</sup> and lower receipt of outpatient psychological health services after pediatric TBI.<sup>43,44</sup> However, Hispanic families may have cultural features, such as extended family support, that promote resilience.<sup>45</sup> Greater social capital was associated with lower rates of somatic, emotional, and cognitive PCSs. Families with greater social networks and connection to community resources may better access to support services, buffer health inequalities, and reduce the risk of adverse outcomes after injury.

We identified several vulnerability factors for prolonged PCSs that may put children at risk for decreased school participation. Consistent with American Academy of Pediatrics guidelines, children with PCSs should be served under return to learning initiatives in which the collaboration of medical, family, and school teams is emphasized.<sup>46</sup> The goal is to target symptoms and institute accommodations to return the children to full participation in school and community activities without significant symptom exacerbation.<sup>47</sup> Academic accommodations range from informal academic adjustments

to services mandated under federal statutes, such as Section 504. Although evidence-based information regarding interventions is lacking, physical and psychological health interventions ranging from graduated exercise to medication management of headache and mood, cognitive behavioral therapy, and family services that are effective in other populations are likely candidates.<sup>48,49</sup>

### LIMITATIONS AND STRENGTHS

Limitations of this study include that data were collected via parent report, which may be subject to bias<sup>50,51</sup> and possible under- or overestimation of PCSs relative to self-report. We did not assess PCSs in the initial weeks after injury and may have lost information regarding characteristics of children who recovered quickly. We did not measure pubertal development or litigation status. Our sample was recruited from the ED, and it may not be generalizable to the larger group of children with mTBI who seek community treatment.<sup>52</sup> Although 18% did not complete all

time points, multivariable model results for PCSI-P total scores were similar when they were rerun, including only the cases with complete data.

Our multicenter study had several notable strengths, including a prospective, longitudinal cohort design with broad racial and ethnic representation and an injury comparison group. Careful evaluation of preinjury psychological and physical health by using validated measures allowed for the dissociation of new postinjury symptoms from preexisting symptoms as well as the identification of the subgroups that were at elevated risk for chronic PCSs.

### CONCLUSIONS

Clinical management of children with mTBI, as well as children with bodily injuries, may be enhanced by understanding which children are at risk for persistent PCSs. Because emotional and cognitive symptoms may emerge over time, children with symptoms persisting at 1 month after injury should be managed clinically to monitor symptom course and refer

for any needed physical, cognitive, or psychological health interventions. The consistent importance of family functioning and social capital on PCS resolution reveals that family support services should be considered as an adjunctive intervention.

### ABBREVIATIONS

ADHD: attention-deficit/hyperactivity disorder  
CBCL: Child Behavior Checklist  
cmTBI: complicated mild traumatic brain injury  
CT: computed tomography  
ED: emergency department  
FAD: McMaster Family Assessment Device  
GCS: Glasgow Coma Scale  
ICD-10: *International Classification of Diseases, 10th Revision*  
mTBI: mild traumatic brain injury  
OI: orthopedic injury  
PCS: postconcussion symptom  
PCSI-P: Postconcussion Symptom Inventory–Parent  
TBI: traumatic brain injury

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## Supplemental Information

**SUPPLEMENTAL TABLE 5** Child, Family, and Injury Characteristics by Completion Status

	Did Not Complete All Time Points ( <i>N</i> = 64)	Completed All Time Points ( <i>N</i> = 283)	<i>P</i>
Enrollment site Texas, <i>n</i> (%)	38 (59)	108 (38)	.002
Preferred language Spanish, <i>n</i> (%)	5 (8)	28 (10)	.61
Age at injury, <i>y</i> , mean (SD)	10.4 (3.6)	10.1 (3.7)	.55
Child sex female, <i>n</i> (%)	23 (36)	98 (35)	.84
Child race and/or ethnicity, <i>n</i> (%)			.02
Hispanic or Latino	23 (37)	58 (21)	
White, non-Hispanic	30 (48)	186 (66)	
African American, non-Hispanic	3 (5)	18 (6)	
Other, non-Hispanic	7 (11)	19 (7)	
Respondent education, <i>n</i> (%)			.29
Less than high school	11 (17)	30 (11)	
High school	13 (20)	46 (16)	
Vocational and/or some college	20 (31)	117 (41)	
Bachelor's degree or more	20 (31)	90 (32)	
Previous concussion with ED or doctor visit, <i>n</i> (%)	5 (8)	18 (6)	.59
Developmental, learning, or behavioral problem, <i>n</i> (%)	8 (13)	31 (11)	.69
CBCL ADHD <i>t</i> score, mean (SD)	54.2 (6.2)	54.2 (6.4)	.97
CBCL anxiety <i>t</i> score, mean (SD)	54.7 (6.7)	53.4 (5.9)	.13
CBCL affective <i>t</i> score, mean (SD)	55.0 (7.7)	54.6 (6.5)	.62
Income at or below poverty level, <i>n</i> (%)	15 (26)	54 (20)	.31
FAD general functioning scale, mean (SD)	1.5 (0.4)	1.5 (0.5)	.76
Social Capital Index, mean (SD)	3.3 (1.0)	3.6 (1.0)	.03
Loss of consciousness, <i>n</i> (%)	17 (27)	77 (27)	.92
PCSI scores at 3-mo follow-up, mean (SD)			
Somatic	3.1 (4.9)	3.1 (5.8)	.93
Emotional	3.1 (5.0)	2.7 (4.4)	.67
Cognitive	2.6 (4.7)	2.1 (4.3)	.53
Fatigue	1.2 (2.5)	1.4 (2.9)	.76
Total	10.0 (14.6)	9.3 (15.0)	.77

Of the original cohort (*N* = 347), 22 (6%) completed 1 follow-up, 42 (12%) completed 2 follow-ups, and 283 (82%) completed all 3 follow-ups. In multivariable analyses, we used all available outcome data.