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The Longitudinal Course, Risk Factors, and Impact of Sleep Disturbances in Children with Traumatic Brain Injury

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Abstract

This study aimed to examine the prevalence and trajectory of sleep disturbances and their associated risk factors in children up to 24 months following a traumatic brain injury (TBI). In addition, the longitudinal association between sleep disturbances and children's functional outcomes was assessed. This was a prospective study of a cohort of children with TBI and a comparison cohort of children with orthopedic injury (OI). Parental reports of pre-injury sleep disturbances were compared to reports of post-injury changes at 3, 12, and 24 months. Risk factors for sleep disturbances were examined, including severity of TBI, presence of psychosocial problems, and pain. Sleep disturbances were also examined as a predictor of children's functional outcomes in the areas of adaptive behavior skills and activity participation. Both cohorts (children with TBI and OI) displayed increased sleep disturbances after injury. However, children with TBI experienced higher severity and more prolonged duration of sleep disturbances compared to children with OI. Risk factors for disturbed sleep included mild TBI, psychosocial problems, and frequent pain. Sleep disturbances emerged as significant predictors of poorer functional outcomes in children with moderate or severe TBI. Children with TBI experienced persistent sleep disturbances over 24 months. Findings suggest a potential negative impact of disturbed sleep on children's functional outcomes, highlighting the need for further research on sleep in children with TBI.

Key words: pediatric; risk factors; sleep disturbances; traumatic brain injury

Introduction

Traumatic brain injury (TBI) is a leading cause of death and disability in the United States (Coronado et al., 2011; Thurman et al., 1999). The increasing prevalence of TBI has become an important public health issue that poses a considerable economic burden owing to the potentially prolonged and extensive consequences of injury (Langlois et al., 2006). Significantly, the highest combined rates of TBI-related hospitalizations and deaths occur in children less than 5 years old, followed by adolescents 15–19 years of age (Faul et al., 2010; Rutland-Brown et al., 2006). The physical and psychological effects have been extensively documented in children post-head injury (Babikian and Asarnow, 2009; Chiaretti et al., 2009; Kirkwood et al., 2000; Yeates et al., 2009). Another potential health consequence post-injury that has been recognized in adults is disturbed sleep and sleep disorders (Castriotta and Murthy, 2011; Verma et al., 2007); however, there is very limited information on sleep disturbances after injury in children with TBI.

Current knowledge about sleep disturbances in the pediatric TBI population has resulted primarily from studies examining post-concussive symptoms. These studies suggest that 10–38% of pediatric TBI survivors experienced sleep disturbances, with the highest prevalence seen during the acute period post-injury (Blinman et al., 2009; Hawley et al., 2002; Kraus et al., 2009). In the few studies designed to examine sleep problems in children with TBI, the findings are equivocal (Beebe et al., 2007; Kaufman et al., 2001; Milroy et al., 2008; Pillar et al., 2003). In a study conducted by Kaufman and associates (2001) using questionnaires in conjunction with polysomnography and actigraphy monitoring, decreased sleep efficiency and increased wake bouts were reported in adolescents with mild TBI compared to healthy

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adolescents. In contrast, in another study of children with mild TBI, there were no differences found in sleep efficiency or total duration and number of nighttime wake bouts using actigraphy monitoring compared to children with isolated orthopedic injuries (OI; Milroy et al., 2008). Even less is known about the risk factors for sleep disturbances in children post-TBI. Increased body mass index and poorer parental education were found to be associated with sleep disturbances (Pillar et al., 2003). Furthermore, there are also limited data on the longitudinal course of sleep problems. Only one study has assessed sleep problems in children with severe TBI over time, finding an initial peak in sleep disturbance at 12 months, which improved over 48 months, but the prevalence remained higher in comparison to an OI group (Beebe et al., 2007).

To our knowledge, there have been no studies examining the relationship between sleep disturbances and children's daily functioning after TBI. It is recognized that in healthy children, disruptive sleep has far-reaching psychological and physical consequences, including neurocognitive dysfunction, anxiety, depression, behavioral issues, and obesity (Cappuccio et al., 2008; Gregory and O'Connor, 2002; Gregory et al., 2008; Kheirandish and Gozal, 2006). It is unknown whether children with TBI experience similar psychological and physical consequences of disrupted sleep, such as poorer adaptive behavior post-injury. In adults with TBI, sleep disturbances have been associated with delayed progress of rehabilitation and poorer performance on neuropsychological tests (Mahmood et al., 2004). Therefore, the aims of the present investigation were to examine the trajectory of sleep disturbances in children with TBI compared to children with orthopedic injury (OI) over the course of 24 months post-injury, and to examine risk factors and functional outcomes associated with sleep disturbances. We hypothesized that children with TBI would display an increased prevalence of sleep disturbances across all post-injury time points, that sleep disturbances would be associated with concurrent complaints of more frequent pain and psychosocial problems, and that sleep disturbances would be associated with decreased adaptive behavior skills and reduced activity participation in children with TBI.

Methods

This study was approved by the institutional review committees of the 10 participating institutions. We present analysis of longitudinal data of children aged 2–17 years old who were part of the Child Health After Injury (CHAI) study, which examined disability associated with TBI post-injury. Preliminary data examining the health-related quality of life and disability outcomes, but not sleep disturbances, of this cohort has been published in Rivara and colleagues (Rivara et al., 2011).

Participants

Potential participants were identified following treatment for TBI at an emergency department or during admission to a study hospital between March 1, 2007 and September 30, 2008. Briefly, the study hospitals were comprised of one Level 1 trauma hospital, four Level 3 or 4 trauma centers, and four non-trauma center hospitals randomly selected from all hospitals in King County, Washington. An additional pediatric Level 1 trauma hospital from Pennsylvania was added to increase the recruitment of younger children with increased severity of injury. The participants with TBI were selected by a computer-generated random number of all eligible participants. Participants for the control group included age- and sex-matched children with isolated arm fractures treated in the same King County study hospitals as those with mild TBI. Sampling proceeded concurrently with TBI case recruitment. This comparison group was used to control for demographic factors and pre-morbid characteristics that may be related to propensity of injury and the actual experience of a trauma. Full recruitment details may be found in Rivara and colleagues (Rivara et al., 2011).

Study design

This was a prospective cohort study with pre-injury, 3-month, 12-month, and 24-month post-injury assessments.

Procedure

A baseline interview was administered as soon as possible after injury to one parent to assess the child's pre-injury functioning. Subsequent parental interviews were conducted at 3, 12, and 24 months after the injury date. Medical charts were reviewed by the principal investigator or a trained research nurse using a standardized online abstraction form. Computed tomography (CT) scans of the head were reviewed by a pediatric neuroradiologist.

Assessment of injury severity

Medical records were abstracted to establish the diagnosis of TBI and to classify the level of severity. The diagnosis of TBI was based on criteria from the 2002 Centers for Disease Control and Prevention (CDC) report (Marr and Coronado, 2004). TBI was defined as a head injury, with one or more of the following: decreased level of consciousness, amnesia, neurological or neuropsychological abnormality, or diagnosed intracranial lesion. For this study, injury severity was established based on both CDC and World Health Organization (WHO) criteria (Carroll et al., 2004; National Center for Injury Prevention and Control, 2003). Mild TBI was defined as any period of transient confusion, disorientation, impaired consciousness, or amnesia lasting less than 24 h, or signs of other neurological or neuropsychological dysfunction, with the worst Glasgow Coma Scale (GCS) score of 13–15 at initial evaluation, and GCS score of 15 at discharge from the emergency department or at 24 h post-injury if hospitalized. Mild TBI was further subclassified into: mild I, no abnormalities on CT scans, or in whom CT scans were not performed; mild II, skull fracture without intracranial hemorrhage; and mild III, those with intracranial hemorrhage who met criteria for mild TBI. Moderate TBI was defined by the best GCS motor scale of 4 or 5 at 24 h after injury, or a score of 6 who did not meet the criteria for mild TBI. Severe TBI was defined as best GCS motor score of 1–3 at 24 h after injury. These methods of classifying injury severity have been used in previous work (Healey et al., 2003; MacKenzie et al., 2006).

Measures

Baseline data were collected on demographic characteristics, socioeconomic status, and medical and developmental history from the parents or medical chart. In addition, parents

completed the following measures at each data collection point.

Sleep disturbances

Sleep disturbances were reported by parents on one item in the Pediatric Quality of Life Inventory (PedsQL) 4.0 Generic Core Scale (McCarthy et al., 2005; Varni et al., 2001): "How often did he/she have a problem with trouble sleeping in the last 4 weeks?" Response options include "never" = 0, "almost never" = 1, "sometimes" = 2, "often" = 3, and "almost always" = 4. Scoring was based on the PedsQL scoring algorithm for ease of interpretability. The scores were then transformed to a 0–100 scale: 0 = 100, 1 = 75, 2 = 50, 3 = 25, and 4 = 0, with lower scores indicating more problems with sleep disturbances. The PedsQL has been validated for children over 24 months of age to 18 years old.

Pain

Pain frequency was obtained by parent report based on an item on the PedsQL: "How often did he/she experience pain" in the last 4 weeks? The response choices included: "never," "almost never," "sometimes," "often," and "almost always." This was used as a categorical variable in analysis.

Pediatric Symptom Checklist-17 (PSC-17)

The PSC-17 is a validated screening instrument for psychosocial problems in children (Gardner et al., 1999). It includes 17 items related to internalizing, externalizing, and attentional symptoms. Each item is rated as "never = 0," "sometimes = 1," or "often = 2." A total score of 15 or above (cut-point) is associated with concerns for significant emotional and behavioral problems. The total score (above or below the cut-point) was used as a dichotomous variable in the analyses.

Adaptive Behavior Assessment System II (ABAS II)

The ABAS II is a validated questionnaire for assessment of children's adaptive functioning (Rust and Wallace, 2004). The two subscales used in the analyses are Communication and Self-Care. Sample items from the Communication domain are "speaks clearly" and "names 20 or more familiar items." For the Self-Care domain, sample items are "washes hands with soap" and "dresses him/herself." Each item is scored using a 4-point Likert-type scale from "is not able" to "always or almost always when needed." Each skill area is scaled to age-normalized performance, with a mean ± SD of 10 ± 3, range 1–19, with higher scores indicating better adaptive functioning (Richardson and Burns, 2005).

Child and Adolescent Scale of Participation (CASP)

This is a validated questionnaire for children over 5 years of age that broadly assesses a child's participation compared to peers in activities at home, school, and in the community (Bedell, 2004, 2009). The CASP consists of 20 items. Each item is rated on a 4-point scale (4 = age expected, 3 = somewhat restricted, 2 = very restricted, 1 = unable) or "not applicable." Summary scores are calculated by dividing the total score by the maximum score, and multiplying this number by 100 to conform to a 100-point scale. Higher scores indicate a greater extent of age-expected activity participation. The summary scores were used in the analyses.

Statistical analysis

Between-group differences on demographic characteristics were examined using the χ^2 or *t*-tests. Means and SD for measures of pain and functional outcomes were compared between the three TBI subgroups (mild TBI I/II, mild TBI III, and moderate/severe TBI), and the OI group at each data collection point using generalized linear models (GLM). To address the first aim, a mixed-effects model was used to examine the pre- to post-injury change in sleep disturbances. This model was run twice: (1) adjusted for baseline pre-injury sleep disturbances, and covariates of age, gender, race, insurance status, household income, and parental education, and (2) further adjusted for sleep disturbances in the OI group. The second aim was to identify risk factors for sleep disturbances. Mixed-effects random coefficient regression models for repeated measures at the baseline, 3-, 12-, and 24-month time points were used to assess the longitudinal relationship between sleep disturbances, pain, emotional and behavioral problems, demographic characteristics, and time. Finally, separate mixed models were constructed to examine the associations between sleep disturbances and functional outcomes of adaptive behavior and activity participation.

Data were analyzed using SAS (SAS Institute Inc., Carey, NC) and STATA software (StataCorp LP, College Station, TX).

Results

Descriptive statistics

Table 1 shows the demographic characteristics of the 926 participants from the TBI ($n = 729$) and OI ($n = 197$) cohorts. The groups differed significantly in ethnicity, household income, insurance status, and mechanism of injury. Children with moderate and severe TBI were more likely to be black, to sustain injury secondary to motor vehicle crashes, to be from slightly lower-income households, and to have no insurance or state-funded insurance. The follow-up rate was 87.1% of the TBI cohort and 90.9% of the OI cohort at 24 months.

Table 2 provides descriptive statistics for all predictor variables (pain frequency, emotional and behavioral symptoms, adaptive behavior, and activity participation) at each data collection point. Children with TBI experienced significantly higher pain frequency up to 12 months post-injury compared to children in the OI group. Assessments for psychosocial problems revealed that children with TBI had higher scores on PSC-17 up to 12 months, and children with moderate or severe TBI continued to have increasing scores at 24 months compared to the OI group. For functional outcome assessments, children with moderate or severe TBI had lower scores on adaptive behavior and activity participation compared to the other TBI and OI groups.

Longitudinal course of sleep disturbances by group

Baseline (pre-injury) sleep disturbances were reported to be higher in the mild TBI I/II group compared to the other TBI and OI groups (Table 3). At 3 and 12 months, all cohorts (children with TBI and OI) displayed significantly more sleep disturbances compared to baseline. In comparison, the OI

Table 1. Descriptive Characteristics of the Study Groups

	Mild I/II TBI n=*510*	*Mild III TBI* n=*106*	*Moderate/severe TBI* n=*113*	*OI* n=*197*	*p*
Age (months)	110.6	113.8	109.7	110.92	0.95
Mean (SD)	(67.3)	(74.6)	(76.5)	(60.8)	
% Male	62.6	74.5	69.0	61.9	0.07
Ethnicity (%)					< 0.0001
Asian	1.6	4.7	2.7	3.1	
Black	2.4	7.6	13.3	2.5	
Hispanic	8.9	10.4	15.9	12.2	
Other	20.7	12.3	23.0	16.8	
White	66.5	65.1	45.1	65.5	
Household income (%)					< 0.0001
< $30 k	21.6	21.7	31.9	16.8	
$30–60 k	16.9	19.8	28.3	15.7	
$60–100 k	19.4	28.3	19.5	25.4	
Over $100 k	37.7	24.5	12.4	37.6	
Unknown	4.5	5.7	8.0	4.6	
Mechanism of injury (%)					< 0.0001
Motor vehicle	7.4	16.4	35.6	3.2	
Pedestrian	6.6	11.5	16.4	2.7	
Fall	57.2	53.9	32.7	83.1	
Struck by	0.0	1.0	5.8	0.5	
Other	28.8	17.3	9.6	10.6	
Insurance status (%)					< 0.0001
No	2.2	6.6	10.6	2.0	
Medicaid	26.3	18.9	40.7	25.9	
Private	69.6	68.9	44.3	71.1	
Tricare	0.2	5.7	3.5	0.0	
Basic health	1.8	0.0	0.9	1.0	

TBI, traumatic brain injury; OI, orthopedic injury.

group no longer demonstrated significant post-injury sleep disturbances at 12 months. At 24 months, children with TBI (with the exception of children with mild TBI III) continued to experience a higher severity of sleep disturbances compared to pre-injury levels. After adjusting for covariates of age, gender, race, insurance, household income, and for the change in sleep in the OI group, the group of children with moderate or severe TBI had significantly increased sleep disturbances persisting to 24 months post-injury compared with their pre-injury baseline.

Table 2. Means and Standard Deviations (SD) of Primary Predictors and Outcome Variables by Group

		Mild I/II TBI	*Mild III TBI*	*Moderate/severe TBI*	*OI*	*p*
Pediatric Quality of Life Inventory item: Pain (0–100 scale)	Baseline	57.7 (18.4)	54.0 (22.5)	61.8 (20.0)	61.9 (17.0)	0.23
	3 months	50.7 (20.6)	58.3 (20.8)	42.8 (25.4)	57.3 (16.6)	0.0001
	12 months	52.4 (17.9)	51.7 (24.5)	42.4 (21.4)	57.5 (18.6)	0.001
	24 months	53.3 (18.8)	54.5 (18.0)	53.0 (21.1)	58.7 (17.0)	0.17
Pediatric Symptom Checklist-17	Baseline	7.9 (5.5)	7.6 (4.9)	6.3 (5.9)	7.2 (5.3)	0.01
	3 months	7.8 (6.0)	8.4 (6.0)	8.9 (6.8)	6.7 (5.8)	0.001
	12 months	8.3 (6.3)	8.9 (6.9)	9.1 (7.2)	6.9 (6.0)	0.08
	24 months	8.2 (6.1)	7.8 (6.0)	9.5 (7.5)	7.3 (6.5)	0.0003
Adaptive Behavior Assessment System II: Communication	Baseline	10.4 (2.7)	10.8 (2.7)	10.7 (2.5)	10.7 (2.3)	0.29
	3 months	10.5 (2.9)	10.4 (2.6)	9.4 (3.5)	10.9 (2.5)	0.0004
	12 months	10.7 (2.8)	10.5 (2.7)	9.0 (3.5)	10.9 (2.5)	< 0.0001
	24 months	10.6 (2.8)	10.9 (2.7)	8.8 (3.8)	10.8 (2.8)	< 0.0001
Adaptive Behavior Assessment System II: Self-Care	Baseline	8.9 (3.1)	10.1 (2.7)	10.3 (3.1)	9.1 (2.9)	< 0.0001
	3 months	9.2 (3.1)	10.2 (2.7)	8.1 (4.1)	9.2 (2.8)	< 0.0001
	12 months	9.3 (3.1)	9.9 (2.9)	8.3 (3.7)	9.9 (3.0)	0.0004
	24 months	9.5 (3.3)	10.4 (2.8)	8.3 (3.9)	10.2 (2.9)	< 0.0001
Child and Adolescent Scale of Participation	Baseline	94.1 (9.0)	96.1 (6.4)	95.7 (7.1)	95.6 (7.6)	0.09
	3 months	93.6 (10.0)	94.3 (9.8)	87.3 (17.4)	95.4 (9.5)	< 0.0001
	12 months	95.0 (9.7)	94.4 (8.5)	90.4 (14.1)	96.8 (6.9)	< 0.0001
	24 months	94.7 (10.2)	96.3 (6.7)	91.7 (14.1)	96.6 (7.4)	0.005

TBI, traumatic brain injury; OI, orthopedic injury.

Table 3. Sleep at Baseline, and at 3, 12, and 24 Months after Injury

	Baseline n = 794 *mean*	*3 months* n = 766 *mean*	*12 months* n = 765 *mean*	*24 months* n = 791 *mean*	*0 to >3 months adjusted mean difference*	*Net difference*	*0 to > 12 months adjusted mean difference*	*Net difference*	*0 to > 24 months adjusted mean difference*	*Net difference*
OI	88.1	84.1	85.3	84.6	−4.0 (−7.1, −0.9)*	Ref	−2.4 (−5.5,0.7)	Ref	−3.5 (−6.7, −0.4)*	Ref
Mild I/II TBI	82.4	75.4	75.4	76.6	−6.8 (−9.4, −4.2)*	−2.8 (−9.0,3.4)	−6.8 (−9.4, −4.2)*	−3.9 (−10.1,2.3)	−5.2 (−7.9, −2.6)*	−2.0 (−8.2,4.2)
Mild III TBI	87.6	79.9	79.5	83.5	−7.4 (−13.2, −1.7)*	−3.5 (−12.7,5.8)	−7.4 (−13.3, −1.4)*	−5.2 (−14.6,4.3)	−5.0 (−10.9,0.9)	0.1 (−9.1,9.2)
Moderate/ severe TBI	90.3	79.9	77.1	76.2	−10.4 (−17.2, −3.6)*	−6.1 (−15.3, −3.1)*	−12.4 (−19.1, −5.6)*	−10.4 (−19.6, −1.3)*	−14.1 (−21.1, −7.1)*	−10.3 (−19.5, −1.2)*

*$p < 0.05$.
Adjusted mean difference: Adjusted for age, child gender, race, insurance, and household income.
Net difference: Adjusted for age, child gender, race, insurance, household income, and changes in the OI group.
TBI, traumatic brain injury; OI, orthopedic injury; Ref, reference group.

Risk factors for sleep disturbances

In mixed linear models, associations among predictor (risk) factors and sleep disturbances were examined over time (Table 4). The OI group was included in the analyses as a reference point to account for changes in sleep disturbances after an incident of trauma. Analyses demonstrated that membership in the mild I/II TBI group was associated with more frequent sleep disturbances ($\beta = -6.3$, 95% CI −9.2, −3.4). Other risk factors associated with increased sleep disturbances included female gender ($\beta = -5.6$, 95% CI −9.1, −3.1), presence of psychosocial problems ($\beta = -14.5$, 95% −12, −16.9), and frequent pain ($\beta = -24.7$, 95% CI −30.5, −18.9). Black racial background ($\beta = 11.6$, 95% CI 5.4,17.9) was associated with decreased sleep disturbances.

Association between sleep disturbances and functional outcomes

Analyses using mixed models indicated that increased frequency of sleep disturbances significantly predicted poorer communication and self-care (lower scores on the ABAS II Communication and Self-Care modules), such that frequent sleep disturbances were associated with worse communication and self-care in children with moderate or severe TBI ($\beta = -1.30$, 95% CI −1.89, −0.71 and $\beta = -1.72$, 95% CI −2.38, −1.05, respectively). A separate mixed model was used to examine the relationship between sleep disturbances and children's participation in activities. Frequent sleep

Table 4. Predictors of Sleep Disturbances

	Coefficients (95% CI)
Injury severity	
OI	Ref
Mild I/II TBI	−6.3 (−9.2, −3.4)*
Mild III TBI	−3.6 (−7.9,0.6)
Moderate/severe TBI	−4.1 (−8.4,0.1)
Time since injury	
Baseline	Ref
3 months	−3.9 (−5.7, −2.0)*
12 months	−4.0 (−5.9, −2.1)*
24 months	−2.9 (−4.8, −1.1)*
Gender	
Male	Ref
Female	−5.6 (−8.1, −3.1)*
Race	
White	Ref
Asian	2.7 (−5.0,10.4)
Black	11.6 (5.3,17.9)*
Hispanic	3.5 (−0.6,7.6)
Other	−2.3 (−5.3,0.8)
Pain frequency	
Never	Ref
Almost never	−5.6 (−7.8, −3.5)*
Sometimes	−10.9 (−12.9, −8.9)*
Often	−14.4 (−18.1, −10.8)*
Almost always	−24.7 (−30.5, −18.9)*
Positive PSC-17 score	−14.5 (−16.9, −12.0)*

*$p < 0.05$
TBI, traumatic brain injury; OI, orthopedic injury; PSC-17, Pediatric Symptom Checklist-17; CI, confidence interval; Ref, reference group.

disturbances also significantly predicted decreased activity participation ($\beta = -8.08$, 95% CI $-10.36, -5.79$).

Discussion

Our findings provide evidence of sleep disturbances post-TBI in children and adolescents that persisted up to 24 months post-injury. Children with moderate or severe TBI demonstrated the highest scores for sleep disturbance at 24 months post-injury. In comparison, children with mild TBI experienced less sleep disturbance and a tendency toward recovery to pre-injury sleep over time. These findings add to the limited pediatric research on sleep disturbances following TBI. We found a similar persistence in the moderate/severe TBI group as reported in a 48-month longitudinal analysis conducted by Beebe and associates (2007).

With regard to risk factors for sleep disturbances, injury severity was a significant predictor of the frequency of sleep disturbances reported by parents. Mild TBI I/II was a significant predictor, but mild TBI III and moderate/severe TBI were not. Similar findings have been documented in the adult literature, where mild TBI has also emerged as a risk factor for sleep disturbances (Beetar et al., 1996; Clinchot et al., 1998; Fichtenberg et al., 2000). While more severe injury was associated with higher overall rates of sleep disturbances in our sample, milder injury was the most predictive factor in a multivariate model with demographic and psychosocial factors. Children with more severe (versus milder) injury may have also had systematic differences in demographic and psychosocial factors that were also related to increased sleep problems. In addition, it has been proposed that persons with mild TBI may have increased recognition of post-injury impairments, and therefore may be more likely to report sleep disturbances as an injury complication. In children with mild TBI, sleep disturbances may also be a symptom of increased awareness of post-injury changes subsequently reported by parents and caregivers. Finally, it is unknown whether there is a physiological or neuroanatomical basis unique to mild TBI injury to account for this finding. Further work is warranted in this area.

Other risk factors associated with sleep disturbances were examined in our TBI cohort, supporting the finding that frequent pain and the presence of psychosocial problems were significant predictors. These same risk factors for disturbed sleep have been identified in various pediatric medical populations, including children with epilepsy, juvenile arthritis, and functional abdominal pain, suggesting some shared risk across medical conditions (Huntley et al., 2007; Ward et al., 2010; Wirrell et al., 2005). Children with acute and chronic medical conditions have an increased risk of sleep disruptions (Hysing et al., 2009), that are more often chronic and persistent compared to children without medical conditions (Sivertsen et al., 2009), as shown in this study comparing children with TBI and children with isolated orthopedic injuries. Common mechanisms that may account for the association between sleep problems and medical conditions include underlying disease-related processes (e.g., pain and inflammation), treatment regimens (including medications), hospitalization, and behavioral and psychological factors (Lewandowski et al., 2011). In the case of pediatric TBI, pain may be a particularly important yet understudied factor contributing to sleep disturbances. It is increasingly recognized that sleep disturbances and pain have a bi-directional relationship (Ohayon, 2005; Smith and Haythornthwaite, 2004). Furthermore, the triad of symptoms of sleep, pain, and depression (Chung and Tso, 2010; Kashikar-Zuck et al., 2010) may be explained by shared neurotransmitter systems that may be affected after a traumatic brain injury event. In addition to sleep regulation, endogenous factors such as serotonin and hypocretin-1 may also play a role in pain transmission and modulation of depression (Bartsch et al., 2004; Lautenbacher et al., 2006). This triad has been described in adults subsequent to a TBI event (Bushnik et al., 2008; Cantor et al., 2008; Ouellet et al., 2006). Further research is needed to identify the mechanisms accounting for disturbed sleep in the pediatric TBI population, which may lead to informed approaches to recognition and clinical management of sleep problems.

Importantly, our findings demonstrated that not only are sleep disturbances likely to occur post-TBI, but that they also are associated with decrements in children's post-injury functioning. This was particularly the case for children with moderate or severe TBI, who may already be struggling with the impact of TBI on physical and cognitive functioning. Further research is needed to better understand the relationship between sleep and outcome parameters such as cognitive function and daytime fatigue, which may also be impacted in children with TBI.

Findings should be interpreted in light of several limitations. First, our measurement of sleep disturbances was limited to a single parent-report question that may not have adequate specificity or sensitivity for identifying the full range of sleep disturbances experienced by children post-TBI. Well-validated questionnaire measures of sleep (such as the Children's Sleep Habits Questionnaire) will be important to use in future studies in the pediatric TBI population to better characterize the specific nature of the sleep problems experienced after injury. The advantage of using this single item to assess for sleep problems is that in a large population cohort it increases feasibility. The validity of a single item of sleep disturbance was examined in a recent study (Gregory et al., 2011), demonstrating that one item from the Child Behavior Checklist, "trouble sleeping," was correlated with sleep latency as assessed by sleep diary and actigraphy. Similarly, functional outcome measures were based on parental reports, resulting in common method variance, which is a limitation of this study. For future investigations, the addition of self-report of sleep disturbances and functional outcomes would complement information obtained from caregiver reports. An additional methodological limitation was that only subjective reporting of sleep problems was used to evaluate for sleep disturbances. Ideally, sleep disturbances should be assessed via a comprehensive approach, using parental reports, self-reports, and objective measures (e.g., actigraphy and polysomnography). Finally, this study did not seek to identify the mechanisms of sleep disturbances in terms of neuroanatomical sites of injury or complications such as neurohormonal changes, which may also be important factors in the development of sleep disturbances post-TBI. Despite these limitations, there were several unique strengths of this study, including the longitudinal study design, the large sample size with high follow-up rates, and the inclusion of an orthopedic injury control group.

Our findings highlight the importance of timely evaluation for sleep problems post-TBI in children and adolescents.

Furthermore, identification of potentially modifiable risk factors (e.g., pain or mood) may allow for the development of targeted interventions to mitigate the negative outcomes of TBI. Unrecognized and untreated sleep problems in this medically-important population may represent a missed opportunity to improve health outcomes.

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Author Disclosure Statement

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