Original Paper

American Society for Neurochemistry

ASN Neuro
Volume 11: 1–10

DOI: 10.1177/1759091418822405
journals.sagepub.com/home/asn
SAGE

A Longitudinal Investigation of Sleep and Daytime Wakefulness in Children and Youth With Concussion

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Abstract

A high proportion of adults who sustain a concussion identify changes in their sleep during the acute stage, typically reporting an increased need for sleep or nonrestful sleep. Our understanding of sleep following concussion is less well understood within a pediatric population. In this study, we investigated the trajectory of sleep and daytime sleepiness in a prospective cohort of 40 children and youth (6–18 years old) with concussion, 40 age-and sex-matched healthy children and youth, and 40 with upper-extremity orthopedic injury. Evaluations occurred during the acute stage (<2 weeks) and at 3-, 6-, and 12-month postinjury using the Sleep Disturbance Scale for Children and the Postconcussion Symptom Scale. There were no significant differences within- or between-group differences in sleep across all four time points with analysis of the groups as a whole. When groups were divided by age (6–11 and 12– < 18 years), there was a significant difference in the ability to initiate sleep for the younger concussed group during the acute stage, compared with healthy controls, as well as significantly greater daytime nap duration that decreased over time. Significant correlations were also found between the frequency and duration of daytime naps and Postconcussion Symptom Scale total score and subscores (cognitive, physical/migraine, mood, and sleep) in the concussed group during the acute stage. Our results suggest that in a group with noncomplicated concussion, children and youth have transient alterations in daytime sleepiness that are related to concussion symptoms. Younger children may be more vulnerable to disturbances in sleep and daytime wakefulness.

Keywords

concussion, sleep, daytime wakefulness, longitudinal, children, youth

Received September 6, 2018; Received revised November 12, 2018; Accepted for publication December 4, 2018

Introduction

Concussion, also referred to as mild traumatic brain injury (mTBI), is an increasingly common diagnosis among children and youth, and its effects on the developing brain remain unclear (Eisenberg and Mannix, 2018). Significant symptom burdens are inherent with this injury, particularly during the acute stage, and associated with the onset of temporary impairments of neurological function (Babcock and Kurowski, 2016; McCrory et al., 2017). These are usually transient, and the majority recovers completely without complications. However, children and youth with concussion have been found to recover more slowly than adults, and approximately 30% continue to present with symptoms after 1 month (Crowe et al., 2016; Zemek et al., 2016).

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Alterations or disturbances in sleep are commonly reported during the acute stage of concussion in adults, characterized by increased variability in nighttime sleep duration (Raikes and Schaefer, 2016), increased overall sleep need (Wiseman-Hakes et al., 2017), and the presence of daytime sleepiness (Wiseman-Hakes et al., 2017). Furthermore, alterations or disturbances in sleep are associated with self-reports of pain, low mood, worrying, and feelings of restlessness (Wiseman-Hakes et al., 2017), and the severity of sleep disturbances significantly predicts severity of concussion-related symptoms (Hinds et al., 2016). However, our understanding of the effects of sleep and recovery from concussion is less well understood within a pediatric population.

There exists an emerging body of literature examining sleep in children and youth with more complex mTBI (Glasgow Coma Scale [GCS] of 13–14), those who required hospitalization and more severe brain injury. There is, however, a paucity of research specific to concussion, which precludes the generalization of findings on more severe brain injuries to this population. Furthermore, there are no longitudinal studies to date involving younger children with concussion that have used a validated pediatric sleep measure as an outcome. The current literature is based primarily on measures of postconcussion symptom scale scores, which have limited and very general questions about sleep. Studies involving youth and young adults have also used sleep measures that have not been validated for this population. For example, the Pittsburgh Sleep Quality Index (Buysee et al., 1989) was used to examine sleep in youth aged 12 years to adults aged 30 years with mTBI (with GCS $\geq$ 13–14) Schmidt et al., 2015). However, the Pittsburgh Sleep Quality Index has not been validated in a pediatric population, and it has only been partially validated in chronic moderate–severe TBI (Mollayeva et al., 2013). There is a need for studies using self (or parental, depending on the age of the child) report measures validated for pediatric sleep. The current literature is, furthermore, limited primarily to those with sport-related concussion (SRC). To our knowledge, only one study has been conducted in a pediatric cohort not limited to SRC (Eisenberg et al., 2014), and the authors identified a median duration of 16 days of unspecified sleep symptoms in adolescents with concussion. Their findings, however, were based solely on the Rivermead Post Concussion Symptom Questionnaire (King et al., 1995), which has only one general question about sleep. This study also included a mixed participant group, including those with mild concussion (GCS 15, no hospitalization) and more severe injuries, indicated by a GCS of 13 to 14, and admitted to hospital. For those with SRC, increased daytime sleepiness has been reported in children and youth during the acute stage, as measured by the Epworth Sleepiness Scale (Johns, 1991), and increased (but nonsignificant) frequency of daytime naps (Ko et al., 2015). However, the Epworth Sleepiness Scale has likewise not been validated in a pediatric population; it has not been validated in acute TBI of any severity and has only been partially validated in chronic TBI (Mollayeva et al., 2013). In another study of adolescents with SRC, sleep symptom scores on the Postconcussion Symptom Scale (PCSS) were examined across three follow-up appointments, and authors reported that self-perception of disrupted sleep was associated with more postconcussion symptoms (Kostyun, 2015). Thus, our understanding of the long-term clinical trajectory of sleep and daytime wakefulness disturbances following concussion in a general population (i.e., not limited to those with SRC) of children and youth remains elusive. To our knowledge, no studies have attempted to delineate the longitudinal course of sleep and daytime wakefulness and development of subsequent disturbances/disorders as a specific postconcussive impairment in children and youth.

The primary objective of this study was to conduct a prospective evaluation of the incidence, duration, and clinical course of sleep; daytime wakefulness; and the development of any sleep disorders in three groups of children and youth, namely, (a) those presenting to a pediatric emergency department (ED) with concussion, (b) healthy age- and sex-matched controls, and (c) age- and sex-matched children and youth with orthopedic (upper-extremity orthopedic injury [OI]). We also assessed any associations between sleep and concussion symptoms across the recovery period from the acute stage to 1-year postinjury in our sample. In addition, given our understanding of brain and cognitive maturation(Hudspeth and Pribram, 1990), previous findings that age has been identified as a predictor of recovery (Field et al., 2003), and the role of sleep in development, we aimed to assess the interaction between age and the trajectory of sleep and sleep disturbances.

We hypothesized that children and youth with concussion would have parental or self-reports of poorer sleep quality, marked specifically by difficulties initiating or maintaining sleep, or excessive sleepiness, when compared with OI and healthy controls, particularly in the acute stage. We further hypothesized that children and youth with concussion would report increased daytime sleepiness, indicated by the presence, frequency, and duration of daytime naps in comparison with healthy children and youth, and children and youth with OI. We also hypothesized that children and youth with concussion would report a higher presence, frequency, and duration of daytime naps during Time 1 (acute stage) which would decrease over time. As pain intensity has been identified as a predictive factor in sleep disturbances (Lavigne et al., 2015), we also hypothesized that children and youth with OI would report some sleep disturbance at Time 1 (acute stage) and possibly Time 2, depending on recovery. Finally, we hypothesized that disturbances in sleep or the presence, frequency, or duration of daytime naps would correlate with cluster scores on the PCSS.

Methods

This study was approved by the Research Ethics Board of the McGill University Health Center (Pediatric Panel).

A prospective inception cohort design with three groups—(a) concussed children and youth, (b) age- and sex-matched healthy controls, and (c) children and youth with upper-extremity OI, across four time points (T1: up to 2 weeks, T2: 3 months, T3: 6 months, and T4: 1-year postinjury)—was used. This study was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology statement for case control studies (Von Elm et al., 2007).

Participants

The study was conducted in the Concussion Clinic at a Pediatric Teaching Hospital and Trauma Centre in Montreal Canada. Participants were recruited over a 2-year period from the ED. Children and youth of ages 6 to < 18 years who were seen in the ED and received a diagnosis of concussion or upper-extremity OI were invited to participate in this study. They were eligible to participate if they were able to understand and speak English or French and were willing to commit to the 1-year study time period. Children had to have no previous history of brain injury or developmental delay or sleep disorder or psychiatric disorder. Those with concussion were invited to bring a friend of the same age and sex to act as healthy control participants.

In total, 120 children and youth agreed to participate in this study, distributed equally across the three study groups: (a) concussed, (b) age- and sex-matched healthy control, and (c) age- and sex-matched OI control. In total, 64 children were approached in the concussed group and 57 in the OI group. All who were approached were eligible and those not included declined participation. Information was not collected on those who refused as per research ethics committee approval. One participant from the concussed group was removed as they sustained a second concussion during the study period. Demographic variables are presented in Table 1 for the three groups. Informed consent to participate was provided by a parent or guardian for all participants prior to beginning the study. Following enrolment in the study, participants were seen in the Concussion Clinic and administered the questionnaires.

Clinical Variables

We documented GCS scores for the concussed group and mechanism of injury (see Table 2). Throughout the study, any change in health status was documented.

Outcome Measures

PCSS revised. The PCSS comprises 22 self-report questions answered on a 0 to 6 Likert scale validated as an assessment tool for the measurement of perceived symptoms associated with concussion (Alla et al., 2009; Kontos et al., 2012). The score is reflective of the severity of each symptom, and the total score reflects the

Table 1. Patient Demographics.

Variables	Group 1: Concussion	Group 2: Healthy Controls	Group 3: Orthopedic Injury
Number of participants	*N* = 39	*N* = 39	*N* = 40
Age, years	12.9 ± 2.7	12.1 ± 2.7	11.5 ± 2.5
Number of female (%)	17 (43%)	17 (43%)	14 (35%)
Group A characteristics (6–11 years)	Age: 9.9± 1.2 *N* = 12, Female = 6 (50%)	Age: 9.9±1.2 *N* = 12, Female= 6 (50%)	Age: 8.9±2.0 *N* = 15, Female = 5 (33.3%)
Group B characteristics (12– < 18 years)	Age: 14.4±1.4 *N* = 27, Female = 10 (37%)	Age: 14.4±1.4 *N* = 27, Female = 10 (37%)	Age: 13.0 ±1.1 *N* = 25, Female = 14 (56%)
PCSS total score at Time 1 (up to 5 days postinjury)	9.3±15.0, range: 0–75	2.5±3.7, range: 0–18	0.55±1.6, range: 0–9
PCS Physical/Migraine subscale score (Time 1)	2.0±2.6, range: 0–10	0.7±1.4, range: 0–5	1.0±2.5, range: 0–11
PCS Cognitive subscale score (Time 1)	4.6±7.6, range: 0–32	0.7±1.8, range: 0–9	1.2±2.3, range: 0–14
PCS Sleep and Fatigue subscale score (Time 1)	1.1±2.2, range: 0–9	0.3±1.3, range: 0–7	0.5±2.0, range: 0–9
PCS Emotion/Mood subscale score (Time 1)	1.9±3.6, range: 0–17	1.1±2.3, range: 0–9	0.3±0.9, range: 0–5

Note. PCSS = Postconcussion Symptom scale. Data are presented as mean ± standard deviation.

Table 2. Injury Characteristics of Concussed Group.

Injury characteristics (concussed group)	6–11 year olds	12–< 18 year olds
Injury Cause		
Sports	5	25
Falls	8	3
Motor vehicle	1	0
Other	0	0
Not reported	0	0
Glasgow Coma Scale Score		
15	7	21
14	3	0
Not reported	4	7
Loss of Consciousness		
Y	2	8
N	12	20
Required Hospitalization		
Y	0	0
N	12	27
Complicated recovery/ development of PPCSs?	0	0

Note. PPCSs = persistent postconcussion symptoms.

individual's subjective report of their concussion symptoms at the time the questionnaire is completed. The ratings are summed across items to produce a single score that may be used as an indicator of injury severity or followed over time as an indicator of recovery. A total score of < 22 is considered mild, 22 to 84 is considered moderate, and > 84 is considered severe (Chen et al., 2007). A factor analysis has identified four symptom clusters including migraine (physical), cognitive, sleep, and psychiatric (mood-affect) Kontos et al., 2012).

2. The Sleep Disturbance Scale for Children (Bruni et al., 1996). The Sleep Disturbance Scale for Children (SDSC) comprises 26 questions that are answered by parents (for the younger children) and by the adolescents themselves on a Likert scale. It evaluates sleep disturbances across six domains to provide a total score and subscale scores:

Subscale 1: Disorders of Initiating and Maintaining Sleep (Insomnia);
Subscale 2: Sleep-Related Breathing Disorders;
Subscale 3: Disorders of Arousal (Parasomnias);
Subscale 4: Sleep–Wake Transition Disorders;
Subscale 5: Disorders of Excessive Somnolence; and
Subscale 6: Sleep Hyperhidrosis.

As increased need for sleep, changes in sleep–wake schedule, and increased daytime sleepiness have been documented following concussion, the following questions (adapted from the Etude Longitudinale Du Développement Des Enfants Du Québec) were also asked at each time point during the study:

- Does your child nap during the day (always, often, sometimes, never)?
- If your child naps, what is the total duration of daytime sleep minutes?
- At what times does your child go to bed at night during weekdays?
- At what times does your child wake up during weekdays?
- At what time does your child go to bed at night during the weekend?
- At what time does your child wake up during the weekend?
- How many minutes does your child stay awake during the night?
- How many hours of sleep does your child get on most nights?
- How long after going to bed does your child usually fall asleep (in minutes)?

Statistical Analysis

To test our main hypothesis that there are changes in sleep and daytime wakefulness over time in the concussion group, differences in sleep and wake parameters between the concussed and nonconcussed groups at the study onset (acute stage), and no differences by the end of the study (1-year follow-up), we conducted both unadjusted and mixed-model age- and sex-adjusted longitudinal analysis to compare the means of the outcomes within groups and between groups. We used generalized estimation equation with AR(1) (first-order autoregressive relationship) covariance structure to adjust for the repeated measures within patients. To account for multiple comparisons, we set alpha Type I error at .01 and calculated 99% confidence intervals. We considered alpha less than .01 to be statistically significant. We also repeated the main analyses by sex to assess potential sex differences. To test our hypothesis that disturbances in sleep or increased duration of daytime naps would correlate with scores on the PCSS, we used Spearman rank correlations across the four time points and point-biserial correlations to determine any associations between nap occurrence (operationalized as a binary variable of Yes/No for nap during the day) and PCSS scores. Given the wide range of brain and cognitive development, and the associated developmental changes in sleep evolution across the pediatric age span, we further repeated all analyses by age groups (6–11 years and 12–< 18 years). The statistical software SAS 9.3 (SAS Institute, Cary NC) was used for analysis and data manipulations.

Table 3. Results on the Sleep Disturbance Scale for the Concussed, Healthy Control, and Orthopedic Injured Group for (a) Age Groups Combined (6– < 18 Years), (b) Younger Children (6–11 Years), and (c) Youth (12– < 18 Years).

	Concussed group	Healthy control group	Orthopedic injury group
(a) Age groups combined (6– < 18 years)			
Sleep Disturbance Scale total score[a]			
Time 1	36.0 ± 7.0	35.2 ± 5.8	36.0 ± 7.3
Time 2	34.5 ± 6.2	34.8 ± 5.5	34.4 ± 7.5
Time 3	35.6 ± 6.9	32.6 + 4.7	34.2 ± 8.7
Time 4	33.8 ± 7.5	33.0 ± 5.9	34.5 ± 8.7
Nap frequency[b]			
Time 1	1.5 ± 0.6	1.2 ± 0.5	1.2 ± 0.6
Time 2	1.2 ± 0.4	1.1 ± 0.2	1.3 ± 0.6
Time 3	1.1 ± 0.3	1.1 ± 0.3	1.1 ± 0.3
Time 4	1.2 ± 0.4	1.1 ± 0.4	1.2 ± 0.6
Nap duration (min)			
Time 1	29.0 ± 45.0	15.0 ± 37.6	16.0 ± 38.6
Time 2	21.0 ± 54.0	13.6 ± 30.2	20.4 ± 42.5
Time 3	9. 3 ± 25.0	20.4 ± 45.2	15.8 ± 34.0
Time 4	41. 8 ± 62.0	20.4 ± 45.2	16.9 ± 34.3
Subscale 1: Disorders of Initiating/Maintaining Sleep[c]			
Time 1	12.0 ± 4.0	11.8 ± 3.7	11.6 ± 3.3
Time 2	11.0 ± 3.5	11.7 ± 3.0	11.6 ± 3.6
Time 3	11.4 ± 3.5	11.0 ± 2.5	11.0 ± 3.6
Time 4	11.0 ± 3.2	10.9 ± 2.5	11.1 ± 3.6
Subscale 5: Disorders of Excessive Somnolence[d]			
Time 1	7.8 ± 2.2	8.2 ± 3.2	7.6 ± 2.1
Time 2	7.9 ± 2.3	8.6 ± 3.0	7.2 ± 2.5
Time 3	8.0 ± 3.1	8.1 ± 3.2	8.0 ± 3.0
Time 4	7.6 ± 2.5	8.2 ± 3.2	8.0 ± 2.9
(b) Younger Children (6–11 years)			
Sleep Disturbance Scale total score[a]			
Time 1	38.4 ± 7.0	34.2 ± 4.6	36.2 ± 7.5
Time 2	36.6 ± 6.6	33.7 ± 6.3	35.2 ± 8.1
Time 3	36.5 ± 5.3	31.2 ± 4.2	35.5 ± 9.4
Time 4	37.4 ± 7.0	34.8 ± 7.1	33.0 ± 13.4
Nap frequency[b]			
Time 1	1.5 ± 0.6	1.0 ± 0.0	1.1 ± 0.5
Time 2	1.2 ± 0.4	1.1 ± 0.2	1.3 ± 0.6
Time 3	1.1 ± 0.3	1.1 ± 0.3	1.1 ± 0.3
Time 4	1.2 ± 0.4	1.1 ± 0.4	1.2 ± 0.6
Nap duration (min)			
Time 1	21.3 ± 40.7	0.0 ± 0.0	2.8 ± 10.7
Time 2	15.0 ± 37.2	2.5 ± 8.7	21.7 ± 49.4
Time 3	1.25 ± 4.3	2.5 ± 8.6	1.1 ± 4.0
Time 4	21.2 ± 40.7	15.0 ± 3.7	3.5 ± 12.5
Subscale 1: Disorders of Initiating/Maintaining Sleep[c]			
Time 1	13.7 ± 5.0	10.0 ± 3.7	10.6 ± 3.2
Time 2	12.9 ± 5.0	10.5 ± 3.7	10.7 ± 2.4
Time 3	12.8 ± 4.1	10.4 ± 2.3	10.8 ± 3.2
Time 4	12.1 ± 3.3	10.7 ± 2.1	11.4 ± 3.6
Subscale 5: Disorders of Excessive Somnolence[d]			
Time 1	7.3 ± 1.8	6.5 ± 3.3	7.1 ± 1.5
Time 2	7.0 ± 1.8	7.6 ± 2.9	6.7 ± 1.8
Time 3	7.4 ± 1.8	6.8 ± 2.1	7.4 ± 2.2
Time 4	7.8 ± 2.0	7.3 ± 2.5	7.2 ± 2.5
(c) Youth (12– < 18 years)			
Sleep Disturbance Scale total score[a]			
Time 1	35.0 ± 6.8	36.0 ± 6.1	35.7 ±7.6
Time 2	33.2± 6.1	35.3 ± 3.2	33.8 ± 7.3
Time 3	34.0 ± 7.7	33.5 ± 4.7	33.3± 8.5
Time 4	32.3 ±7.4	32.8 ± 5.2	33.3 ± 10.3
Nap frequency[b]			
Time 1	1.5 ± 0.6	1.3 ± 0.5	1.3 ± 0.7
Time 2	1.3 ± 0.7	1.3 ± 0.5	1.4 ± 0.8
Time 3	1.3 ± 0.6	1.3 ± 0.7	1.4 ± 0.7
Time 4	1.6 ± 0.7	1.6 ± 0.8	1.4 ± 0.7
Nap duration (min)			
Time 1	32.2 ± 47.5	21.9_±44	24.0 ±46.6
Time 2	24.4 ± 60.7.	17.4 ± 35	18.7 ± 38.0
Time 3	12.8 ± 30.1	28.0 ± 53.6	24.0 ± 40.4
Time 4	51.0 ± 69.8	26.5 ± 36.7	20.4 ± 32.5
Subscale 1: Disorders of Initiating/Maintaining Sleep[c]			
Time 1	11.4 ± 3.2	11.7± 3.4	12.2 ± 3.3
Time 2	10.4 ± 2.2	11.8 ± 4.0	11.7 ±4.8
Time 3	10.5 ± 2.7	10.8± 3.3	10.7 ± 4.4
Time 4	10.5 ± 3.2	11.2 ± 3.5	9.8 ± 4.7
Subscale 5: Disorders of Excessive Somnolence[d]			
Time 1	8.1 ± 2.4	8.1 ± 2.8	7.9 ± 2.4
Time 2	8.4 ± 3.3	8.8 ± 3.4	7.5 ±3.2
Time 3	8.4 ± 3.5	8.7 ± 3.8	8.2 ± 3.6
Time 4	7.7 ± 2.8	7.9 ± 3.1	7.8 ± 4.8

(continued)

Note. All data are presented as mean ± standard deviation.
[a]Sleep Disturbance Scale total score interpretation: 26–35: *normal*, 36–51: *mild disturbance*.
[b]Nap frequency: 1 = *never*, 2 = *sometimes*, 3 = *often*, 4 = *always*.
[c]Disorders of Initiating/Maintaining Sleep score interpretation: 7–10: *normal*, 11–13.5: *mild disturbance*, 13.6–16: *moderate disturbance*.
[d]Disorders of Excessive Somnolence score interpretation: 4–7.2: *normal*, 7.3–10: *mild disturbance*.

Results

Table 3 presents the sleep variables for each group at each time point—for the groups as a whole (age 6– < 18 years), for the younger children (age 6–11 years), and for the youth (age 12– < 18 years).

Between-Group Comparison on Sleep Variables

When we analyzed the groups as a whole, there were no significant differences at any time point for SDSC total score or subscale scores. Moreover, we found no significant group differences in total sleep scores (SDSC) or any subscale scores across all four time points (see Table 3). Finally, there were no significant mean differences over time. No children were identified as needing or receiving treatment for any sleep disorders throughout the study.

Some clinically interesting trends were observed for the group as a whole; for example, the average nap duration for the concussed group was 29 min compared with 15 min in healthy controls and 16 min in the OI group at Time 1 (acute stage). Furthermore, 15 participants in the concussed group reported napping *often* or *sometimes*, compared with 8 control participants and 6 OI participants at Time 1; however, this was not statistically significant. It is important to note that there was significant heterogeneity in nap duration across all groups in particular at Time 4 (12 months post), and thus, our average data are skewed by outliers in some instances.

Interaction Between Age and Trajectory of Sleep

When the groups were separated according to age (children: 6–11; youth: 12– < 18), the younger concussed group had a significant difference in the ability to initiate sleep (Subscale 1: *Insomnia*) compared with the healthy controls (mixed-model p value = .009) at Time 1. There was also a significant decrease in nap duration from Time 1, Time 2, and Time 3 (mixed-model p value = .006) for the younger concussed group. There were no significant differences observed for the older youth concussed group and the two control groups. Moreover, no significant differences were found for the other SDSC subscores.

Associations Between Sleep and Nap Variables and Postconcussion Symptom Scores Among Children and Youth With Concussion

Table 4 presents correlations between sleep disturbances (SDSC total score and subscales) and concussion symptoms (PCSS total score and subscores) during the acute stage—for the group as a whole, the younger children (age 6–11 years), and the youth (age 12– < 18 years). For the concussed group as a whole, significant positive correlations were observed between the PCSS physical subscore and both duration and frequency of naps (defined as a binary variable); similar positive correlations were observed between the SDSC subscales and the aforementioned sleep-related variables at Time 1 (see Table 4 for statistics), including frequency and duration of daytime naps with sleep, physical/migraine subscores. Interestingly, there was also a significant association between nap duration and the total PCSS score. The results were very similar for both sexes. For the younger group, significant positive correlations were observed between nap duration and all PCSS four subscores (cognitive, sleep, physical/migraine, mood) as well as PCSS total score. We also observed the same results for two PCSS subscores (sleep and physical/migraine) and the occurrence of naps (see Table 4 for statistics). For youth (age 12– < 18), no significant correlations (either positive or negative) were identified between PCSS and the SDSC questionnaire (see Table 4 for statistics).

Analysis by Sex

The results were very similar for both females and males. No statistically significant differences were identified by sex across all time points and within and between groups.

Discussion

While we did not identify any statistically significant sleep–wake deregulation after concussion with the group as a whole (age 6– < 18 years) at any time, we did identify clinically relevant increases in nap frequency and duration in the acute stage. Furthermore, there were clear age differences in nighttime and daytime sleep within the concussed group during the acute stage, with younger children (age 6–11) having increased difficulty initiating sleep as well as increased nap duration, which showed a significant decrease over time. Moreover, our results revealed that reported daytime nap frequency and duration were highly correlated with PCSS subscores including sleep and migraine/physical symptoms during the acute stage among the concussed group as a whole; these correlations between sleep disturbances and PCSS were observed for the four PCSS subscores when tested in the younger group. Interestingly, we did not find any associations between sleep and PCSS for the older youth, indicating that the younger children were driving the significant associations for the group as a whole. Given that sleep is neuroprotective and necessary for learning and synaptic plasticity (Eugene and Masiak, 2015; Sabir et al., 2015; Koo and Marshall, 2016), these postconcussion changes in sleep and wakefulness are an important issue for children and youth with vulnerable and developing brains.

Our findings are consistent with the limited available data regarding sleep and concussion in SRC for older children and youth, which describe a nonsignificant increase in daytime sleepiness during the acute stage (Ko et al., 2015) and a strong correlation with total symptoms and symptom clusters including sleep symptoms and migraine (physical symptom cluster) (Murdaugh et al., 2018). Furthermore, our results indicate that younger children are more susceptible to changes in their sleep–wake patterns following concussion. Our findings extend the limited available data describing the clinical course and duration of nighttime and daytime sleep in children and youth with concussion, from the acute stage to 1-year postinjury. Unlike some other studies examining general symptoms of concussion, we did not identify any differences by sex (Frommer et al., 2011; Zemek et al., 2016).

Table 4. Associations Between Postconcussion Symptom Scores (Subscores and Total) and Sleep-Related Outcome Variables at Time 1 for (a) the Whole Sample of Concussed Participants (6– < 18 Years), (b) Younger Concussed Children (6–11 Years Old), and (c) the Concussed Youth (12–< 18 Years Old).

Total concussed group (age 6– < 18 years)	Postconcussion Symptoms Scale subscores				
	Cognitive	Sleep	Physical	Mood	Total
Sleep Disturbance Scale Total Score: Total Concussed Group (age 6 - < 18 years)	$r = -.345$	$r = -.355$	$r = -.264$	$r = -.258$	$r = -.088$
	$p = .046$	$p = .040$	$p = .131$	$p = .135$	$p = .622$
Daytime naps	$r = .395$	$r = .526$	$r = .587$	$r = -.108$	$r = .485$
	$p = .021$	$p = .001$*	$p = .000$*	$p = .105$	$p = .004$*
Nap duration	$r = .416$	$r = .552$	$r = .587$	$r = -.166$	$r = .479$
	$p = .015$	$p = .001$*	$p = .000$*	$p = .339$	$p = .004$*
Subscale 1: DIMS	$r = -.211$	$r = -.267$	$r = -.223$	$r = -.198$	$r = -.275$
	$p = .230$	$p = .128$	$p = .205$	$p = .257$	$p = .116$
Subscale 5: DES	$r = -.117$	$r = -.161$	$r = -.088$	$r = -.127$	$r = -.073$
	$p = .511$	$p = .365$	$p = .622$	$p = .466$	$p = .687$
Younger children (6–11 years)					
Sleep Disturbance Scale total	$r = -.529$	$r = -.440$	$r = -.417$	$r = —.406$	$r = -.308$
	$p = .094$	$p = .175$	$p = .202$	$p = .215$	$p = .323$
Daytime naps	$r = .709$	$r = .741$	$r = .733$	$r = .516$	$r = .355$
	$p = .015$	$p = .009$*	$p = .010$*	$p = .104$	$p = .257$
Nap duration	$r = .938$	$r = .997$	$r = .979$	$r = .886$	$r = .824$
	$p < .0001$*	$p < .0001$*	$p < .0001$*	$p = .0003$*	$p = .001$*
Subscale 1: DIMS	$r = -.481$	$r = -.390$	$r = -.446$	$r = -.327$	$r = -.300$
	$p = .134$	$p = .236$	$p = .170$	$p = .327$	$p = .345$
Subscale 5: DES	$r = .174$	$r = .232$	$r = .340$	$r = .314$	$r = .298$
	$p = .608$	$p = .492$	$p = .306$	$p = .347$	$p = .346$
Youth (12– < 18 years)					
Sleep Disturbance Scale total	$r = -.286$	$r = -.150$	$r = -.262$	$r = -.183$	$r = -.288$
	$p = .187$	$p = .495$	$p = .227$	$p = .403$	$p = .146$
Daytime naps	$r = .417$	$r = .464$	$r = .387$	$r = -.250$	$r = .037$
	$p = .048$	$p = .026$	$p = .068$	$p = .251$	$p = .854$
Nap duration	$r = .122$	$r = .197$	$r = .282$	$r = -.337$	$r = .020$
	$p = .579$	$p = .367$	$p = .192$	$p = .116$	$p = .921$
Subscale 1: DIMS	$r = .218$	$r = .046$	$r = .006$	$r = -.050$	$r = .085$
	$p = .317$	$p = .835$	$p = .979$	$p = .821$	$p = .673$
Subscale 5: DES	$r = -.348$	$r = -.134$	$r = -.421$	$r = .025$	$r = -.294$
	$p = .104$	$p = .542$	$p = .045$	$p = .911$	$p = .137$

Note. DIMS: Disorders of Initiating and Maintaining Sleep; DES: Disorders of Excessive Somnolence. *Significant at $p < .01$.

Contrary to our hypothesis, there were no differences in the ability to initiate or maintain sleep between our groups nor evidence of overt sleep disorders at any time among any of our sample populations, when the concussed group were examined as a whole. However, despite the lack of significance, there was a clinically relevant trend of increased nap frequency and duration during the acute stage, consistent with adult studies which also reported daytime sleepiness (Wiseman-Hakes et al., 2017). Younger children with concussion, however, did have a significant difference in their ability to initiate sleep, as well as significantly increased nap frequency and duration during the acute stage, although these dissipated by the third month postinjury. Consistent with previous studies, we did identify that the occurrence and duration of naps was associated with higher total symptom, sleep symptoms, and physical/migraine symptom scores, in the acute stage only.

It is important, however, that the lack of significant findings for the concussed group as a whole be considered within the context of the study itself rather than interpreted as a clinical conclusion. Our data, particularly among the adolescents, were characterized by considerable between- and within-subject variability over time. In addition, there are a number of factors that should be considered. First, adolescence is a period of marked changes in sleep and a shift in the circadian cycle. Younger children's sleep habits are more likely to be controlled by parents, whereas adolescents' sleep habits are highly variable and influenced by homework, extracurricular activities, part-time employment, and social demands (Becker et al., 2017). Younger children are more likely to maintain a stable sleep–wake schedule across the week than their adolescent counterparts (Becker et al., 2017). Second, as a whole, our concussed sample was quite mild and recovered quickly. Moreover, our findings may be reflective of the loss of power that occurs with multiple comparisons and the associated setting of a conservative alpha Type 1 error at .01 to establish significance rather than a lack of actual changes in sleep per se. Our study is also the first to follow patients for a full year, which adds a confound of seasonal changes in sleep patterns. For example, some participants maintained early morning wake time and consistent bedtime during the school year; however, this changed markedly during the summer months, while others maintained a consistent sleep–wake cycle throughout the year. As noted earlier, there was considerable heterogeneity in nap duration in particular, at Time 4. Thus, our data are also reflective of current demographic and sociological factors impacting sleep at a societal level.

Limitations and Future Directions

Our study included relatively small sample sizes within each group, with multiple comparisons, which may have limited our ability to detect statistically significant between-group differences or within-group differences over time. Furthermore, the sample size did not allow us to control for seasonal variations in sleep, as we did not have sufficient numbers injured during each of the four seasons to compare by season. The SDSC, consistent with other measures, is one that looks at sleep retrospectively, and for this study, the time frame was within the last month. However, the SDSC does not account for immediate changes in sleep either in response to concussive events or over time with recovery. Development of measures that are more sensitive to the alterations in sleep and daytime wakefulness specifically associated with concussion are needed.

Conclusions

To our knowledge, this study is the first to capture the clinical trajectory of sleep and daytime wakefulness longitudinally in a cohort of children and youth with concussion including both SRC and non-SCR, compared with age- and sex-matched controls and those with upper-extremity OI. It is also the first study to include younger children (age $<$ 10 years) and is the first to use a validated measure of pediatric sleep. There was no evidence of sleep disorders per se nor any reported group differences in nighttime sleep as a whole. However, there were significant differences for the younger children in the acute stage for both sleep and daytime wakefulness. Consistent with previous findings, acute pediatric concussion may be characterized by increased daytime sleepiness (Ko et al., 2015) and, for younger children, may also be characterized by difficulties in initiating nighttime sleep. Moreover, acute daytime sleepiness was strongly associated with reports of increased physical/ migraine symptoms such as pain, as well as increased mood symptoms, cognitive symptoms and overall symptom burden for the younger children. Given that pain, sleep, or wake disturbance and alterations in cognition and emotional deregulation can affect school reentry, academic performance, and social function during critical periods of development and maturation, assessment and monitoring of sleep and daytime wakefulness during the acute stage of concussion is warranted (Blume et al., 2011). Our findings suggest that self-reported symptoms of daytime sleepiness may be a predictor of concussion symptom recovery. Furthermore, we suggest that younger children appear to be particularly vulnerable and should be monitored closely during this time. Finally, as enduring sleep symptoms and sleep disturbance have been associated with persistent postconcussion in adults and that children and youth are a vulnerable population undergoing periods of rapid neurological development, monitoring and evaluation of sleep and daytime wakefulness are an important component of pediatric concussion evaluation and management (Hinds et al., 2016).

Summary

We conducted a longitudinal study of sleep and daytime wakefulness in children and youth with concussion over 1 year compared with age- and sex-matched healthy controls and those with upper-extremity orthopedic injury. While there was no evidence of sleep disorders per se, younger subjects had increased frequency and duration of naps during the acute stage, which was associated with overall symptom burden. Younger children aged 6 to 11 years also had more difficulty initiating sleep in the acute stage. These findings may help to elucidate the trajectory of sleep and recovery following concussion in children and youth.

Acknowledgments

The authors are grateful to Dr. Rahim Moineddin for statistical support.

Author Contributions

C. W. -H. was responsible for conceptualizing the article, review of background literature, data interpretation, and writing of the article. N. G. was responsible for contributions to the conceptualization of the study and inclusion of the pediatric sleep measure and additional questions, data interpretation, and writing of the article. B. S. and L. L. were responsible for data analysis and contributed to the interpretation. B. S. contributed to the writing of the article. I. G. is responsible for the conceptualization of the study and data analysis and contributed to the interpretation.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by a postdoctoral fellowship to Dr. Catherine Wiseman-Hakes through Sleep and Biological Rhythms Toronto, a CIHR team and training grant to the University of Toronto, as well as by the SickKids Foundation and the Research Institute of the McGill University Health Center.

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