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Evaluation of Sleep Outcomes After Traumatic Brain Injury in Children Using Questionnaires and Actigraphy

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Evaluation of sleep outcomes after traumatic brain injury in children using questionnaires and actigraphy

By

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Abstract

Traumatic brain injuries are the result of a sudden external blunt force to the brain and can result in long-term complications or death. In pediatrics, it is the leading cause of acute and chronic sleep-wake disturbances, as well as cognitive deficits, which can lead to a reduction in the quality of life for these children. These impairments can later result in lowered performance in work and school settings or decreased psychosocial function. Currently, there is a need to determine the relationship between traumatic brain injury (TBI) and sleep. There is a need for more research on whether or not sleep-wake disturbances are a possible factor in cognitive function in pediatrics who have TBIs. This study investigates whether or not sleep questionnaires can be used to diagnose sleep disturbances compared to actigraphy measurements. First, we found if there was any correlation between TBIs and sleep, then found if there was any correlation between Sleep Disturbances Scale for Children (SDSC) and Children's ChronoType Questionnaire (CCTQ) to Wrist Watch Actigraphy for certain variables such as sleep duration and sleep period. Results indicate that children with TBIs have increased sleep disturbances compared to healthy controls and that the overall agreement was poor between questionnaires and actigraphy, especially for sleep latency and efficiency measures. However, CCTQ questionnaires could be further investigated as a possible test to be used to diagnose sleep-wake disturbances, as there is some correlation. As a result, further research is required to determine variables with stronger correlations between questionnaires and actigraphy in different subpopulations.

Introduction

Traumatic brain injuries are one of the leading causes of death and disability for children in the United States. There are an estimated 475,000 children who suffer from traumatic brain injury every year (Dewan et al. 2016), making traumatic brain injuries known as a worldwide epidemic. Traumatic brain injuries occur when there is a sudden external blunt force to the head, injuring the brain in the process. There are two types of traumatic brain injuries: penetrating and non-penetrating. Penetrating injuries are caused by objects that penetrate the skull and dura mater of the skull, while non-penetrating injuries are caused by direct impact on the skull that damages the neuronal and vascular structures of the brain (Vlahos and Tapia 2021).

Traumatic Brain Injury Impact

Traumatic brain injuries can be especially impactful on children due to their age-related structural differences compared to adults (ARAKI, YOKOTA, and MORITA 2017). This makes them extremely vulnerable to post-traumatic brain injury morbidities, one of them being sleep-wake disturbances. In the current literature regarding this topic, sleep-wake disturbances affect more than 50% of children who have a traumatic brain injury (Williams, Lim, and Shea 2018). The most common types of sleep-wake disturbances are insomnia, excessive daytime sleepiness, disorders with the circadian rhythm, and as well as an increase in sleep need (Ouellet, Beaulieu-Bonneau, and Morin 2015). As a result, a person might find extreme fatigue throughout the day, the inability to fall or stay asleep, and the constant need to sleep. These can later impact the quality of life, some of which are impaired cognitive functions, decreasing psychosocial function. Specifically for children, it can also affect the brain during childhood development as it can change synaptic plasticity and memory consolidation (Williams, Lim, and Shea 2018). In current literature, there is an increasing recognition of sleep-wake disturbances, yet it still lacks attention from clinical care teams and appropriate follow-up in a clinical setting. It is also noted that there are substantial knowledge gaps regarding incidence, risk factors, and pathophysiologic mechanisms in regard to sleep-wake disturbances (Williams, Lim, and Shea 2018). Further clinical research is needed to investigate traumatic brain injuries and sleep-wake disturbances to better provide treatment.

Quantifying and Diagnosing Sleep-Wake Disturbances

In addition to needing more research, there needs to be an appropriate way to quantify and measure sleep-wake disturbances, especially after a traumatic brain injury (Williams, Lim, and Shea 2018). There are two main ways of assessing sleep-wake disturbances: subjective and objective methods. Subjective methods are self-reported and range from sleep questionnaires to sleep diaries. On the other hand, objective methods include actigraphy and polysomnography (Abad and Guilleminault 2003). Polysomnography is an umbrella term that encapsulates all types of medical procedures that measure different markers for sleep, sleep stages, and sleep related disorders. Polysomnography includes electroencephalogram (EEG), which measures activities within the brain, and electrocardiogram (EKG) which measures the heart rate and rhythm (Ibáñez, Silva, and Cauli 2018). Currently, polysomnography is the most widely used to diagnose sleep-wake disturbances, but this method can often be unreliable in different populations like children as performed in unfamiliar settings, as well as failing to diagnose different types of sleep-wake disturbances like daytime somnolence (Williams, Lim, and Shea 2018). Another way to objectively diagnose sleep-wake disturbances is through actigraphy, which measures body movements and human activity. Ultimately, it will record sleep patterns for a long period of time and the data will be analyzed. On the contrary, sleep questionnaires are often the cheaper and quicker test, as compared to the objective methods. Depending on the specific sleep disorder, there are different questionnaires that can be utilized for different populations and different disorders, but the reliability and validity of many of the questionnaires is unknown.

Literature Gaps

As mentioned before, traumatic brain injuries affect many children every year in the United States. Sleep-wake disturbances are one of the morbidities of traumatic brain injuries, however, there is a lack of research to diagnose these problems in children. Actigraphy is being more widely used, but it lacks specificity in detecting wake-after-sleep onset and also has some concerns with standard scoring rules or definitions in literature with respect to children (Meltzer et al. 2012). Conversely, sleep questionnaires could be reliable, however, a 2011 review states that only 2 out of 183 questionnaires fit the qualifications to properly diagnose sleep-wake disturbances in children (Spruyt and Gozal 2011). Due to these gaps in research, this clinical study was conducted to collect more information on the relationship between traumatic brain injuries and the morbidity of sleep-wake disturbances and to ultimately quantify ways to measure sleep-wake disturbances as a result of traumatic brain injury in children. It is hypothesized that the SDSC and CCTQ questionnaires will have variables that can agree with actigraphy measurements to better understand how sleep questionnaires may be used as a substitute for actigraphy to diagnose sleep-wake disturbances in children with traumatic brain injuries.

Methods

<u>Study Design</u>

The goal of this prospective longitudinal clinical research study conducted at Oregon Health & Sciences University located in Portland, Oregon is to better understand the effects of traumatic brain injuries, specifically how sleep-wake disturbances occur after a traumatic brain injury, how it can impact recovery, and ultimately whether actigraphy or sleep questionnaires are useful for monitoring sleep-wake disturbances. This study will enroll approximately 400 patients into this study to investigate sleep outcomes. There are two aims for this specific study, located in Table 1. In addition, demographic data was also collected.

Table 1: *The specific aims and objectives for this sleep outcome after traumatic brain injury research study.*

Aim 1.	Comparison of sleep outcomes after traumatic brain injury to healthy controls.
Aim 2.	Agreement between questionnaires and actigraphy measures of sleep outcomes after traumatic brain injury.

<u>Screening and Consenting Process</u>

This is a clinical research study conducted at Oregon Health & Sciences University located in Portland, Oregon in the United States of America. Patients are screened based on their eligibility after acute stabilization during their hospital admission. These inclusion and exclusion criteria are presented in Table 2. Once patients have been screened and the study has been explained to the patient, they are then approached for informed consent. Patients who are over the age of 18 are able to sign the consent form for themselves and patients who are younger than 18 will need written consent from one parent or guardian. Additionally, those between the ages of 7 and 18, will have to provide an assent and a written signature. Contact information from the required documents is then verified in EPIC and recorded.

Table 2: *Inclusion and Exclusion Criteria used to enroll participants in this sleep outcome after traumatic brain injury research study.*

Inclusion	Exclusion
Age ≥6 years and <19 years	Patients who are unlikely to survive their injuries
Admitted with a traumatic brain injury to the hospital	No informed consent from legal guardian and/or child
Any source of primary injury	Pregnancy
Any TBI severity: concussion, mild complicated, moderate, and severe TBI	Patients who have abusive trauma
English or Spanish-speaking	
Obtain informed consent from legal guardians and/or assent from the child	

Sleep Questionnaires

This study focuses primarily on two different types of pediatric sleep questionnaires: the Sleep Disturbances Scale for Children (SDSC) and the Children's ChronoType Questionnaire (CCTQ). The SDSC questionnaire involves 27 items that are answered on a Likert scale that ranges from a 1 (never) to 5 (always) scale and has studies showing that it is a useful tool for evaluating sleep-wake disturbances in children (Bruni et al. 1996), as seen in Figure 1 and 2. In addition, the SDSC can diagnose specific sleep-wake disturbances such as the means of SDSC total, disorders of initiation and maintenance of sleep (DIMS), sleep breathing disorder (SBD), disorders of arousal (DA), sleep-wake transition disorders (SWTD), disorders of excessive somnolence (DOES) or hypersomnolence, and sleep hyperhidrosis (SHY).

Appendix A. SLEEP DISTURBANCES SCALE FOR CHILDREN

INSTRUCTIONS**: This questionnaire will allow to your doctor to have a better understanding of the sleep-wake rhythm of your child and of any problems in his/her sleep behavior. Try to answer every question; in answering, consider each question as pertaining to the* ***past 6 months *of the child's life. Please answer the questions by circling or striking the number 1 to 5.* Thank you very much for your help.

Name:________________________________ Age:________ Date:________

1. How many hours of sleep does your child get on most nights.	1 *9-11 hours*	2 *8-9 hours*	3 *7-8 hours*	4 *5-7 hours*	5 *less than 5 hours*
2. How long after going to bed does your child usually fall asleep	1 *less than 15'*	2 *15-30'*	3 *30-45'*	4 *45-60'*	5 *more than 60'*

	1 Never	2 Occasionally (once or twice per month or less)	3 Sometimes (once or twice per week)	4 Often (3 or 5 times per week)	5 Always (daily)
3. The child goes to bed reluctantly	1	2	3	4	5
4. The child has difficulty getting to sleep at night	1	2	3	4	5
5. The child feels anxious or afraid when falling asleep	1	2	3	4	5
6. The child startles or jerks parts of the body while falling asleep	1	2	3	4	5
7. The child shows repetitive actions such as rocking or head banging while falling asleep	1	2	3	4	5
8. The child experiences vivid dream-like scenes while falling asleep	1	2	3	4	5
9. The child sweats excessively while falling asleep	1	2	3	4	5
10. The child wakes up more than twice per night	1	2	3	4	5
11. After waking up in the night, the child has difficulty to fall asleep again	1	2	3	4	5
12. The child has frequent twitching or jerking of legs while asleep or often changes position during the night or kicks the covers off the bed.	1	2	3	4	5
13. The child has difficulty in breathing during the night	1	2	3	4	5
14. The child gasps for breath or is unable to breathe during sleep	1	2	3	4	5
15. The child snores	1	2	3	4	5
16. The child sweats excessively during the night	1	2	3	4	5
17. You have observed the child sleepwalking	1	2	3	4	5
18. You have observed the child talking in his/her sleep	1	2	3	4	5
19. The child grinds teeth during sleep	1	2	3	4	5
20. The child wakes from sleep screaming or confused so that you cannot seem to get through to him/her, but has no memory of these events the next morning	1	2	3	4	5
21. The child has nightmares which he/she doesn't remember the next day	1	2	3	4	5
22. The child is unusually difficult to wake up in the morning	1	2	3	4	5
23. The child awakes in the morning feeling tired	1	2	3	4	5
24. The child feels unable to move when waking up in the morning	1	2	3	4	5
25. The child experiences daytime somnolence	1	2	3	4	5
26. The child falls asleep suddenly in inappropriate situations	1	2	3	4	5

Disorders of initiating and maintaining sleep (sum the score of the items 1,2,3,4,5,10,11)	
Sleep Breathing Disorders (sum the score of the items 13,14,15)	
Disorders of arousal (sum the score of the items 17,20,21)	
Sleep-Wake Transition Disorders (sum the score of the items 6,7,8,12,18,19)	
Disorders of excessive somnolence (sum the score of the items 22,23,24,25,26)	
Sleep Hyperhydrosis (sum the score of the items 9,16)	
Total score (sum 6 factors' scores)	

After summing the scores for the different scales report the values in the scoring sheet in order to obtain a sleep profile

Figure 1. The Sleep Disturbances Scale for Children (SDSC) questionnaires that patients answer on a Likert-scale.

T score	DIMS	SBD	DA	SWTD	DOES	SHY	TOTAL	T score
100+	26+	11+	8+	21+	20+		74+	100+
99	25			20			73	99
98							72	98
97							71	97
95	24			19	19		70	95
94			7				69	94
93	23	10		18	18	10	68	93
90							66	90
89	22						65	89
88					17		64	88
86	21	9		17		9	63	86
85					16		62	85
84				16			61	84
82	20		6				60	82
81					15		59	81
80						8	58	80
79	19	8		15			57	79
77					14		56	77
76	18						55	76
75				14		7	54	75
73	17				13		53	73
72		7					52	72
70	16		5	13			51	70
69					12	6	50	69
68							49	68
67							48	67
66	15			12			47	66
64	14	6			11	5	46	64
63							45	63
62				11	10		44	62
60	13						43	60
59							42	59
58	12	5	4	10	9	4	41	58
56							40	56
55							39	55
54	11			9			38	54
53					8		37	53
51		4				3	36	51
50	10			8	7		35	50
49							34	49
47	9		3				33	47
46					6		32	46
45	8	3		7		2	31	45
42					5		29	42
41	7			6			28	41
40							27	40
38		2			4	1	26	38

Figure 2. The scoring guidelines for the SDSC questionnaires. In each column, there are the different types of sleeping disorders and how they are quantified in relation to the total SDSC score and the T score.

Similarly, the CCTQ questionnaire consists of 16 items for scheduled and free days that investigate parameters for sleep-wakefulness, 10 items on the morningness/eveningness scale, and 1 item on chronotype (Ishihara, Doi, and Uchiyama 2014), as seen in Figures 3-5. Scheduled days refer to when the child's sleep is impacted by their own or others' responsibilities, such as going to school or having to wake up early to go to daycare. On the other hand, free days refer to when the child's sleep is not impacted by their own individual responsibilities or others' responsibilities. For this clinical study, the CCTQ investigated the following variables: bed time, wake time, mid-sleep time, sleep efficiency, sleep latency, morningness-eveningness (MEQ) score, and MEQ category.

Please answer the following questions or choose the best answer.

Directions: The following questions ask about sleep/wake patterns during "Scheduled Days" in contrast to "Free Days". Think about your child's behavior during recent weeks when answering these questions. For questions with changing conditions (e.g., child goes to day care at 7:00am 1 day/week and 9:00am 3 days/week), fill in or select the most frequent or common answer.

Scheduled Days

Child's sleep-wake pattern is directly influenced by individual or family activities (e.g., by school, day care, work, athletics etc.)

On Scheduled Days, my child …

1. …wakes up at _____:_____ am
2. …regularly wakes up:
   □ by him/herself □ with help from a family member □ with an alarm clock
3. …gets up at _____:_____ am
4. …is fully awake by _____:_____ am
5. …takes regular naps: □ Yes □ No
   If yes, he/she naps ______ days/week.
   If yes, he/she sleeps for ____ minutes/nap.
   If no, why does he/she not nap? ____________________________

On nights before Scheduled Days…

6. …my child goes to bed (body in bed) at _____:_____pm
7. …my child is ready to fall asleep (lights turned out) at ______: ____ pm
8. …it takes him/her _____ minutes to fall asleep (after lights turned out).

Figure 3. The Children's ChronoType Questionnaire (CCTQ) and the scheduled days parameters that investigate sleep-wakefulness. The same questions are asked for free days.

Directions: For each of the following questions, please select the answer that best describes your child. Make your judgments based on how the behavior of your child was in recent weeks. There are no "right" or "wrong" answers.

17. If your child has to be awakened, how difficult do you find it to wake your child up in the morning?
    □ very difficult □ fairly difficult □ moderate difficult □ slightly difficult
    □ not at all difficult/my child has never to be awakened

18. How alert is your child during the first half hour after having awakened in the morning?
    □ not at all alert □ slightly alert □ moderate alert □ fairly alert □ very alert

19. Considering your child's "feeling best" rhythm, at what time would your child **get up** if he/she could decide and were entirely free to plan the day (e.g., vacation)?
    □ prior to 6:30 am □ 06:30–7:14 am □ 7:15 – 9:29 am □ 9:30 – 10:14 am
    □ after 10:15 am

20. Considering your child's "feeling best" rhythm, at what time would your child **go to bed** if he/she could decide and were entirely free to plan the next day (e.g., weekend)?
    □ prior to 6:59 pm □ 7:00 – 7:59 pm □ 8:00–9:59 pm □ 10:00 – 10:59 pm
    □ after 11:00 pm

21. Let's assume that your child has to be at peak performance for a test that will be mentally exhausting for 2 hours. Considering your child's "feeling best" rhythm and that you are entirely free to plan your child's day, which ONE of the three time intervals would you choose for the test?
    □ 7:00 – 11:00 am □ 11:00 am - 3:00 pm □ 3:00 – 8:00 pm

Figure 4. The Children's ChronoType Questionnaire (CCTQ) and the morningness/eveningness sample questions.

Directions: After answering the above questions, you may have a feeling which "Chronotype" or "Time-of-Day type" your child is. For example, if your child would like to sleep quite a bit longer on "Free Days" compared to "Scheduled Days" or if it is difficult for your child to get out of bed on Monday mornings, then he/she is more likely to be an Evening Type person (a "Night Owl"). If your child, however, regularly wakes up and feels perky once he/she gets out of bed, and your child prefers to go to bed rather early than late, then he/she is more likely a Morning Type person (a "Morning Lark").

Please categorize your child using one of the following choices. Please choose only one!

27. My child is…
    □ Definitely a Morning Type
    □ Rather a Morning Type than an Evening Type
    □ Neither a Morning nor an Evening Type
    □ Rather an Evening Type than a Morning Type
    □ Definitely an Evening Type
    □ I do not know

Figure 5. The Children's ChronoType Questionnaire (CCTQ) and the chronotype question.

Actigraphy

Additionally, this study uses actigraphy to better understand how traumatic brain injuries affect sleep-wake disturbances. Participants in this study will be wearing a Philips Actiwatch-2 as their wristwatch actigraphy device. This device will record all bodily movements and activity to diagnose sleep-wake disturbances for the following variables: sleep latency, sleep efficiency, total sleep time, sleep duration, wake after onset, sleep period onset time, and sleep period offset time. These watches are meant to be worn at all times continuously. It is waterproof and can withstand regular daily activities.

Procedures and Follow-ups

Immediately after participants are enrolled in the study, a baseline is taken for both the questionnaires and actigraphy. The questionnaire packet is handed out with the CCTQ and SDSC questionnaires to the patient's family. The party responsible for the patient will fill out both questionnaires. Spanish forms are not provided, but participants can ask for a Spanish translator to help participants' parents or guardians fill it out. In addition, patients will also wear the actigraphy watch for a 2-week period. After the baseline data has been collected for both

During follow-up at both 1-month and 6-months after injuries, patients will be asked to complete the questionnaires either over the phone with a research assistant or electronically. If the patient is still in the hospital or will visit the hospital within the 1-month or 6-month timeframes, the questionnaires will be handed to the patient's parents or guardians instead. Similarly, the actigraphy watches will also be distributed by mail or through patient visits. The actigraphy watch may be returned in person to any member of the research study or through the mail. Phone calls may be made as needed in order to remind the participants about the study and the steps they will have to complete at the 1-month and 6-month follow-ups. At the end of these follow-ups, patients should have completed questionnaires and actigraphy for a total of 3 time periods: baseline, 1-month follow-up, and 6-month follow-up. Participants who complete this will receive a complimentary $25 ClinCard debit card.

Data Analysis

The secondary data analysis conducted for the first aim compares actigraphy, SDSC, and CCTQ variables with the healthy control groups. For these following 3 variables, the mean was calculated, as well as the standard deviation for both the 1-month and 6-month follow-ups. The measured mean was compared to the literature number of these samples that were the healthy control group, meaning they did not have a traumatic brain injury.

Furthermore, a corresponding variable table was created to help compare variables from both the questionnaires and the actigraphy in Table 3. T-tests were done to compare average cohort values to healthy reference populations to be able to create correlation coefficients for the comparison of actigraphy and sleep questionnaires. Spearman correlation coefficients evaluated the relationship between SDSC and actigraphy, which included specific subcategories such as DIMS T-score, Total T-score, Q1, and Q2. There is a focus on Q1 and Q2 due to this study's focus on insomnia and circadian rhythms. In addition, intraclass correlation coefficients explained how CCTQ and actigraphy were related which further encapsulated average, free, and scheduled days. It also included for the actigraphy variable mid-sleep time, an MEQ score through Spearman's correlation. These specific numbers were tested for significance using p-values where $p<0.05$ is significant.

Actigraphy	SDSC	CCTQ
Onset Latency - Sleep Onset Latency (minutes)	DIMS Q2 Q3 Q4 Q5	Average time to fall asleep (do it for free, scheduled, avg of free/sched reports)
Snooze Time	Q22 Q23	Difference between wake up and be fully awake times (do it for free, scheduled, and avg free/sched report) Q17 categories Q26
Sleep Efficiency	DIMS score SDSC total score Q10 Q11	Calculate from times reported (total time asleep/total time in bed for free, scheduled, and avg of free/sched reports) ****Total time asleep is difference in bed time and wake time – sleep latency (Q1-Q6 in minutes then subtract Q8) ***total time in bed is Q3-Q6 in minutes
WASO	DIMS score Q10 Q11	
Average bedtime		Time to bed and time ready to fall asleep questions for free, scheduled and avg free/sched days
Average wake time		Time to wake and time to Get up for free, scheduled, and avg of free/sched days
Mid sleep time (calculate from avg bedtime and waketime)		Time halfway between wake time and ready to sleep times. For free, sched, and avg of free/scheduled days Q27 categories MEQ score categories for chronotype
Wake Time (minutes awake during sleep period)	DIMS Q10 Q11	
Wake Fraction	DIMS Q10 Q11	
Wake bouts	DIMS Q10 Q11	
Avg Wake Bout duration	DIMS Q10 Q11	
Fragmentation (restlessness index)	DIMS Q10 Q11	
Sleep duration	Q1 Total score	Wake time – time ready to sleep for free, sched, and avg of free/sched days
Sleep Time - Scored Total Sleep Time (minutes)	Q1 Total score	Wake time – time ready to sleep for free, sched, and avg of free/sched days

Table 4: *The corresponding variables between actigraphy and both the SDSC and CCTQ sleep questionnaires.*

Results

Demographics

Demographic and population characteristics are recorded in Tables 5 and 6. There is a total of 63 participants enrolled in this study at Oregon Health & Sciences University over the course of 4 years. Most participants enrolled in this study were 6-11 years old (50.8%). 36 out of the 63 participants were assigned male at birth, and 53 of those 63 participants are white. The Glasgow Coma Scale is a score that is assigned to a patient regarding their consciousness on a scale from 3-15 with 3 being the most severe and 15 being fully conscious. The most common severity of TBI was mild (GCS 13-15), while the other severities of moderate (GCS 9-12) and severe (GCS 3-8) were evenly distributed. The most common type of injury would be split evenly between subdural hematoma and contusion with both being abundant at 31.7% each.

Variable	N (%) or Median (IQR)
Age, years Median (IQR)	11.9 (7.6,15)
6-11 years	32 (50.8)
12-14 years	16 (25.4)
15-18 years	15 (23.8)
Sex assigned at birth	
Male	36 (57.1)
Female	27 (42.9)
Race	
White	53 (84.1)
Pacific Islander	3 (4.8)
More than one race	3 (4.8)
Native American/Alaska Native	2 (3.2)
Asian	1 (1.6)
Other or not reported	1 (1.6)
African American	0
Hispanic ethnicity	9 (14.3)
Insurance	
Medicaid	34 (54.0)
Private	28 (44.4)
Other or Self-pay	1 (1.6)
Admission GCS Median (IQR)	15.0 (9,15)
Severity of TBI by GCS	
Mild (13-15)	44 (69.8)
Moderate (9-12)	9 (14.3)
Severe (3-8)	10 (15.9)
Type of Intracranial injury, Any	40 (63.5)
Subdural Hematoma	20 (31.7)
Contusion	20 (31.7)
Subarachnoid Hematoma	15 (23.8)
Diffuse axonal injury	9 (14.3)
Intraparenchymal	6 (9.5)
Epidural Hematoma	5 (7.9)
Intraventricular	3 (4.8)
Penetrating Injury	1 (1.6)

Table 5: *Demographic data for patients enrolled in the study for age, sex assigned at birth, race, Hispanic ethnicity, insurance, admission GCS median, severity of TBI by GCS, and type of intracranial injury.*

Variable	N (%) or Median (IQR)
Critical Care Intervention, Any	34 (54.0)
Intubation	19 (30.2)
Other surgery	17 (27.0)
Neurosurgery	12 (19.0)
Arterial line	9 (14.3)
Central venous line	7 (11.1)
ICP monitor	3 (4.8)
Other injuries, Any	40 (63.5)
Extremity fracture	16 (25.4)
Pulmonary contusion	11 (17.5)
Spine fracture	6 (9.5)
Splenic laceration	5 (7.9)
BCVI	4 (6.3)
Nerve palsy	4 (6.3)
Spine ligamentous injury	3 (4.8)
Liver laceration	2 (3.2)
Pelvic fracture	1 (1.6)
Spinal cord injury	1 (1.6)

Table 6: *Demographic data continued for patients enrolled in the study for critical care intervention and other injuries.*

<u>Comparing SDSC questionnaire outcomes in TBI individuals to healthy normal controls</u>

SDSC questionnaires from the study group were compared to a healthy normal control group as seen in Table 7. Generally, those in the study tended to have a higher score compared to the control group. There is an increase in both the 1-month and 6-month follow-ups in comparison to the healthy control group for the total SDSC score, disorders of initiating and maintaining sleep, and disorders of excessive daytime somnolence. The biggest difference between the healthy cohort reference subgroup and the 1-month and 6-month follow-ups in the study is the total SDSC score. The healthy reference cohort's total SDSC score is 35.1, while the 1-month sample is 41.6 and the 6-month sample is 43. There are some other categories such as sleep breathing disorders where the 1-month follow-up had a score of 3.8 which is the same as the healthy reference cohort score of 3.8. However, for the 6-month follow-up, there seems to be an increase of 0.2. Interestingly, the sleep-wake transition disorders had a much higher score for their 1-month, but their 6-month follow-up sample had a lower score than the 1-month, but not lower than the healthy control group score. The score for sleep hyperhidrosis generally was around the healthy control sample, but the 1-month follow-up sample had a lower score of 0.1 than the healthy and 6-month groups.

Sleep Disturbance Scale for Children (SDSC) Variables	Healthy Control sample, Mean (SD)	1-month follow-up sample, Mean (SD)	6-month follow-up sample, Mean (SD)
SDSC Total	35.1 (7.7)	**41.6 (10.5)***	**43 (12.8)***
Disorders of Initiation and Maintenance of Sleep	9.9 (3.1)	**14.1 (5.3)***	**14.9 (6.3)***
Sleep Breathing Disorder	3.8 (1.5)	3.8 (1.3)	4 (1.3)
Disorders of Arousal	3.3 (0.8)	3.44 (0.9)	3.6 (1.2)
Sleep-Wake Transition Disorders	8.1 (2.4)	**10.4 (3.5)***	9.5 (3.7)
Hypersomnolence	7.1 (2.6)	7.3 (2.6)	8.2 (2.8)
Sleep Hyperhidrosis	2.9 (1.7)	2.8 (1.3)	2.9 (1.8)

Table 7: *SDSC Questionnaires from the clinical research study in comparison to the healthy control sample (Williams et al. 2020). *P<.05 when compared to a healthy cohort.*

<u>Comparing CCTQ questionnaire outcomes in TBI individuals to healthy normal controls</u>

On the contrary, the CCTQ questionnaire from the study group were compared to a healthy normal control group as seen in Table 8. Generally, there is an agreement that those in the 1-month and 6-month follow-ups have a much later bed time, wake time, and mid sleep time as compared to the healthy reference cohort. For example, on a free day, a healthy cohort goes to bed at around 20:47 on average, while the 1-month group goes to bed around 22:11 on average. Individuals in the 1-month or 6-month group also tend to have a lower sleep efficiency score. In addition, for sleep latency, the 1-month and 6-month groups are much longer compared to the healthy cohort group. As for the differences between the free and scheduled days, participants generally go to bed later and wake up later on the free days as compared to the scheduled days for the 1-month and 6-month follow-ups.

Children's ChronoType Questionnaire (CCTQ) Variables	Healthy Control sample, Mean (SD)	1-month follow-up sample, Mean (SD)	6-month follow-up sample, Mean (SD)
Bed time, Avg			
Free day	20:47 (0:46)	**22:11 (1:20)***	**22:46 (1:22)***
Scheduled day	20:17 (0:31)	**21:27 (1:13)***	**21:52 (1:13)***
Wake time, Avg			
Free day	7:51 (0:46)	**9:06 (1:48)***	**9:51 (1:57)***
Scheduled day	7:07 (0:25)	**7:38 (1:03)***	**7:18 (0:55)***
Mid-sleep time, Avg			
Free day	2:32 (0:43)	**3:39 (1:26)***	**4:16 (1:28)***
Scheduled day	1:58 (0:26)	**2:40 (1:04)***	**2:49 (1:05)***
Sleep latency, Avg			
Free day	0:11 (0:10)	0:26 (0:34)	0:24 (0:24)
Scheduled day	0:12 (0.09)	0:23 (0:27)	0:32 (0:37)
MEQ category, N (%)			
Morning types	69 (46.6)	4 (12.5)	1 (6.3)
Neither	23 (15.5)	13 (40.6)	10 (62.5)
Evening Types	56 (37.8)	15 (46.9)	5 (31.3)

Table 8: *CCTQ Questionnaires from the clinical research study in comparison to the healthy control sample (Werner et al. 2009). *P<.05 when compared to a healthy cohort.*

Comparing actigraphy outcomes in TBI individuals to healthy normal controls

Last but not least, the actigraphy variables from the study group were compared to the actigraphy variables for a healthy normal control group as seen in Table 9. This showed that participants in the study had longer sleep latency (time to fall asleep), lower sleep efficiency (percentage spent sleeping while in bed), longer sleep duration (how much time spent asleep), and a later sleep period offset and onset time (time that the individual wakes up and goes to sleep, respectively) than those in the healthy reference cohort. The amount of total sleep time is less in the 1-month and 6-month follow-up groups when compared to the healthy reference. However, those 6-11 years old have a higher total sleep time of 449.4 minutes on average compared to the healthy cohort which has 484 minutes on average. The sleep duration for a healthy cohort when in comparison to the traumatic brain injury participants was generally higher for the 1-month follow-up. However, during the 1-month follow-up, the 12-14 year-olds had a lower sleep duration of 8:55, respectively, as compared to the healthy group, which was 8:03. This result was not statistically significant. Sleep period onset time was later on for the 1-month group than the healthy group. These results would be statistically significant. On the other hand, sleep period offset time resulted in a statistically significant variable for the 6-month follow-up in comparison to the healthy cohort, but not for the 1-month follow-up.

Actigraphy	1 month follow up sample, Mean (SD)	6 month follow up sample, Mean (SD)	Healthy reference cohort, Mean (95% conf. interval)
Sleep Latency, minutes	**36.2 (31.9)***	**33.7 (37.7)***	19.4 (16.6-22.1)
Sleep Efficiency, %	**81.2 (7)***	**81.6 (9)***	88.3 (85.9-90.6)
Total Sleep Time, minutes	464.6 (70.2)	425.4 (54.3)	
6-11 years	494.3 (76.8)	**449.4 (54.2)***	**484 (472-496)****
12-14 years	422.1 (52.6)	**400.4 (44.5)***	429 (394-464)
15-18 years	453.6 (47.3)	**398.7 (45)***	421 (406-436)
Sleep Duration, hours	9:35 (1:08)	8:47 (1:23)	
6-11 years	**9:54 (1:09)***	8:46 (1:10)	**8:51 (8:37-9:05)****
12-14 years	8:55 (0:52)	7:51 (0:55)	8:03 (7:43-8:22)
15-18 years	**9:40 (1:09)***	9:21 (1:46)	7:24 (6:54-7:54)
Wake After Onset, minutes	48.8 (15.5)	46.8 (22)	55 (43-68)
Sleep period onset time	22:41 (1:49)	23:19 (1:37)	
6-11 years	**21:55 (1:55)***	22:46 (1:43)	**22:04 (21:55-22:13)****
12-14 years	**23:31 (1:31)***	24:43 (1:14)	23:09 (22:51-23:28)
15-18 years	**23:16 (1:20)***	23:27 (1:13)	23:27 (22:58-23:56)
Sleep period offset time	8:17 (1:27)	8:07 (1:25)	
6-11 years	7:49 (1:22)	**7:33 (0:56)***	**6:57 (6:42-7:12)****
12-14 years	8:27 (1:04)	**8:35 (1:11)***	7:17 (7:00-7:36)
15-18 years	8:57 (1:44)	**8:49 (1:56)***	7:27 (6:58-7:45)

Table 9: *Actigraphy from the clinical research study in comparison to a healthy control sample (Galland et al. 2018). *P<.05 when compared to a healthy cohort. **Reference subgroup is 9-11 years, rather than 6-11 years.*

Forming a relation between actigraphy and questionnaires

Comparisons were made between the SDSC and CCTQ questionnaires with actigraphy variables is shown in Table 10. For SDSC, the t-scores were found specifically for DIMS, total SDSC score, Q1, and Q2. It was found that Q1 was negatively correlated with the total sleep times and sleep duration with actigraphy at -0.51 and -0.50, respectively. There were no significant correlations in the p values for the DIMS t-score, total t-score, and Q2. On the other hand, CCTQs have moderate ICC levels. This is especially seen in the sleep period onset time, sleep period offset time, and mid-sleep time. There is also some moderately significant correlation between the total sleep times at the average and scheduled sections. However, these ICC correlations are very poor, and absolute differences were found for these values due to parents overestimating these values for CCTQ.

	Sleep Disturbances Scale for Children (SDSC)		Children's ChronoType Questionnaire (CCTQ)	
Actigraphy Variables	**Spearman, r (p)**		**Intraclass Correlation Coefficient, 95% CI (p)**	
Sleep Latency, minutes	DIMS T-score	-0.17	Average reported	0.37 (0.10-0.59)
	Q2	-0.02	Free reported	0.34 (0.07-0.57)
			Scheduled reported	0.40 (0.12-0.61)
Sleep Efficiency, %	DIMS T-score	0.07	Average	0.34 (0.05-0.57)
	Total T-score	0.001	Free	0.23 (-0.06-0.49)
			Scheduled	0.36 (0.08-0.59)
Total Sleep Times, minutes	Total T-score	-0.06	Average	**0.46 (0.19-0.66)***
	Q1	**-0.51***	Free	-0.06 (-0.35-0.23)
			Scheduled	**0.53 (0.29-0.71)***
Sleep Duration, minutes	Total T-score	-0.05	Average	0.25 (-0.03-0.50)
	Q1	**-0.50***	Free	-0.09 (-0.36-0.20)
			Scheduled	0.33 (0.06-0.55)
Wake After Onset, minutes	DIMS T-score	0.05		
Sleep period onset time			Average	**0.60 (0.40-0.75)***
			Free	**0.60 (0.38-0.74)***
			Scheduled	**0.56 (0.34-0.72)***
Sleep period offset time			Average	**0.70 (0.51-0.82)***
			Free	**0.61 (0.40-0.76)***
			Scheduled	**0.62 (0.41-0.76)***
Mid-sleep time			Average	**0.73 (0.57-0.84)***
			Free	**0.76 (0.60-0.86)***
			Scheduled	**0.63 (0.44-0.78)***

Table 10: *Relationship between actigraphy and SDSC and CCTQ questionnaires using Spearman's rank correlation coefficient and intraclass correlation coefficient, respectively.*

**P*≤*.01.*

Discussion

Traumatic Brain Injuries on Sleep

By conducting patient sleep questionnaire studies and asking patients to wear actigraphy watches, these different methods showed that traumatic brain injuries do indeed impact their sleep. Different methods such as actigraphy, SDSC, and CCTQ questionnaires all show that there is a difference between the healthy control groups and the 1-month and 6-month study groups. When comparing SDSC questionnaires for our study group and the healthy cohort group, the specific variables that increased in both the 1-month and 6-month follow-up are the total SDSC score, disorders of initiating and maintaining sleep, and disorders of excessive daytime somnolence. There are some other variables including sleep breathing disorder, sleep hyperhidrosis, and sleep-wake transition disorders where there were some differences, but not significant enough values. When looking at CCTQ and comparing it to the healthy group, there is a much later bed time, wake time, and mid-sleep time. There is data that supports that sleep latency is longer in those with traumatic brain injuries when compared to those in the healthy group. On the other hand, for actigraphy, participants in the study had more sleep latency, lower sleep efficiency, longer sleep duration, later wake onset and offset times. There is also a good amount of data supporting total sleep time, sleep duration, however, there are some confounding data points.

Although there are statistically significant variables discussing the differences between a healthy individual compared to a TBI individual, results from comparing actigraphy and questionnaires are poor. Results from the study regarding the correlation between actigraphy and questionnaires show that there is a negative correlation for the SDSC variables total sleep times and sleep duration, specifically for question 1, which is expected as higher values on this question indicate short sleep times/duration (see Figure 1). There were no other significant or strong correlations for any of the other variables. The CCTQ comparison with actigraphy shows a series of possible correlations for sleep period offset time, mid-sleep time, and total sleep times variable for the average and the scheduled day. There is also a moderate correlation for total sleep times. However, these results are not reliable due to the parents' overestimation in the different actigraphy variables from the CCTQ questionnaires. Due to the inaccuracy of the absolute values, we are unable to use these variables as a strong candidate for predicting sleep-wake disturbances.

This is consistent with a number of studies that investigate the impact of traumatic brain injuries, which is known to affect many people throughout the world. Due to this phenomenon, there have been many studies on how it can impact sleep, specifically how it can contribute to sleep-wake disturbances. A number of animal and human studies have been conducted throughout the years which explain that there is an increase in excessive daytime sleepiness, nighttime sleep fragmentation, insomnia, and electroencephalography spectral changes (Ouellet, Beaulieu-Bonneau, and Morin 2015). There are also multiple studies done about how to treat these sleep-wake disturbances. For example, known effective treatments include sleep hygiene, pharmacological interventions, and follow-up for sleep apnea (Wiseman-Hakes et al. 2013).

However, this specific clinical study is different in that it addresses the problem of diagnosing and measuring these sleep-wake disturbances. Currently, actigraphy and polysomnography are known as the gold standard of care for sleep-wake disturbances. There is also some published literature about how actigraphy is helpful in measuring insomnia, circadian rhythm disorders, sleep breathing disorders, and hypersomnolence. However, in the same study, there was a lack of accuracy in recording patient movements, so this method could become unreliable (Smith et al., n.d.). In addition, this method can be very expensive and taxing for the individual seeking help after a traumatic brain injury. Instead, it was proposed for patients to use sleep questionnaires, specifically SDSC and CCTQ, which are optimized to be used with pediatrics. In order to identify if sleep questionnaires can be used in replacement of actigraphy, more research had to be done to look at the correlation between these two methods of diagnosing sleep-wake disturbances.

Lack of correlation between actigraphy and questionnaires

Due to the data collected from this study regarding the correlation of actigraphy and sleep questionnaires, SDSC questionnaires are most likely not able to substitute actigraphy due to the lack of correlations. Our data indicate parents could identify trends with sleep duration and sleep times, but the overall accuracy of the reports was low. This is different from other studies that describe that the variable that stands out the most to them is sleep latency, rather than the mentioned variables (Gaina et al. 2004). However, it was found that even though these questionnaires were able to properly measure specific variables, they were being administered differently through a Likert scale. It is important to consider study design especially when investigating validity and reliability of other forms of literature.

On the other hand, CCTQ seems like a method that could be used to substitute actigraphy when diagnosing a child with sleep-wake disturbances, although further research is needed since the correlation was not an absolute value. Variables such as bed time, wake time, and mid-sleep time could possibly be a more accurate way of measuring sleep-wake disturbances. This is a could be a more reliable method of measuring sleeping patterns because the parent interacts with the child and is able to more accurately answer specific questions regarding time.

Other than the mentioned issues with the questionnaires, these are also answered by the child's parents, which may cause bias and inaccuracy. Compared to an objective method, such as actigraphy, it won't be able to accurately measure the body movements and collect data. On the other hand, a parent may think that their child fell asleep by 9:00 PM, however, in reality, they do not fall asleep until 10:30 PM. These are data points that actigraphy will only be able to accurately measure. Altogether, questionnaires cannot be used to screen and diagnose sleep-wake disturbances, as the accuracy is too low. It is more than likely that these questionnaires can be a method to assist with screening sleep-wake disturbances and then using actigraphy to help diagnose further.

Future Directions

In the future, it is something that is worth investigating different demographics, such as age or gender. In this study, Table 9 showed that data extremely differed from each other, depending on different age ranges, so future studies can focus more specifically on different age groups. Further investigation also shows that this study was limited by a small sample size, to which future research could involve a larger group to have more accuracy in different variables. In addition, rather than having parents answer the questions, it could be that these questionnaires are made more accessible for children to answer. Further research is needed to better understand the best and most accurate methods for diagnosing sleep-wake disturbances after a traumatic brain injury.

Conclusion

This longitudinal clinical research study is being conducted to understand the impact of traumatic brain injuries on children. Specifically, this study is investigating how sleep-wake disturbances are affected. This study is also interested in researching more about different methods to better diagnose and treat sleep-wake disturbances. I was able to address this by analyzing SDSC and CCTQ questionnaires, and actigraphy independently to see how traumatic brain injuries affect sleep. In addition, these questionnaires with actigraphy variables were also analyzed to find any correlations. I found that CCTQ questionnaires could possibly be used, however, there is a lack of an absolute value, which lowers the accuracy of these correlations. Ultimately, there still lacks substantial research and backing from the scientific literature, so questionnaires will have to be used alongside actigraphy. Further research is needed to better understand sleep-wake disturbances and ways that we can better diagnose them, specifically for children who suffer from traumatic brain injuries. Some future work includes investigating different demographics and making questionnaires more substantial and specific to age ranges.

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