Published in final edited form as:

J Neurosci Nurs. 2019 June ; 51(3): 134–141. doi:10.1097/JNN.0000000000000441.

Injury, Sleep, and Functional Outcome in Hospital Patients with TBI

Ellita T. Williams, PhD, RN,

University of Pittsburgh School of Nursing, Postdoctoral Scholar, Department of Health Promotion and Development, 440 Victoria Building/3500 Victoria Street, Pittsburgh, PA 15261

Diana Taibi Buchanan, PhD, RN,

University of Washington School of Nursing, Associate Professor, Department of Biobehavioral Nursing and Health Informatics, University of Washington School of Nursing, 1959 NE Pacific Street, Seattle, WA 98195-7266, P: 206-685-8938, F: 206-543-4771, dmtaibi@uw.edu

Daniel J. Buysse, MD,

University of Pittsburgh & University of Pittsburgh Medical Center, Professor of Sleep Medicine, Psychiatry, and Clinical & Translational Science, Department of Psychiatry, University of Pittsburgh School of Medicine, 3811 O'Hara St., Pittsburgh, PA 15213, P: 412 246-6413, F: 412 246-5300, buyssedj@upmc.edu

Hilaire Thompson, PhD, RN, ARNP, CNRN, AGACNP-BC, FAAN

University of Washington School of Nursing, Professor, Department of Biobehavioral Nursing and Health Informatics, University of Washington School of Nursing, 1959 NE Pacific Street, Seattle, WA 98195-7266, P: 206-616-5641, F: 206-543-4771, hilairt@uw.edu

Abstract

Problem: Uninterrupted nighttime sleep is associated with better cognition and functional outcomes in healthy adults, but the relationship between sleep and functional outcome in individuals hospitalized with severe TBI remains to be clarified.

Objective: (1) Describe nighttime rest-activity variables—wake bouts (WB) (counts), total wake time (TWT) (minutes), and sleep efficiency (SE) (%; time asleep/time in bed)—in people on a neuroscience step-down unit (NSDU) post-TBI; (2) Describe association between injury and nighttime rest-activity on post-TBI functional outcome (using functional independence measure (FIM) at discharge from in-patient care).

Methods: Cross-sectional, descriptive pilot study. We recruited participants from the NSDU (N=17, (age, $M = 63.4$, $SD = 17.9$); 82% male; 94% Caucasian) who wore wrist actigraphy (source of nighttime rest-activity variables) for up to 5 nights. Injury variables: Glasgow coma scale score (GCS); injury severity score (ISS). We used Spearman's rho & regression to measure associations.

Corresponding Author: P: 412-383-7641, F: 412-624-8521, ellitaw@pitt.edu.

DISCLOSURE STATEMENT: The authors declare that there are no conflicts of interest regarding the publication of this article. All of the authors have seen and approved the current manuscript.

Permission Letter: No permissions needed to be obtained for this manuscript.

Results: GCS ($M= 8.8$, $SD= 4.9$); ISS ($M= 23.6$, $SD= 6.7$); and FIM ($M= 48$, $SD= 14.5$). Averages of nighttime rest-activity variables (8pm–7am): SE, 73% ($SD= 16$); WB, 41 counts ($SD= 18$); TWT, 74 minutes ($SD= 47$). Correlations showed significance between FIM and GCS (p -value = 0.005) & SE and GCS (p -value = 0.015). Regression: GCS was the only statistically significant variable associated with FIM (p -value = 0.013); we eliminated other variables from the model as non-significant (p -values > 0.10). SE and FIM association was (p -value = 0.40). In a separate model (ISS, GCS, and SE (dependent variable)), GCS was significant, (p -value = 0.04), but ISS was not (p -value = 0.25).

Conclusion: Patients with severe TBI on the NSDU have poor actigraphic sleep at night. GCS has a stronger association to functional outcome than nighttime rest-activity variables.

Keywords

Neuro step-down unit; actigraphy; TBI; outcome

INTRODUCTION

The quality of nighttime sleep is an important, yet obscure phenomenon for the nearly 300,000 people in the U.S. who are in the hospital for traumatic brain injury (TBI) each year.^{1,2} TBI is a very serious public health issue as it contributes to about a third (30%) of all injury deaths in the United States.¹ After a severe TBI, 43% of victims experience severe life long-disability.^{3,4} And although the disability outcomes are highly variable and unpredictable between patients with a severe TBI, sleep may be an important mediator for recovery following a TBI. Particularly for patients whose TBI require hospitalization. Patients in the sub-acute and chronic phases of moderate and severe TBI experience a wide range of sleep disturbances and sleep disorders, including hypersomnias, parasomnias, insomnia, narcolepsy, and somnolence.^{5,6} The current investigation draws its conceptual framework from principles outlined in the Human Ecology Model.⁷ The concepts of “environment”, “human”, and “interaction” correspond with the neuroscience step-down unit, the patient with TBI, and the association between TBI and nighttime rest-wake activity on functional outcome, respectively. The biological rationale for exploring the sleep behavior of patients hospitalized with TBI is this: empirical evidence associates sufficient sleep with 3 key markers in neural recovery: (1) synaptic plasticity; (2) neurological functioning; (3) increased memory consolidation.^{8,9} Sleep may also be important for emotional regulation¹⁰ and somatic function (i.e. metabolic function)¹¹ post-TBI.

So what? We know some studies have shown that sleep disturbances (poor sleep consolidation and architecture) are common in hospitalized patients with TBI,^{12,13,14,15} but they have either all occurred in the ICU, have used only subjective measures of sleep, or have included patients with only mild TBI. Therein lies a missed opportunity for exploring nighttime sleep for patients with TBI hospitalized on the neuroscience step-down unit. Why the neuroscience step-down unit? First, it is a decisive phase of care often occurring *after* the ICU and *before* clinicians discharge the patient from in-patient care. Finally, clinicians and researchers do not have a full understanding of the association between nighttime sleep with post-TBI recovery on a neuroscience step-down unit. It may seem like sleep should not be a concern in the acute phase of hospitalization for patients with TBI, but it is important

because consciousness and sleep-wake consolidation, an index of sleep quality, improve in parallel during the immediate post-injury period of hospitalization.¹⁶ This suggests that sleep may aid in the recovery process which is why neuroscience hospital staff and clinicians and patients and family dealing with acute TBI should care. The inability of hospitalized patients with moderate and severe TBI to consolidate their sleep associates with poor outcomes,¹⁷ while positive sleep traits associates with less disability.¹⁸

Previous studies have missed the opportunity to capitalize on the transformative potential of the neuroscience step-down unit's care of patients with moderate and severe TBI particularly since it is: (a) a place where interdisciplinary teams tests patients for post-hospital disposition (i.e., rehabilitation, skilled nursing facility) and; (b) most often the last phase of in-patient care and subsequently one of the final chances to centralize acute-care resources for the patient's benefit.¹⁹ Prior studies have not focused on the nighttime period of hospitalization of patients with TBI and its relationship to sleep even though there is evidence that unique care activities are underway.^{20,21}

Therefore, the purpose of this cross-sectional, descriptive pilot study is to generate hypotheses for subsequent studies by exploring the following aims: (1) Describe nighttime rest-activity variables—wake bouts (counts), total wake time (minutes), and sleep efficiency (%; time asleep/time in bed)—in people hospitalized on a neuroscience step-down unit following a moderate or severe TBI; (2) Describe the association between this same sample's injury and nighttime rest-activity on functional outcome (*outcome/dependent variable*) (measured at discharge from in-patient care).

METHODS

Participants, Procedures, Setting

Our pilot study is exploratory and cross-sectional in design. We recruited participants from June 2016 through January 2017 using consecutive convenience sampling. The study participants were patients with moderate or severe TBIs recruited from the neuroscience step-down unit of a level-1 trauma center hospital. This 36-bed unit treats adults with acute and chronic neurological /neurosurgical conditions of the brain and spinal cord. Each patient was in a private hospital room. Unlike the ICU, the patients on the neuroscience step-down unit were not hard-wired to get vital signs, but some patients had telemetry monitoring and standard fluid therapy (i.e. intravenous normal saline or enteral nutrition, when appropriate). Patients had neurological and vital-sign checks every 4 hours unless otherwise specified. During the months of recruitment, the unit had a high census (83% of beds occupied by patients).

Screening

We admitted eligible participants to the hospital with blunt TBI confirmed by computerized tomography of the head; had a Glasgow Coma Scale score (GCS) between 3 and 11 (a score indicative of moderate and severe brain injury)²² on admission to the emergency department; were 18 years of age; were < 24 hours on the neuroscience unit at time of enrollment; and 5) had a Rancho Los Amigos (RLA) cognitive functioning score of 5 (to include

participants who could meaningfully contribute to the assessment of rest/activity with wrist actigraphy). We excluded participants if they had a diagnosed pre-existing sleep disorder based on a review of the electronic medical record; if they had a planned length of stay of less than 24 hours (which would have prevented nighttime actigraphy data collection); left in-patient care before study procedures were complete; or if they or a legally authorized representative (LAR) could not consent on their behalf. All study procedures occurred after approval from the University's Institutional Review Board (IRB) and the participant or the participant's LAR gave written, informed consent.

Measures

Rest/Activity Cycles—Actiwatch Spectrum Plus® (Phillips Respironics, Bend, OR, USA) actigraphs were used to assess wake bouts, total wake time, and sleep efficiency (percentage of time in bed spent asleep). We used these measures of rest/activity to characterize sleep continuity and nighttime awakenings because of their relevance to understanding functional outcomes in human and animal models of TBI.^{5,16,23,24} Actigraphy is a reliable and valid way to capture sleep, wake, and light exposure in the acute rehabilitation phase of TBI and during hospitalization of patients with TBI across the continuum of severity.²⁵ We set the Actiwatch to sample data in 30-second epochs and continuously collected data from 8pm to 7am. The participants wore the Actiwatch on the non-dominant wrist or the uncluttered wrist (intravenous lines, slings or casts).

We did not collect sleep diaries or use subjective questionnaires because we expected our sample to have cognitive impairments; these impairments reduce the completeness and reliability of diaries.²⁶ Second, it was not feasible to require staff to complete diaries. We determined the start and end of the nighttime period using the University of Washington's Center for Innovation in Sleep Self-Management scoring algorithm.²⁷ The scoring algorithm provided a hierarchy for using actigraphy-measured activity and light levels to determine bedtimes and rise times. We scored each epoch within each nighttime period as "sleep" or "wake" using the automated algorithm in Actiware 6. Outcome measures included wake bouts, total wake time, and sleep efficiency for each night. We only used nighttime data in the analysis. We did not examine daytime naps because our scientific goal was to focus on rest-activity cycles exclusive to the nighttime period.

Injury Variables—Rancho Los Amigos scale (RLA): The first author used the RLA scale to screen the participants for study eligibility. The RLA score yields a reliable assessment of the awareness, cognition, and behavior^{28–30} needed for purposeful interaction in patients with TBI. The RLA scale score ranges from 1 to 8; a score of 1 means the participant has no response to external stimuli while a score of 8 means the participant responds purposefully and appropriately. Studies show that RLA has good reliability and validity in the brain-injured population.³¹ An RLA score of greater than or equal to 5 was the cut-off for eligibility. A score of 5 or greater would mean that the participant has purposeful enough wrist movement for a reliable actigraphy assessment. We used the RLA to screen patients and we did not include RLA in our analyses because of its bias toward patients with purposeful movements and minimal variability.

Glasgow Coma Scale (GCS): The GCS score, ranging from 3 (*worst*) to 15 (*better*) indicates the level of consciousness. We extracted GCS from the medical record during screening for study eligibility.²² We used the worst (i.e., lowest) GCS score the participant received from clinical care team while in the emergency department. GCS reliability is high ($\alpha = 0.85$)³² when used in patients with TBI.

Injury Severity Score (ISS): The ISS, extracted from the trauma registry, reflects the overall intensity of a participant's injuries³³ and ranges from 1 (least severe) to 75 (most severe). The ISS has a high inter-rater reliability (ICC >0.80) and a high intra-rater reliability ($\kappa = >0.80$).³⁴

Functional Outcome—Functional Independence Measure (FIM®): The FIM, assigned to the participant by the first author, blinded to actigraphy data, is an 18 item scale (13 motor tasks, 5 cognitive tasks) used to assess the participant's level of disability at hospital discharge. We collected the FIM in the hours leading up to the patient's departure from the neuroscience step-down unit. The FIM is sensitive to patient progress and includes tasks affected by sleep including memory, comprehension, and problem solving.³⁵ FIM developers rate each item on a scale of 1 to 7 (total range 18-126) with lower scores showing more dependence and subsequently greater disability. Studies demonstrated construct and predictive validity (predictive of disability severity long-term) of the FIM in patients with TBI; inter-rater reliability of the FIM is >.90 with a >.90 test-retest reliability.³⁵

Demographic & Clinical Data—We extracted demographic and clinical data from 3 main sources: The electronic medical record, the hospital's trauma registry, and interview/observations of the patient, the LAR, or the bedside staff nurse assigned to the patient by the first author. We then entered data into data management software (REDCap).

Data Management and Analysis

We computed the nighttime rest-activity variables for each participant's individual nighttime periods with Actiware 6 software and exported it to [R]Studio software ([R] version 3.3.1) and SAS for data analysis. For our modest sample size of N=17, we used non-parametric analyses to underscore the relationship between the variables measuring nighttime sleep, injury, and functional outcome. We calculated the averages of the median values of nighttime rest-activity variables for our analyses. We conducted a Spearman's rho rank correlation test to identify variables that were statistically significant. We followed our Spearman's rho correlation with an Exact Significance Test, a complementary non-parametric test, to ensure we extracted the exact *p-values* for the correlation coefficients for our nighttime sleep, injury, and functional outcome variables. Next, to select the variables most associated with functional outcome in this sample of hospitalized patients with TBI, we conducted a backward stepwise linear regression (Outcome/Dependent Variable: Functional Outcome). First, we put all the independent variables in the model (nighttime rest-activity variables & injury variables). Second, we deleted the variable with a *p-value* that was larger 0.10. Third, we re-ran the model without the recently deleted variable and repeated this step until we reached the independent variable(s) that met our cut-off (*p*

0.05). We also conducted descriptive statistics on clinical and demographic data and report these data below. *P*-values of 0.05 or less for statistical significance.

RESULTS

Clinical and Demographic Data

Thirteen of the 17 participants needed a LAR to provide informed consent. The sample was predominantly male, average age was 63.4 years ($SD = 17.9$), with severe GCS scores on admission ($M = 8.8$, $SD = 4.9$). The most common type of injury was fall. The average FIM at discharge was 48 ($SD = 14.5$) indicating severe disability.³⁶ See Table 1 for the complete sample description.

The average within-participant number of nights of observation was 2.6 ($SD = 1.3$, range = 1-5) and the average length of actiwatch measurement was 8.3 hours ($SD = 2.78$) or 8 hours and 18 minutes. Frequent wake bouts, high total wake time, and poor sleep efficiency^{37, 38} (Table 1) characterized participants' sleep. On average, participants woke up 41 times ($SD = 18$ times), were awake for 1 hour and 14 minutes ($SD = 47$ minutes), and had sleep efficiency of 73% ($SD = 16\%$). Specifically, in a night, a participant woke up 41 times *during* the designated period as evidenced by the sleep measure, *Wake Bouts*. Conversely, the average time a participant was awake was over an hour during the designated sleep period, evidenced by the sleep measure *Total Wake Time*, in a night. Finally, the percentage of sleep quality, evidenced by the sleep measure *Sleep Efficiency*, was 73%.

Figure 1(Supplemental Digital Content) shows raw actigraphy data with the best sleep efficiency (1A; 93%) and the participant with the worst sleep efficiency (1B; 38%). The participant in 1A has a rhythmic nighttime decrease and daytime increase in movement and light, showing an organized rest and wake activity pattern. Conversely, light and movement data in 1B show poor day-night consolidation has frequent wake bouts at night, and highly variable sleep timing.

Associations of Sleep, Injury, and Functional Outcome

Table 2 shows a Spearman's rho correlation matrix of coefficient for sleep, injury, and functional outcome variables. The correlation matrix shows that there is a statistically significant relationship between functional outcome, as measured by the FIM, and the injury variable, GCS (exact test *p*-value = 0.005). Of the 3 sleep domains, there is a statistically significant relationship also between GCS and sleep efficiency (exact test *p*-value = 0.01). The other injury variable, ISS, has a negative, statistically significant relationship with GCS (exact test *p*-value = 0.02) and age (exact test *p*-value = 0.001). There is a statistically significant relationship between wake bouts and sleep efficiency (exact test *p*-value = 0.001).

Regression Analysis Output, Injury Is Associated with Functional Outcome

The regression model included only the injury variables and sleep variables, based on statistically significant correlations found between these two categories of variables (Table 2). With our modest sample size, we chose the most scientifically relevant variables to include in the regression model. Our multiple linear regression analysis (backward step-wise

model) showed that GCS was the only statically significant variable related to functional outcome (p -value = 0.05). This same model also included ISS (p -value = 0.37), wake bouts (p -value = 0.13), total wake time (p -value = 0.23), and sleep efficiency (p -value = 0.40), none of which were significant associated with functional outcome.

In a model which included only the injury variables, the results showed that GCS was still the only statistically significant variable of functional outcome (p -value = 0.02), compared to ISS (p -value = 0.61). Finally, in a model with injury variables and sleep efficiency as the dependent variable, GCS was a statistically significant variable of sleep efficiency (p -value = 0.04) compared to ISS (p -value = 0.25).

DISCUSSION

Patients hospitalized with moderate and severe TBI, have frequent nighttime awakenings and poor rest/activity cycles^{37,38}, even as they prepare for discharge on the neuroscience step-down unit. Although only a “snap-shot” of sleep quality during the nighttime hours, the low sleep efficiency observed raises the possibility that patients hospitalized with TBI may suffer from the consequences of nighttime wakefulness. We also found that GCS close to the time of admission is the strongest correlate of functional outcome after initial TBI. Although nighttime sleep efficiency associates with functional outcome in the simple correlations, regression analyses suggest that this effect was less robust than initial injury severity.

Nighttime Rest/Activity for Patients Hospitalized with TBI

The sleep characteristics in the present sample are consistent with those of others samples following TBI in post-hospital phases.^{5,15,39,40} Specifically, the average sleep efficiency of the participants in this sample was 73%, lower than the 80-90% sleep efficiency recognized as normal in adults without TBI.^{37,38} Despite evidence that poor sleep is a common symptom of TBI⁵ and that poor sleep can undermine rehabilitative efforts^{3,39} none of the nighttime rest/activity measures associate with functional outcome in a comprehensive model. Any potential effects of sleep on functional outcomes may have been limited by the relatively small sample size and limited variability in the sample.

Previous studies found statistical significance between outcomes particularly, cognitive functioning and rest/activity cycles in patients with TBI.¹² However, there were associations during the patient's *daytime sleep* period; a majority of their participants had mild TBI (67%) and those who needed ICU care post-injury were excluded¹². Similarly, findings from an actigraphic study by Duclos et al.¹⁶ showed an association between cognitive functioning and a linear decrease in nighttime fragmentation in ICU patients with TBI in a 24-hr rest-activity cycle; in these studies injury severity was not an independent variable.

Glasgow Coma Scale score, Functional Outcome

GCS is associated with an array of outcome measures, including functional outcome, in TBI.⁴¹ GCS is also a strong predictor of in-hospital mortality and poor neurological outcome.^{32,42} We assessed functional outcome at discharge from the in-patient neuroscience step-down unit while the aforementioned studies assessed functional outcome between 14-days to 6 months post-injury. While the association between injury severity and outcome in patients

with moderate and severe TBI is well known, what we can conclude about initial injury severity and functional outcome in this sample is this: GCS could be a signal for subsequent functional outcome, but cannot supplant other important clinical factors.

Strengths and Limitations

The lack of association of sleep characteristics and outcome in the present study may result from a combination of the outcomes chosen and the time we assessed them (at discharge).³ More sensitive methods, such as continuous EEG monitoring or polysomnography, may have identified stronger associations of sleep with injury and functional outcome. Previous studies have shown relationships between specific sleep EEG features, such as K complexes, sleep spindles, and vertex waves, and functional outcomes, specifically the modified rankin scale (mRS)¹⁸ which may be an even keener assessment of disability than FIM. As relates to actigraphy, patients with more severe injuries may not show the same actigraphic features that were the basis for algorithm development in healthy participants. In this way, the range and sensitivity of the outcomes may have been a limitation.

Also, variability between and within participants on actigraphy is limited by the hospital setting. Our modest sample size limits the generalizability of our study and we chose only the most scientifically relevant variables to include in our regression model and could not afford, statistically, to enter co-variables; however, we attempted to mitigate this by using within-person analysis. Incorporating daytime sleep in future analyses, despite the methodological challenge of noting exact wake and sleeps times, may also be important. Future studies should have post-discharge assessment and outcome measures like neuropsychological tests and tests that assess memory and information consolidation because these are more likely to be impacted by poor sleep. Exploring sleep changes and FIM scores during rehabilitation and non-rehabilitation settings beyond acute-care may also be useful. However, we have shown that it is feasible to access this niche and understudied population. Also by explaining three different domains of sleep, we have been able to show the pattern of nighttime awakenings (wake bouts, total wake time) and its relation to sleep quality (sleep efficiency).

NURSING IMPLICATIONS

For clinicians, the results suggest that patients with moderate and severe TBI have disturbed nighttime sleep even while hospitalized on a neuroscience step-down unit. Clinicians can explore taking precautions to reduce nighttime interruptions. Specifically, where appropriate for the safety and well-being of the patient, bundle and administer extensive care treatments toward the beginning or the end of the night-shift. Informing ancillary staff of these intentions is very important so they can consider following suit. For day-shift, keeping the patient engaged and active may be helpful for promoting more restful nighttime sleep.

SUMMARY

Our study adds to the growing body of literature about sleep disturbances among people with TBI by focusing on patients with moderate and severe injury hospitalized on the neuroscience unit. Clinicians should know patients with TBI are prone to disturbed

nighttime sleep *during* their hospitalization. Our study and others like it aim to generate the empirical data to develop clinically accessible guidelines for identifying sleep disturbances in this population. These data may better inform the anecdotal or “checklist” list type of tools that are more that are more relevant to direct care staff and the hard work they put in.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

The 3W-Nursing staff and Unit Secretaries at Harborview Medical center, study participants, and their families. Noah Simon, Colin Beam, Elmi Kaheerman, Doris Boutain, & Pamela Mitchell. This work was funded, in part, by the following grants :NIH/NCATS 5TL1TR000422, NIH/NINR F31NR015715, and NIH/NINR T32NR009759.

REFERENCES

1. Taylor C, Bell JM, Breiding M., Xu L. Traumatic Brain Injury–Related Emergency Department Visits, Hospitalizations, and Deaths — United States, 2007 and 2013. Morbidity and Mortality Weekly Report (MMWR). 2017;66(9):1–16. [PubMed: 28081055]
2. Williams ET, Thompson HJ. Sleep of Intermediate Care Patients with TBI: Role of Nursing Activities during Nighttime Hours. Journal of Nursing Doctoral Student Scholarship. 2017;7:48–60.
3. Beck B, Gantner D, Cameron PA, et al. Temporal Trends in Functional Outcomes after Severe Traumatic Brain Injury: 2006–2015. J Neurotrauma. 2018;35(8):1021–1029. doi:10.1089/neu.2017.5287 [PubMed: 29256832]
4. Selassie AW, Zaloshnja E, Langlois JA, Miller T, Jones P, Steiner C. Incidence of long-term disability following traumatic brain injury hospitalization, United States, 2003. J Head Trauma Rehabil. 2008;23(2):123–131. doi:10.1097/01.HTR.0000314531.30401.39 [PubMed: 18362766]
5. Grima NA, Ponsford JL, St Hilaire MA, Mansfield D, Rajaratnam SM. Circadian Melatonin Rhythm Following Traumatic Brain Injury. Neurorehabil Neural Repair. 2016;30(10):972–977. doi: 10.1177/1545968316650279 [PubMed: 27221043]
6. Vermaelen J, Greiffenstein P, deBoisblanc BP. Sleep in traumatic brain injury. Crit Care Clin. 2015;31(3):551–561. doi:10.1016/j.ccc.2015.03.012 [PubMed: 26118920]
7. Bubolz MM, Sontag MS. Human ecology theory; In Boss PG, Doherty WJ, LaRossa R, Schumm WR, Steinmetz SK (Eds.), Sourcebook of family theories and methods: A contextual approach. 1993 (pp.419–450).New York: Plenum Press.
8. Abel T, Havekes R, Saletin JM, Walker MP. Sleep, plasticity and memory from molecules to whole-brain networks. Curr Biol. 2013;23(17):R774–788. doi:10.1016/j.cub.2013.07.025. [PubMed: 24028961]
9. van Enkhuizen J, Acheson D, Risbrough V, Drummond S, Geyer MA, Young JW. Sleep deprivation impairs performance in the 5-choice continuous performance test; Similarities between humans and mice. Behav Brain Res.2014;261:40–48. doi:10.1016/j.bbr.2013.12.003. [PubMed: 24333377]
10. Ren D, Fan J, Puccio AM, Okonkwo DO, Beers SR, Conley Y. Group-Based Trajectory Analysis of Emotional Symptoms Among Survivors After Severe Traumatic Brain Injury. J Head Trauma Rehabil. 2017;32(6):E29–E37. doi:10.1097/HTR.0000000000000294 [PubMed: 28195956]
11. Anafi RC, Pellegrino R, Shockley KR, Romer M, Tufik S, Pack AI. Sleep is not just for the brain: transcriptional responses to sleep in peripheral tissues. BMC Genomics. 2013;14:362. doi: 10.1186/1471-2164-14-362 [PubMed: 23721503]
12. Chiu H-Y, Chen P-Y, Chen N-H, Chuang L-P, Tsai P-S. Trajectories of sleep changes during the acute phase of traumatic brain injury: a 7-day actigraphy study. J Formos Med Assoc. 2013;112(9):545–553. doi:10.1016/j.jfma.2013.06.007. [PubMed: 23906685]

13. Chiu H-Y, Lo W-C, Chiang Y-H, Tsai P-S. The effects of sleep on the relationship between brain injury severity and recovery of cognitive function: a prospective study. *Int J Nurs Stud*. 2014;51(6):892–899. doi:10.1016/j.ijnurstu.2013.10.020. [PubMed: 24246095]
14. Duclos C, Dumont M, Blais H, et al. Rest-activity cycle disturbances in the acute phase of moderate to severe traumatic brain injury. *Neurorehabil Neural Repair*. 2014;28(5):472–482. doi:10.1177/1545968313517756. [PubMed: 24379082]
15. Wiseman-Hakes C, Duclos C, Blais H, et al. Sleep in the acute phase of severe traumatic brain injury: A snapshot of polysomnography. *Neurorehabil Neural Repair*. 2016;30(8):713–721. doi:10.1177/1545968315619697. [PubMed: 26704256]
16. Duclos C, Dumont M, Arbour C, et al. Parallel recovery of consciousness and sleep in acute traumatic brain injury. *Neurology*. 2017;88(3):268–275. doi:10.1212/WNL.0000000000003508. [PubMed: 28003503]
17. Van der Maren S, Duclos C, Arbour C, et al. 1175 Sleep wake cycle and early neurological recovery after moderate to severe traumatic brain injury. *Sleep*. 2017;40(suppl_1):A438–A438. doi:10.1093/sleep/zsx050.1174.
18. Sandsmark DK, Kumar MA, Woodward CS, Schmitt SE, Park S, Lim MM. Sleep features on continuous electroencephalography predict rehabilitation outcomes after severe traumatic brain injury. *J Head Trauma Rehabil*. 2016;31(2):101–107. doi:10.1097/HTR.0000000000000217 [PubMed: 26959664]
19. Asemota AO, George BP, Cumpsty-Fowler CJ, Haider AH, Schneider EB. Race and Insurance Disparities in Discharge to Rehabilitation for Patients with Traumatic Brain Injury. *J Neurotrauma*. 2013;30(24):2057–2065. doi:10.1089/neu.2013.3091 [PubMed: 23972035]
20. Nelson J, Valentino L, Iacono L, Ropollo P, Cineas N, Stuart S. Measuring workload of nurses on a neurosurgical care unit. *J Neurosci Nurs*. 2015;47(3):E9–19. doi:10.1097/JNN.0000000000000136. [PubMed: 25944002]
21. U ra GA, Babayigit S, Tosun K, Aksoy G, Turan Y. The effect of nocturnal patient care interventions on patient sleep and satisfaction with nursing care in neurosurgery intensive care unit. *J Neurosci Nurs*. 2015;47(2):104–112. doi:10.1097/JNN.0000000000000122. [PubMed: 25700196]
22. Teasdale G, Jennett B. Assessment of coma and impaired consciousness. A practical scale. *Lancet*. 1974;2(7872):81–84. [PubMed: 4136544]
23. Chen P-Y, Tsai P-S, Chen N-H, et al. Trajectories of Sleep and Its Predictors in the First Year Following Traumatic Brain Injury. *J Head Trauma Rehabil*. 2015;30(4):E50–55. doi:10.1097/HTR.0000000000000086 [PubMed: 25119653]
24. Skopin MD, Kabadi SV, Viechweg SS, Mong JA, Faden AI. Chronic Decrease in Wakefulness and Disruption of Sleep-Wake Behavior after Experimental Traumatic Brain Injury. *J Neurotrauma*. 2015;32(5):289–296. doi:10.1089/neu.2014.3664 [PubMed: 25242371]
25. Kamper JE, Garofano J, Schwartz DJ, et al. Concordance of Actigraphy With Polysomnography in Traumatic Brain Injury Neurorehabilitation Admissions. *J Head Trauma Rehabil*. 2016;31(2):117–125. doi:10.1097/HTR.0000000000000215 [PubMed: 26959665]
26. Nazem S, Forster JE, Brenner LA, Matthews EE. Actigraphic and Sleep Diary Measures in Veterans With Traumatic Brain Injury: Discrepancy in Selected Sleep Parameters. *J Head Trauma Rehabil*. 2016;31(2):136–146. doi:10.1097/HTR.0000000000000225 [PubMed: 26959667]
27. Buchanan DT, Landis CA, Hohensee C, et al. Effects of Yoga and Aerobic Exercise on Actigraphic Sleep Parameters in Menopausal Women with Hot Flashes. *J Clin Sleep Med*. 2017;13(1):11–18. doi:10.5664/jcsm.6376 [PubMed: 27707450]
28. Hagen C, Malkmus D, Durham P. Rancho Los Amigos levels of cognitive functioning scale. Downey (CA): Professional Staff Association 1972.
29. Hagen C Rancho Los Amigos Cognitive Scales (and Later revisions) San Diego, Communication Disorders Service. Rancho Los Amigos Hospital. 1997.
30. Malkmus P, Stenderup K Levels of cognitive functioning. Downey, (CA): Rancho Los Amigos Hospital, Communications Disorders Service .1974.

31. Johnston MV, Findley TW, DeLuca J, Katz RT. Research in physical medicine and rehabilitation. XII. Measurement tools with application to brain injury. *Am J Phys Med Rehabil.* 1991;70(1):40–56. [PubMed: 1994970]
32. Sadaka F, Patel D, Lakshmanan R. The FOUR score predicts outcome in patients after traumatic brain injury. *Neurocrit Care.* 2012;16(1):95–101. doi:10.1007/s12028-011-9617-5 [PubMed: 21845490]
33. Baker SP, O'Neill B. The injury severity score: an update. *J Trauma.* 1976;16(11):882–885. [PubMed: 994270]
34. MacKenzie EJ, Shapiro S, Eastham JN. The Abbreviated Injury Scale and Injury Severity Score. Levels of inter- and intrarater reliability. *Med Care.* 1985;23(6):823–835. [PubMed: 3925257]
35. Hamilton BB, Laughlin JA, Fiedler RC, Granger CV. Interrater reliability of the 7-level functional independence measure (FIM). *Scand J Rehabil Med.* 1994;26(3):115–119. [PubMed: 7801060]
36. Sandhaug M, Andelic N, Vatne A, Seiler S, Mygland A. Functional level during sub-acute rehabilitation after traumatic brain injury: course and predictors of outcome. *Brain Inj.* 2010;24(5):740–747. doi:10.3109/02699051003652849. [PubMed: 20334472]
37. Ohayon MM, Vecchierini M-F. Normative sleep data, cognitive function and daily living activities in older adults in the community. *Sleep.* 2005;28(8):981–989. [PubMed: 16218081]
38. Ohayon MM, Carskadon MA, Guilleminault C, Vitiello MV. Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. *Sleep.* 2004;27(7):1255–1273. [PubMed: 15586779]
39. Mazwi NL, Fusco H, Zafonte R. Sleep in traumatic brain injury. *Handb Clin Neurol.* 2015;128:553–566. doi:10.1016/B978-0-444-63521-1.00035-2 [PubMed: 25701907]
40. Parcell DL, Ponsford JL, Redman JR, Rajaratnam SM. Poor sleep quality and changes in objectively recorded sleep after traumatic brain injury: a preliminary study. *Arch Phys Med Rehabil.* 2008;89(5):843–850. doi:10.1016/j.apmr.2007.09.057. [PubMed: 18452730]
41. Watanitanon A, Lyons VH, Lele AV, et al. Clinical Epidemiology of Adults With Moderate Traumatic Brain Injury*. *Critical Care Medicine.* 2018;46(5):781–787. doi:10.1097/CCM.0000000000002991 [PubMed: 29369057]
42. Hosseini SH, Ayyasi M, Akbari H, Gorji MA Heidari. Comparison of Glasgow Coma Scale, Full Outline of Unresponsiveness and Acute Physiology and Chronic Health Evaluation in Prediction of Mortality Rate Among Patients With Traumatic Brain Injury Admitted to Intensive Care Unit. *Anesth Pain Med.* 2017;7(5):e33653. doi:10.5812/aapm.33653 [PubMed: 29696116]

Table 1.

Demographic and Summary Statistics of Study Sample

Measure	Mean $\pm$ SD or n (%)
Demographics	
Patient Age (in years), Mean $\pm$ SD	63.4 $\pm$ 17.9
Gender Male, n (%)	14 (82.4)
Race White, n (%)	16 (94.1)
Mechanism of Injury, n (%)	
<i>Assault</i>	1 (5.8)
<i>Motor Vehicle Accident</i>	1 (5.8)
<i>Pedestrian Hit by a Vehicle</i>	2 (11.8)
<i>Sporting Activity</i>	3 (17.6)
<i>Falling</i>	10 (59.0)
Neuroimaging Result, n (%)	
<i>Epidural Hemorrhage</i>	1 (5.8)
<i>Intraparenchymal Hemorrhage</i>	1 (5.8)
<i>Subarachnoid Hemorrhage</i>	3 (17.6)
<i>Diffuse/Complex</i>	2 (11.8)
<i>Subdural Hemorrhage</i>	10 (59.0)
Injury Variables, Mean $\pm$ SD	
<i>GCS</i>	8.8 $\pm$ 4.9
<i>ISS</i>	23.6 $\pm$ 6.7
Functional Outcome, Mean $\pm$ SD	
<i>Functional Independence Measure</i>	48 $\pm$ 14.5
Nights of Observation, Mean $\pm$ SD	
<i>Nights</i>	2.6 $\pm$ 1.3
Discharge Destination, n (%)	
<i>Rehabilitation Care</i>	3 (17.7)
<i>Skilled Nursing Facility</i>	6 (35.2)
<i>Home</i>	8 (47.1)
Obtaining Written Informed Consent, n (%)	
<i>Legally Authorized Representative</i>	13 (76.5)
<i>Participant</i>	4 (23.5)
Nighttime Rest/Activity Variables, Mean $\pm$ SD	
<i>Wake Bouts (counts, across nights)</i>	41 $\pm$ 18
<i>Total Wake Time (minutes, across nights)</i>	74 $\pm$ 47
<i>Sleep Efficiency (percentage, across nights)</i>	73 $\pm$ 16
<i>Length of Actiwatch Measurement (hours, across nights)</i>	8.3 $\pm$ 2.7

Table 2.

Spearman's Rho Correlation Matrix Coefficients of Sleep, Injury, and Functional Outcome Variables

	FIM	GCS	ISS	Age	Gender	WB	TWT	Sleep Eff	Night
FIM									
GCS	0.66**								
ISS	-0.33	-0.58*							
Age	-0.11	0.24	-0.72**						
Gender	0.19	-0.02	-0.29	0.20					
WB	0.03	-0.14	-0.11	0.02	0.02				
TWT	0.10	-0.05	-0.05	-0.12	-0.06	0.84**			
Sleep Eff	-0.25	-0.58**	0.22	-0.05	0.28	0.30	0.02		
Night	-0.12	0.034	0.23	-0.02	0.34	0.37	0.30	0.66	

Note.

* indicates p -value of 0.05,** indicates p -value of 0.01.

Abbreviations: FIM, Functional Independence Measure; GCS, Glasgow Coma Scale; ISS, injury severity scale; TWT, total wake time; WB, wake bouts; Sleep Eff, sleep efficiency.