AMERICAN PSYCHOLOGICAL ASSOCIATION

Rehabilitation Psychology

© 2022 American Psychological Association
ISSN: 0090-5550

2022, Vol. 67, No. 3, 325–336
https://doi.org/10.1037/rep0000418

The Association Between Sleep and Cognitive Function in People With Spinal Cord Injury (SCI)

Noelle E. Carlozzi[1], Jonathan P. Troost[2], Ivan R. Molton[3], Dawn M. Ehde[3], Jenna Freedman[1], Jie Cao[4], Jennifer A. Miner[1], Kayvan Najarian[4, 5], and Anna L. Kratz[1]

[1] Department of Physical Medicine and Rehabilitation, University of Michigan, Ann Arbor
[2] Michigan Institute for Clinical and Health Research, University of Michigan, Ann Arbor
[3] Department of Rehabilitation Medicine, University of Washington
[4] Department of Computational Medicine and Bioinformatics, University of Michigan, Ann Arbor
[5] Department of Emergency Medicine, University of Michigan, Ann Arbor

Purpose/Objective: While there is evidence in other clinical groups to suggest that sleep problems can negatively impact cognitive performance, this relationship has not yet been examined in people with spinal cord injury (SCI). Thus, we sought to examine the association between sleep and cognitive function in people with SCI. ***Research Method/Design:*** Over the course of 7 days, 167 individuals with SCI completed daily subjective ratings of sleep (sleep quality, number of hours slept per night, and bedtime variability) and wore a wrist-worn device that continuously monitored autonomic nervous system (ANS) activity (i.e., blood volume pulse [BVP] signal and electrodermal activity [EDA] signal). At the end of this home monitoring period, participants completed a subjective rating of cognition and six objective cognitive tests. A series of multivariable linear regressions were used to examine associations between eight measures of sleep/ANS activity during sleep and eight cognitive variables. ***Results:*** Subjective ratings of sleep were not related to either objective cognitive performance or self-reported cognitive function. However, there were some relationships between ANS activity during sleep and objective cognitive performance: lower BVP signal was associated with poorer performance on measures of processing speed, working memory, learning and long-term memory, and EDA signals were associated with poorer performance on a measure of executive function. ***Conclusions/Implications:*** Future work is needed to better understand the relationship of sleep, especially sleep physiology, and cognitive functioning for individuals with SCI, and how that may be similar or different to relationships in the general population.

Impact and Implications

Sleep problems may be associated with cognitive problems in people with spinal cord injury (SCI). Given that objective measures of sleep were more predictive of cognitive outcomes than self-reported measures of sleep, clinicians may need to assess sleep by objective means (e.g., polysomnography, sleep diary plus actigraphy) to elucidate relationships between sleep and cognition. Future work is needed to determine if improvements in sleep may result in better cognitive functioning in people with SCI.

Keywords: sleep, spinal cord injury, cognitive function

Supplemental materials: https://doi.org/10.1037/rep0000418.supp

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Editor's Note. Stephen Wegener served as the action editor for this article.—DME

This article was published Online First May 12, 2022.
Noelle E. Carlozzi https://orcid.org/0000-0003-0439-9429
Jonathan P. Troost https://orcid.org/0000-0002-1183-8330
Jenna Freedman https://orcid.org/0000-0001-7540-9079
Jennifer A. Miner https://orcid.org/0000-0003-2722-1121
Research reported in this publication was supported by a Grant from the Craig H. Neilsen Foundation under Award 440343 (PI: Noelle E. Carlozzi). The content is solely the responsibility of the authors and does not necessarily represent the views of the Craig H. Neilsen Foundation. Jonathan P. Troost was supported in part by the National Center for Advancing Translational Sciences (NCATS) for the Michigan Institute for Clinical and Health Research (UL1TR002240). The authors have no conflicts of interest to report. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Correspondence concerning this article should be addressed to Noelle E. Carlozzi, PhD, Department of Physical Medicine and Rehabilitation, University of Michigan, North Campus Research Complex, 2800 Plymouth Road, Building NCRC B14, Room G216, Ann Arbor, MI 48109–2800, United States. Email: carlozzi@med.umich.edu

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Introduction

A new spinal cord injury (SCI) is generally associated with significant changes in physical and psychological function, and often requires changes in lifestyle to preserve function and health-related quality of life (Ahuja et al., 2017; Burke et al., 2018; North, 1999; Sachdeva et al., 2018; Spong et al., 2015). A significant challenge following SCI is the development of so-called secondary health conditions (SHCs), including spasms and pain, which require active management and represent a threat to community participation and independence (Barclay et al., 2015; Ullrich et al., 2012). One particularly disruptive secondary condition is cognitive impairment; up to 25% of individuals with SCI have scores that are impaired relative to the general populations(i.e., individuals with SCI have scores ≥ 1 *SD* below those of a demographically matched comparative control group; Cohen et al., 2017). It is documented that people living with SCI are more likely to experience problems with cognition including problems with attention and concentration, processing speed, episodic memory, and executive functioning (Bradbury et al., 2008; Cohen et al., 2017; Davidoff et al., 1985, 1992; Dowler et al., 1997, 1995; Hess et al., 2003; Lazzaro et al., 2013; Macciocchi et al., 2013; Roth et al., 1989; Sachdeva et al., 2018; Wilmot et al., 1985), at rates greater than matched control participants (matched on age, sex, race/ethnicity, and education; Cohen et al., 2017).

Cognitive dysfunction in people with SCI is likely multifactorial. First, concurrent traumatic brain injury (TBI), which is a significant risk factor for cognitive problems, is thought to be relatively common and underdiagnosed in persons with SCI (Hagen et al., 2010; Macciocchi et al., 2008; Roth et al., 1989; Sharma et al., 2014). In fact, the few studies that have examined this directly have found that people with SCI and concurrent severe TBI have longer recovery times (as evidenced by longer hospitalization stays), as well as problems with processing speed, language comprehension, memory, and problem solving, relative to those without concurrent TBI (Macciocchi et al., 2004, 2012). We also know that secondary complications, including mood disorders (Bonanno et al., 2012; Boyer et al., 2000; Dryden et al., 2005; Krause et al., 2010; Migliorini et al., 2015) and chronic pain (Dijkers et al., 2009; Hassanijirdehi et al., 2015; Masri & Keller, 2012), are common after SCI and are associated with cognitive problems. A number of medications commonly used to treat spasticity in SCI, including Baclofen, may cause subjective cognitive dysfunction, although these findings remain equivocal (Distel et al., 2020).

One potential but understudied mechanism by which SCI may affect cognitive function is through sleep. Problems such as pain and spasticity after SCI can lead to disturbances in sleep, which are very common in people with SCI (Biering-Sørensen & Biering-Sørensen, 2001; Buzzell et al., 2020; Hultén et al., 2018; Sankari et al., 2019; Schilero et al., 2018; Spong et al., 2015). Sleep difficulties may present as problems initiating sleep, restless sleep, sleep disordered breathing, snoring, or daytime sleepiness (Berlowitz et al., 2012; Biering-Sørensen & Biering-Sørensen, 2001; Hultén et al., 2018; Sankari et al., 2019; Spong et al., 2015). Not surprisingly, sleep disturbance can have a profound impact on the health-related quality of life of these individuals (Battalio et al., 2018; Biering-Sørensen & Biering-Sørensen, 2001; Giannoccaro et al., 2013; January et al., 2015; Norrbrink Budh et al., 2005; Rintala et al., 1998; Vega et al., 2019; Widerström-Noga et al., 2001). There is also evidence that sleep problems can have a negative impact on cognitive function in various populations (Dzierzewski et al., 2018; Killgore, 2010; McSorley et al., 2019; Short & Chee, 2019); however, very little is known about the effect of sleep on cognitive function in individuals with SCI.

In addition, there is also evidence from other populations to show that sleep dysregulation can have a negative impact on cognitive function (Goel, 2017; Klumpers et al., 2015). Furthermore, there is additional evidence to suggest that inconsistent sleep patterns, or intraindividual sleep variability (ISV; assessed by examining the variability in self-reported bedtimes over the course of a week), is associated with a number of poor outcomes in other populations. Specifically, ISV appears to be associated with higher depressive symptomatology (Dillon et al., 2015; Lemola et al., 2013; Vanderlind et al., 2014) and next day sleepiness and fatigue (Manber et al., 1996). It is unclear from this literature if ISV is related to cognition (McCrae et al., 2012; Patel et al., 2014; Vanderlind et al., 2014). While ISV has not yet been examined in SCI, there are several demographic risk factors for ISV, including younger age (Kramer et al., 1999; Minors et al., 1998; Monk et al., 1991), non-White race/ethnicity (Knutson et al., 2007; Mezick et al., 2009; Patel et al., 2014), higher body mass index (Patel et al., 2014), weight gain (Roane et al., 2015), and physical health conditions (Geoffroy et al., 2014), that are common in SCI and may lead one to expect high rates of ISV in this population. Thus, we also wanted to explore the relationship between ISV and cognition in people with SCI.

To address these gaps in the literature, we conducted a prospective, repeated measures observational study of sleep and cognitive function in adults with SCI. Because it is often recommended to include both objective and subjective measures when evaluating sleep (Landry et al., 2015), we were interested in understanding how both subjective ratings and objective measures of sleep influenced both subjective and objective assessments of cognitive function in people with SCI over the course of a week. We hypothesized that there would be significant relationships between sleep (both for self-reported sleep and objective proxy measures of sleep) and cognitive performance. We did not anticipate associations between sleep (both for self-reported sleep and objective proxy measures of sleep) and self-reported ratings of cognitive function. Specifically, we expected to see small relationships between sleep (both for self-reported sleep and objective proxy measures of sleep) and memory performance given a well-documented body of literature that would suggest that these relationships are inconsistent (Cook & Marsiske, 2006; Jungwirth et al., 2004; Lineweaver et al., 2004; Podewils et al., 2003; Reese & Cherry, 2006; Sawrie et al., 1999; Schmidt et al., 2001) and that subjective report may be more indicative of overall distress rather than objective symptoms (Derouesné et al., 1999; Hutchinson et al., 2012; Jungwirth et al., 2004; Lautenschlager et al., 2005; Sawrie et al., 1999; Schmidt et al., 2001; Zandi, 2004). We expected more robust relationships between sleep (both for self-reported sleep and objective proxy measures of sleep) and performance on measures of processing speed, attention, and working memory, given that these domains are the most sensitive to neurological insult and lay the foundation for other cognitive domains (Chiaravalloti et al., 2003; DeLuca, 2008; DeLuca & Kalmar, 2008; Donders et al., 2001; Gontkovsky & Beatty, 2006; Mayes & Calhoun, 2007).

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Method

Participants

Individuals with medically documented SCI were recruited at two sites: the University of Michigan, Ann Arbor, MI, and the University of Washington, Seattle, WA. Potential participants were identified through medical record review, clinic and community settings (e.g., study flyers, websites, community events, etc.), and established participant registries. Participants were required to be fluent in English, capable of providing informed consent, capable of operating the study wristband monitor (independently or with the assistance of another person), and willing to complete all study assessments. We excluded participants who were currently hospitalized or receiving intensive outpatient physical therapy. The International Standards for Neurological Classification of SCI (Kirshblum et al., 2011) were used to characterize the sample as paraplegia or tetraplegia. All data were collected in accordance with each site's local Institutional Review Board.

Study Procedures

Participants completed a baseline visit, seven consecutive days of home monitoring, and a follow-up visit. Previously published feasibility data in people with SCI support this study design (Kratz et al., 2017). At the baseline visit, participants provided informed consent, a brief interview covering medical history was conducted, and participants completed a 30- to 45-min battery of online self-report measures. In addition, the participant was provided instructions for the home monitoring period including training on using the wrist-worn device (E4 Wristband), completing the real-time assessments (conducted via an app or by text message), and completing the daily diaries on their own Internet-connected device or on paper (for those without an Internet-connected device). During the home monitoring period, all participants wore the E4 Wristband (described under Measures, below) along with completing morning ratings of sleep, and end of day ratings of health-related quality of life (HRQOL). During the follow-up visit (median follow up time was 8 days postbaseline; *SD* = 7), participants completed a comprehensive battery of neuropsychological assessments and repeated the self-report measures. Participants were compensated $25 for completing the baseline visit, $5 for completing 1 day of the home monitoring period; $10 for completing 2 days; $20 for completing 3 days; $30 for completing 4 days; $45 for completing 5 days; $60 for completing 6 days; and $80 for completing 7 days, and $100 for completing follow-up cognitive testing visit. The baseline and follow-up visits were generally conducted at the site, except if it was too difficult for the participant to travel to the site. In such cases, these visits were conducted at the participant's home. All neuropsychological tests were administered by an examiner that was trained and certified to administer the cognitive tests by a neuropsychologist (NEC) and all self-report measures were completed independently by the participant. Participants provided informed consent before their participation in study activities. This article is included alongside two other manuscripts in this issue that also explore cognitive performance in people with SCI: one focused on examining the relationship between medication use and cognitive function (Carlozzi, Troost, et al., 2021); and the other focused on examining the relationship between physical and mental symptoms and cognitive function (Carlozzi, Graves, et al., 2021).

Measures

Demographic Variables

At the baseline appointment, study participants completed a self-report demographic questionnaire. The survey included questions about the participants' age, sex, education, ethnicity, race, marital status, living situation, household income, work status, mobility, SCI (level, completeness, and cause), and medications.

Sleep Measures

Self-Reported Sleep.

Sleep Diary. Participants answered questions about sleep duration and sleep quality upon waking each morning over the 7-day home monitoring period. Sleep duration was measured by self-reported bedtime and wake times. Sleep quality was measured by a morning question that was based on items from the consensus sleep diary (i.e., and evidence-based approach to monitoring sleep; Carney et al., 2012). Specifically, we asked "On a scale from 0–10 where 0 = totally unrefreshed and 10 = totally refreshed, how refreshed did you feel when you woke up this morning?" Sleep duration (i.e., the total number of self-reported hours of sleep), bedtime variability (calculated as the *SD* of self-reported bedtimes over the course of the week), and average sleep quality ratings were used as subjective measures of sleep.

Epworth Sleepiness Scale (Johns, 1991, 1992; Nguyen et al., 2006). Participants completed eight items designed to evaluate perceptions of typical daytime sleepiness. Total scores can range from 0–24; higher scores indicate more perceived sleepiness. In addition, scores can be interpreted as follows: scores from 0 to 5 indicate lower than normal daytime sleepiness, from 6 to 10 indicate higher than normal daytime sleepiness, from 11 to 12 indicate mild excessive daytime sleepiness, from 13 to 15 indicate moderate excessive daytime sleepiness, and from 16 to 24 indicate severe excessive daytime sleepiness.

PROMIS Sleep Disturbance (Yu et al., 2011). Participants completed the PROMIS Sleep Disturbance computer adaptive test (CAT) that provided an assessment of perceived sleep quality, as well as perceived difficulties with getting to sleep or staying asleep; and adequacy of and satisfaction with sleep. A CAT is an adaptive test where each item is chosen based on the participant's response to the previous item. Scores are on T metric (i.e., *M* = 50, *SD* = 10); higher scores represent greater sleep disturbance.

Objective Proxy Measures of Sleep.

Sleep Duration. The E4 wristband was also used to determine amount of time asleep (i.e., sleep duration). Specifically, participants were instructed to "mark" instances of sleep by pressing the button on the E4 device when going to sleep and upon waking. These "marks" were compared with the self-reported sleep and wake times to determine sleep start time and sleep end time (in cases with discrepancies, the actigraphy data was used to determine sleep onset or wake time).

Autonomic Nervous System (ANS) Activity. The E4 wristband (Empatica) is a wearable device the collects raw physiological signals including heart rate variability (HRV), electrodermal activity (EDA), body movement (accelerometer data), and skin

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

temperature data (Empatica, 2020). During sleep, heart rate is expected to drop to the low end of normal. High heart rate and low heart rate variability during sleep may indicate psychological or medical conditions, for example, anxiety, obstructive sleep apnea, and atrial fibrillation (Bonnet & Arand, 2010; Fujiki et al., 2013; Palatini & Julius, 1997; Silvani, 2019; Stein & Kleiger, 1999; Stein & Pu, 2012; Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology, 1996; Tsuji et al., 1994). In addition, literature shows that HRV, EDA levels, and body movement are highly correlated with various phases of sleep (Borazio & Laerhoven, 2012; Kurihara & Watanabe, 2012; Onton et al., 2016, 2018; Paragliola & Coronato, 2017; Sadeghi et al., 2019; Sano et al., 2014). It was worn all day and night for the home monitoring period, except for 1 hr each day to charge the device. We examined signals from blood volume pulse (BVP; a measure of heart-rate variability), which detects systolic peaks (a result of the direct pressure wave traveling from the left ventricle to the periphery of the body) and diastolic peaks (a result of reflections of the pressure wave by arteries of the lower body), as well as the phasic (fast-changing) components (a measure of emotional arousal) of EDA (a marker of sympathetic nervous system arousal; Braithwaite et al., 2015). Specifically, for BVP, we examined the mean of the mean time between systolic peaks and diastolic peaks in a pulse wave in 5 min windows. We also examined the skewness of the maximum frequency of the phasic components of the EDA signal in 5-min windows.

Cognition Measures

Subjective Ratings of Cognition. Subjective cognitive function was measured with the Patient Reported Outcomes Measurement Information System (PROMIS) Cognitive Function CAT. This was administered at the follow-up. The PROMIS Cognitive Function CAT evaluates perceived cognitive abilities. This item bank is scored on a T metric (i.e., $M = 50$, $SD = 10$); a higher score represents more of the concept being measured (i.e., better cognitive function; Lai et al., 2014).

Objective Measures of Cognition. During the follow-up visit, participants also completed six neuropsychological measures assessing a range of functions. These measures were deliberately selected to include tests with scores that did not rely heavily on motor function, given that these scores likely underrepresent the cognitive capabilities of individuals with upper limb impairments that are common in people with SCI (American Educational Research Association, American Psychological Association, & National Council on Measurement in Education, 2014; Cicerone et al., 2011).

The NIH Toolbox (NIHTB) Oral Symbol Digit Test (Weintraub et al., 2013, 2014). The NIHTB Oral Symbol Digit test provides a measure of processing speed. Participants were given nine symbols that were arranged in a key at the top of the page, where each symbol was paired with a number from 1 to 9. The participants were then given a series of symbols without numbers and asked to orally pair each symbol with its number; this task was completed in order, without skipping any symbols. They had 120 s to complete as many matches as they could. The score was computed by summing the number of correctly identified numbers. The scores could range from 0–144, where a higher score indicated better processing speed.

The Paced Auditory Serial Addition Test (PASAT; Diehr et al., 1998). The PASAT examines attention, auditory processing speed, and working memory. The 3-s version was used in this study. Every 3 s, the participants heard a single digit number, added that number to the previous number, and said the sum out loud. The raw score was equivalent to the total number correct out of 49; higher scores indicate better cognitive function.

The NIHTB List Sorting Working Memory Test (Tulsky et al., 2014, 2013). The NIHTB List Sorting Working Memory test examines working memory by sequencing familiar pictures of food and animals. The pictures were displayed both visually and orally and the participants were required to recite them in size order. The assessment started with a one-list version where the participant only saw pictures from a single category and then moved into a two-list version where the participant saw items from both categories. Scores were calculated by combining the total number of items correct on the one- and two-list versions, where a higher score indicated better performance (maximum 28).

The California Verbal Learning Test-II (CVLT-II; Delis et al., 2000). The CVLT-II evaluates verbal learning and memory. Sixteen words were read to the participant and the participant was asked to recall the list; this was repeated for five learning trials. A distractor list was then read, followed by short-delay free recall and a short-delay cued recall of the original list. The cued recall was completed using word categories. After 20 min, long-delay free recall, long-delay cued recall, and recognition trials of the original list were completed. We examined learning trials and long-delay free recall raw scores in this study.

The Delis-Kaplan Executive Function System (D-KEFS) Color/Word Interference Test (Delis et al., 2001). The DKEFS Color/Word Interference test measures cognitive flexibility and resistance to interference. This assessment has three timed trials. The participants were timed while naming colors, reading names of colors in black ink, and reading names of colors printed in the wrong color of ink (e.g., the word red, printed in green ink). We examined scores on the interference trial of this test (scores reflect the amount of time it took the participant to complete the trial); higher scores indicate poorer cognitive performance.

The Verbal Fluency Test (Lezak et al., 2004). Verbal Fluency assesses language (phonemic) and executive function (Whiteside et al., 2016). The test instructed the participants to produce as many words as they could that started with a particular letter within 60 s. Scores were calculated by summing the total number of words across the three different letter trials (F, A, S); higher scores indicate better cognitive function.

Additional Self-Report Measures

In addition, several potential covariates were considered in analyses including PROMIS measures of Anxiety, Depression, Fatigue and Pain (Cella et al., 2007, 2010). The PROMIS Anxiety CAT was used to assess fear, anxiousness, hyperarousal, and potential anxiety-related symptoms. The PROMIS Depression CAT was used to assess feelings of sadness and worthlessness. The PROMIS Fatigue CAT was used to assess feelings of tiredness and exhaustion. PROMIS Pain Intensity is a three-item fixed short form was used to measure how much someone hurts. All of these PROMIS measures are scored on a T metric ($M = 50$, $SD = 10$); higher scores indicate more of the named construct (i.e., poorer functioning).

Table 1
Participant Characteristics and Distributions of Sleep and Cognitive Measures (N = 167)

Variable	Distribution
Participant characteristics	
Age (years), *M* (*SD*)	49.2 (14.59)
Female, *n* (%)	58 (35)
Education, *n* (%)	
Grades 9−12, without graduating	4 (2)
GED	3 (2)
High school graduate	13 (8)
Some college credit, but less than 1 year	33 (20)
Associate's degree (e.g., AA, AS)	27 (16)
Bachelor's degree (e.g., BA, AB, BS)	51 (31)
Master's degree (e.g., MA, MS, MEng, Med, MSW, MBA)	20 (12)
Professional degree (e.g., MD, DDS, DVM, JD, LLB)	4 (2)
Doctorate degree (e.g., Ph.D., EdD)	5 (3)
Vocational degree/certificate	6 (4)
Unknown	1 (1)
Injury classification, *n* (%)	
Paraplegia	66 (40)
Tetraplegia	72 (43)
Unknown/missing	29 (17)
Time since injury (years), *M* (*SD*)	16.7 (13.7)
Comorbidities, *n* (%)	
Circadian rhythm sleep wake disorder	0 (0)
Objective sleep apnea	10 (6)
Insomnia	2 (1)
Other neurological injury (TBI, stroke, or other brain injury)	5 (3)
Mood disorder (depressive disorder, anxiety disorder, or bipolar disorder)	7 (4)
Medications, *n* (%)	
Opioid analgesics	52 (30)
Anticonvulsants	56 (32)
Tricyclics	17 (10)
SSRI/SSNRIs	58 (34)
Benzodiazepines	39 (23)
Stimulants	7 (4)
Cannabis	17 (10)
Antispasmodics	87 (50)
Skeletal/muscle relaxants	25 (14)
Sedatives	10 (6)
Sleep measures	
Average sleep quality in hours, *M* (*SD*)	6.0 (1.66)
Bedtime variability in hours, *M* (*SD*)	0.9 (0.66)
Average hours slept (self-report), *M* (*SD*)	7.9 (1.16)
Average hours slept (wristband), *M* (*SD*)	7.7 (1.16)
Epworth Sleepiness Scale, *M* (*SD*) [a]	7.5 (4.5)
Lower normal daytime sleepiness, *n* (%)	58 (40)
Higher normal daytime sleepiness, *n* (%)	66 (40)
Mild excessive daytime sleepiness, *n* (%)	15 (9)
Moderate excessive daytime sleepiness, *n* (%)	17 (10)
Severe excessive daytime sleepiness, *n* (%)	8 (5)
PROMIS sleep disturbance, *M* (*SD*), (impairment rate)	51.4 (7.8) (10.8)
BVP signal (from E4 wristband), *M* (*SD*)	0.8 (0.12)
EDA signal (from E4 wristband), *M* (*SD*)	3.9 (1.76)
Objective cognitive function measures	
Oral Symbol Digit Test, *M* (*SD*)	74.7 (21.31)
Oral Symbol Digit Test (T score), *M* (*SD*), (% impaired)	62.9 (12.34) (9)
PASAT, *M* (*SD*)	37.7 (9.65)
PASAT (fully corrected T score), *M* (*SD*), (% impaired)	49.3 (10.73) (9)
Listing sorting working memory, *M* (*SD*)	17.3 (2.79)
Listing sorting working memory (fully corrected T score), *M* (*SD*), (% impaired)	50.8 (9.71) (10)
CVLT: Learning Trials, *M* (*SD*)	49.6 (10.1)
CVLT: Learning Trials (standardized), *M* (*SD*), (% impaired)	53.2 (9.8) (7)
CVLT: Long-Delay Free Recall, *M* (*SD*)	10.7 (3.26)
CVLT: Long-Delay Free Recall (age and sex corrected scaled score), *M* (*SD*), (% impaired)	0.1 (1.00) (11)
D-KEFS: Inhibition, *M* (*SD*)	54.9 (13.78)
D-KEFS: Inhibition (age and sex corrected scaled score), *M* (*SD*), (% impaired)	10.9 (2.68) (11)

(*table continues*)

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Table 1 (*continued*)

Variable	Distribution
Verbal Fluency, *M* (*SD*) [a]	41.0 (13.07)
Verbal Fluency, range	16.0 to 81.0
Verbal Fluency (standardized), *M* (*SD*), (% impaired)	47.5 (11.2) (25)
Subjective cognitive function measure	
PROMIS: Cognitive abilities, *M* (*SD*), (% impaired)	49.5 (9.62) (17)
Other covariates	
PROMIS depression, *M* (*SD*)	49.8 (9.84)
PROMIS fatigue, *M* (*SD*)	50.9 (9.00)
PROMIS pain intensity, *M* (*SD*)	45.8 (7.77)

Note. TBI = traumatic brain injury; SSRI = selective serotonin reuptake inhibitors; SSNRI = seratonin and norepinephrine reuptake inhibitor; PROMIS = Patient Reported Outcomes Measurement Information System; BVP = blood volume pulse; EDA = electrodermal activity; PASAT = Paced Auditory Serial Addition Test; CVLT = California Verbal Learning Test; D-KEFS = Delis-Kaplan Executive Function System. Although raw scores were used on analyses that examined objective cognitive function measures, we report standardized scores here to aid clinical interpretation (in all cases higher scores indicate better cognitive performance).
[a] Data are missing for $n = 3$ participants.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Analysis Plan

Participant characteristics were described using mean and standard deviation for continuous variables and frequencies and percentages for categorical variables. Clinical impairment rates were calculated for standardized tests by indicating the number of participants with scores that were greater than or equal to 1 *SD* away from the mean in the abnormal direction (Heaton et al., 2004). A series of multivariable linear regressions were used to test for associations between eight measures of sleep/ANS activity during sleep and eight cognitive variables. Each sleep-cognition relationship was tested in a separate model (i.e., 64 separate models). Given that scaled scores for the different objective cognitive tests used different normative corrections, raw scores were utilized in analyses and all models adjusted for age, sex, education (≥college vs. <college), time since injury, as well as PROMIS Depression, PROMIS Fatigue, and PROMIS Pain Intensity, and injury classification (i.e., tetraplegia vs. paraplegia). Given that this is the first article, to our knowledge, to explore the relationship we report false-discovery rate adjusted *p*-values for reference (i.e., $q < .15$; adjusting for 64 tests) using linear step-up (Benjamini & Hochberg, 1995). We also provide conventional *p* values for reference (although we do not discuss these values separately in the text). Analyses considered the inclusion of medication as a potential covariate; the inclusion of medication category as a covariate did not change the results herein and thus, they are not reported, but rather are explored in detail in a separate article with detailed analyses examining the relationship between medication use and cognitive function that is simultaneously presented in this same journal issue (Carlozzi, Troost, et al., 2021). Analyses were performed in SAS V9.4 (SAS Institute Inc., Cary, NC).

Results

Table 1 provides descriptive characteristics of the sample for all variables included in the analyses. Participants had a mean age of 49, 35% were female and 48% had a college degree. Mean reported sleep quality throughout the week was 6.0 (on a scale from 0–10) with an average bedtime variability of .9 hr and an average of 7.7 hr slept/night. Correlations of the five sleep variables are shown in online Supplemental Materials Table 1. All correlations were <.2 indicating these were relatively independent markers of sleep.

Table 2 summarizes results from the multivariable linear regression models. Proposed hypotheses were only partially supported. We did not see the anticipated relationships between self-reported sleep variables and either objective cognitive performance or self-reported cognitive function. However, we did see some significant relationships between objective proxy measures of sleep and objective cognitive performance. Specifically, lower BVP signal was associated with poorer performance on measures of processing speed (i.e., Oral Symbol Digit), working memory (i.e., List Sort Working Memory), learning (CVLT: Learning Trials), and long-term memory (i.e., CVLT: Long-Delay Free), but not with measures of executive function (i.e., Color/Word Interference; Verbal Fluency) or a complex measure of attention, processing speed, and working memory (i.e., PASAT), nor was it associated with subjective reports of cognitive function. Additionally, EDA signals were associated with poorer performance on a test of executive function (i.e., Verbal Fluency).

Discussion

This report focuses on the relationships between sleep and both subjective and objective assessments of cognitive function in people with SCI. In general, findings did not support the anticipated relationships between self-reported aspects of sleep and cognitive function. First, there was no relationship between self-reported sleep (i.e., sleep quality, number of hours slept per night, and bedtime variability) and cognitive function (this included both objective cognitive performance and subjective reports of cognitive function). Because the general literature relating to the relationships between objective symptoms and subjective cognition is mixed (Cook & Marsiske, 2006; Jungwirth et al., 2004; Lineweaver et al., 2004; Podewils et al., 2003; Reese & Cherry, 2006; Sawrie et al., 1999; Schmidt et al., 2001), and the general literature relating ISV to cognition is also mixed (McCrae et al., 2012; Patel et al., 2014; Vanderlind et al., 2014), and the sample size for these

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Table 2

Summary Findings for Regression Models: Effects of Sleep on Cognitive Function Outcome Variables

Sleep variable	Cognitive outcome: Oral Symbol Digit β[95% CI]	PASAT β[95% CI]	List sort working memory β[95% CI]	CVLT: Learning Trials β[95% CI]	CVLT: Long-Delay Free Recall β[95% CI]	D-KEFS: Inhibition β[95% CI]	Verbal Fluency β[95% CI]	PROMIS: Cognitive abilities β[95% CI]
Self-reported sleep quality (per 1 point)	0.17 [−2.00, 2.33]	0.25 [−0.84, 1.34]	0.12 [−0.19, 0.43]	−0.11 [−1.14, 0.91]	−0.11 [−0.46, 0.24]	0.55 [−0.78, 1.89]	0.25 [−1.24, 1.73]	0.41 [−0.42, 1.23]
Self-reported number of hours slept (per 1 hr)	−0.96 [−3.63, 1.71]	−0.58 [−1.88, 0.73]	−0.19 [−0.56, 0.18]	0.12 [−1.11, 1.35]	−0.08 [−0.50, 0.33]	−0.29 [−1.92, 1.34]	0.05 [−1.73, 1.82]	0.53 [−0.48, 1.54]
Self-reported bedtime variability (per 1 hr)	1.91 [−3.03, 6.84]	1.60 [−0.84, 4.05]	0.47 [−0.25, 1.19]	1.71 [−0.63, 4.05]	0.78 [0.01, 1.55]*	−3.20 [−6.25, −0.16]*	3.01 [−0.38, 6.40]	−0.22 [−2.17, 1.72]
Epworth Sleepiness Scale (per 1 point)	−0.35 [−1.06, 0.36]	0.05 [−0.31, 0.40]	0.02 [−0.08, 0.12]	0.04 [−0.28, 0.37]	0.03 [−0.08, 0.15]	0.00 [−0.44, 0.44]	−0.11 [−0.59, 0.37]	−0.30 [−0.55, −0.04]*
PROMIS sleep disturbances (per 1 point)	0.18 [−0.40, 0.75]	0.04 [−0.24, 0.31]	−0.03 [−0.11, 0.05]	0.13 [−0.12, 0.38]	0.07 [−0.02, 0.15]	−0.03 [−0.39, 0.32]	−0.09 [−0.47, 0.30]	−0.09 [−0.30, 0.12]
Average hours slept (from wristband)	−0.78 [−3.60, 2.03]	0.47 [−1.02, 1.96]	−0.01 [−0.40, 0.37]	0.39 [−0.86, 1.64]	−0.15 [−0.57, 0.27]	0.03 [−1.67, 1.74]	0.47 [−1.32, 2.27]	0.55 [−0.53, 1.63]
BVP signal (from E4 wristband)	**6.04 [3.25, 8.83]****a	1.64 [0.20, 3.09]*	**0.77 [0.39, 1.15]***a	**1.74 [0.44, 3.04]***a	**0.62 [0.19, 1.06]***a	−1.28 [−3.04, 0.48]	0.66 [−1.26, 2.59]	0.34 [−0.80, 1.48]
EDA signal (from E4 wristband)	−1.10 [−3.08, 0.88]	−0.98 [−1.96, −0.01]*	−0.25 [−0.51, 0.02]	−0.27 [−1.15, 0.61]	−0.26 [−0.56, 0.03]	1.15 [−0.00, 2.30]	**−1.75 [−3.00, −0.49]***a	0.66 [−0.07, 1.39]

Note. CI = confidence interval; PROMIS = Patient Reported Outcomes Measurement Information System; BVP = blood volume pulse; EDA = electrodermal activity; PASAT = Paced Auditory Serial Addition Test; CVLT = California Verbal Learning Test; D-KEFS = Delis-Kaplan Executive Function System. Each cell represents an independent, adjusted, linear regression model. All models adjust for age, sex, education (≥college vs. <college), PROMIS Depression, PROMIS Fatigue, and PROMIS Pain Intensity, and injury classification (i.e., tetraplegia vs. paraplegia); full model results for each sleep variable are reported in the online Supplemental Materials Table 2.
[a] False-discovery rate adjusted *q*-value significant with false discovery rate = .15 (these values are also bolded above for emphasis).
* $p < .05$. ** $p < .0001$.

analyses is relatively small, findings should be interpreted with caution and replication in other independent samples is warranted.

Findings for objective proxy measures of sleep identified significant relationships between our ANS-specific markers of sleep and cognitive performance. Specifically, lower heart rate variability during sleep (represented by our BVP signal) was related to worse cognitive performance on tests of long-term memory, processing speed, working memory, and learning. This is consistent with reports that indicate that that high HR and low HRV is a general marker for disease (Bonnet & Arand, 2010; Fujiki et al., 2013; Palatini & Julius, 1997; Silvani, 2019; Stein & Kleiger, 1999; Stein & Pu, 2012; Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology, 1996; Tsuji et al., 1994), and that both low HRV (during the day and at night) is also associated with anxiety and stressors (Brosschot et al., 2007; Hall et al., 2007). In addition, increased arousal during sleep (represented by our EDA signal) was related to worse cognitive performance on a measure of executive function. This is consistent with other literature that has found a positive relationship between EDA and cognitive load (Benedek & Kaernbach, 2010; Critchley, 2005; Raikes & Schaefer, 2016). For example, persons with concussion exhibit greater physiologic arousal (as measured by EDA; Raikes & Schaefer, 2016). In addition, persons with concussion also exhibited worse performance on a delayed memory task relative to nonconcussed controls, even despite similar levels of arousal patterns during the initial learning phases of the task (Raikes & Schaefer, 2016). Findings suggest that poorer sleep (i.e., greater sympathetic nervous system arousal), may indeed have a negative impact across multiple cognitive domains.

While our study included both subjective and objective measures of sleep, we did not include the traditional gold standard assessment of sleep (i.e., polysomnography) and instead focused on subjective self-report measures of sleep, as well as signals that were derived from a wrist-worn study device given that these approaches provided both a cost savings and were low burden for the participants, and were able to capture sleep in the real-word environment (Chen et al., 2018; Gao et al., 2019). In addition, the cognitive assessment was only conducted post the home-monitoring period; future studies should examine cognitive performance both before and after a home-monitoring period. We also did not comprehensively evaluate the absence/presence of sleep disorders in our sample, nor did we evaluate premorbid comorbidities (including premorbid history of development or learning disabilities). The comorbidity data that is provided was based on self-report data for these conditions and likely underestimates the true rates of these comorbidities. It is possible that stronger relationships, and a more consistent pattern of findings among sleep and cognitive function may emerge for those individuals with clinical sleep disorders. In addition, medication data was also based on self-report data, which was not verified by medical record or pharmacy data. It is possible that medication use, especially use of medications that may impact cognitive performance, may influence the relationship between sleep and cognitive performance; future inquiry in samples with well characterized medication data (including dosage and frequency) is warranted. Furthermore, this study only examined persons with SCI, it is unknown if the sleep problems that are experienced are unique to people with SCI, or is simply a product of dysregulated sleep. Future work that compares people with SCI to other groups would better elucidate how these relationships may or may not be unique to people with SCI.

Given the preliminary nature of these findings, any clinical implications are tentative. One potential suggestion raised by the finding that, compared with subjective measures, objective measures were relatively more predictive of cognitive outcomes is that clinicians may need to look beyond self-report report measures of sleep. For patients where sleep is suspected to contribute to poor cognitive functioning, clinicians may need to assess sleep by objective means (e.g., polysomnography, sleep diary plus actigraphy) to explore the nature of the sleep-cognition relationship.

In summary, there appears to at least some relationship between some sleep variables and objective cognitive performance in persons with SCI. Future work is needed to confirm these findings, but suggest that there may be a relationship between objective sleep (i.e., measures of sleep physiology) and cognitive functioning in individuals with SCI.

References

American Educational Research Association, American Psychological Association, and National Council on Measurement in Education. (2014). *Standards for educational and psychological testing*. American Educational Research Association.

Ahuja, C. S., Wilson, J. R., Nori, S., Kotter, M. R. N., Druschel, C., Curt, A., & Fehlings, M. G. (2017). Traumatic spinal cord injury. *Nature Reviews. Disease Primers*, *3*, 17018. https://doi.org/10.1038/nrdp.2017.18

Barclay, L., McDonald, R., & Lentin, P. (2015). Social and community participation following spinal cord injury: A critical review. *International Journal of Rehabilitation Research. Internationale Zeitschrift Fur Rehabilitationsforschung. Revue Internationale de Recherches de Readaptation*, *38*(1), 1–19. https://doi.org/10.1097/MRR.0000000000000085

Battalio, S. L., Glette, M., Alschuler, K. N., & Jensen, M. P. (2018). Anxiety, depression, and function in individuals with chronic physical conditions: A longitudinal analysis. *Rehabilitation Psychology*, *63*(4), 532–541. https://doi.org/10.1037/rep0000231

Benedek, M., & Kaernbach, C. (2010). A continuous measure of phasic electrodermal activity. *Journal of Neuroscience Methods*, *190*(1), 80–91. https://doi.org/10.1016/j.jneumeth.2010.04.028

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B. Methodological*, *57*(1), 289–300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x

Berlowitz, D. J., Spong, J., Gordon, I., Howard, M. E., & Brown, D. J. (2012). Relationships between objective sleep indices and symptoms in a community sample of people with tetraplegia. *Archives of Physical Medicine and Rehabilitation*, *93*(7), 1246–1252. https://doi.org/10.1016/j.apmr.2012.02.016

Biering-Sørensen, F., & Biering-Sørensen, M. (2001). Sleep disturbances in the spinal cord injured: An epidemiological questionnaire investigation, including a normal population. *Spinal Cord*, *39*(10), 505–513. https://doi.org/10.1038/sj.sc.3101197

Bonanno, G. A., Kennedy, P., Galatzer-Levy, I. R., Lude, P., & Elfström, M. L. (2012). Trajectories of resilience, depression, and anxiety following spinal cord injury. *Rehabilitation Psychology*, *57*(3), 236–247. https://doi.org/10.1037/a0029256

Bonnet, M. H., & Arand, D. L. (2010). Hyperarousal and insomnia: State of the science. *Sleep Medicine Reviews*, *14*(1), 9–15. https://doi.org/10.1016/j.smrv.2009.05.002

Borazio, M., & Van Laerhoven, K. (2012). *Combining wearable and environmental sensing into an unobtrusive tool for long-term sleep studies*. Proceedings of the 2nd ACM SIGHIT Symposium on International Health Informatics - IHI ′12. https://doi.org/10.1145/2110363.2110375

Boyer, B., Knolls, M., Kafkalas, C., & Tollen, L. (2000). Prevalence of posttraumatic stress disorder in patients with pediatric spinal cord injury: Relationship to functional independence. *Topics in Spinal Cord Injury Rehabilitation*, *6*(Suppl. 1), 125–133. https://doi.org/10.1310/4FJ8-3VCH-EE0N-HNCD

Bradbury, C. L., Wodchis, W. P., Mikulis, D. J., Pano, E. G., Hitzig, S. L., McGillivray, C. F., Ahmad, F. N., Craven, B. C., & Green, R. E. (2008). Traumatic brain injury in patients with traumatic spinal cord injury: Clinical and economic consequences. *Archives of Physical Medicine and Rehabilitation*, *89*(12), S77–S84. https://doi.org/10.1016/j.apmr.2008.07.008

Braithwaite, J., Watson, D. G., Jones, R., & Rowe, M. (2015). *A guide for analysing Electrodermal Activity (EDA) & Skin Conductance Responses (SCRs) for psychological experiments (Revised version: 2.0)*. https://www.birmingham.ac.uk/Documents/college-les/psych/saal/guide-electrodermal-activity.pdf

Brosschot, J. F., Van Dijk, E., & Thayer, J. F. (2007). Daily worry is related to low heart rate variability during waking and the subsequent nocturnal sleep period. *International Journal of Psychophysiology*, *63*(1), 39–47. https://doi.org/10.1016/j.ijpsycho.2006.07.016

Burke, D., Lennon, O., & Fullen, B. M. (2018). Quality of life after spinal cord injury: The impact of pain. *European Journal of Pain*, *22*(9), 1662–1672. https://doi.org/10.1002/ejp.1248

Buzzell, A., Chamberlain, J. D., Schubert, M., Mueller, G., Berlowitz, D. J., Brinkhof, M. W. G., & the SwiSCI Study Group. (2020). Perceived sleep problems after spinal cord injury: Results from a community-based survey in Switzerland. *The Journal of Spinal Cord Medicine*. Advance online publication. https://doi.org/10.1080/10790268.2019.1710938

Carlozzi, N. E., Graves, C. M., Troost, J. P., Ehde, D. M., Miner, J. A., & Kratz, A. L. (2021). Association of physical and mental symptoms with cognition in people with spinal cord injury. *Rehabilitation Psychology*, *66*(4), 532–540. https://doi.org/10.1037/rep0000416

Carlozzi, N. E., Troost, J. P., Singhal, N., Ehde, D. M., Bakshi, R., Molton, I. R., Miner, J. A., Graves, C. M., & Kratz, A. L. (2021). The association between medication use and cognitive performance in people with SCI. *Rehabilitation Psychology*, *66*(4), 541–549. https://doi.org/10.1037/rep0000412

Carney, C. E., Buysse, D. J., Ancoli-Israel, S., Edinger, J. D., Krystal, A. D., Lichstein, K. L., & Morin, C. M. (2012). The consensus sleep diary: Standardizing prospective sleep self-monitoring. *Sleep*, *35*(2), 287–302. https://doi.org/10.5665/sleep.1642

Cella, D., Riley, W., Stone, A., Rothrock, N., Reeve, B., Yount, S., Amtmann, D., Bode, R., Buysse, D., Choi, S., Cook, K., Devellis, R., DeWalt, D., Fries, J. F., Gershon, R., Hahn, E. A., Lai, J.-S., Pilkonis, P., Revicki, D., . . . the PROMIS Cooperative Group. (2010). The Patient-Reported Outcomes Measurement Information System (PROMIS) developed and tested its first wave of adult self-reported health outcome item banks: 2005-2008. *Journal of Clinical Epidemiology*, *63*(11), 1179–1194. https://doi.org/10.1016/j.jclinepi.2010.04.011

Cella, D., Yount, S., Rothrock, N., Gershon, R., Cook, K., Reeve, B., Ader, D., Fries, J. F., Bruce, B., & Rose, M., & the PROMIS Cooperative Group. (2007). The Patient-Reported Outcomes Measurement Information System (PROMIS): Progress of an NIH Roadmap cooperative group during its first two years. *Medical Care*, *45*(5), S3–S11. https://doi.org/10.1097/01.mlr.0000258615.42478.55

Chen, D., Yin, Z., & Fang, B. (2018). Measurements and status of sleep quality in patients with cancers. *Supportive Care in Cancer*, *26*(2), 405–414. https://doi.org/10.1007/s00520-017-3927-x

Chiaravalloti, N. D., Christodoulou, C., Demaree, H. A., & DeLuca, J. (2003). Differentiating simple versus complex processing speed: Influence on new learning and memory performance. *Journal of Clinical and Experimental Neuropsychology*, *25*(4), 489–501. https://doi.org/10.1076/jcen.25.4.489.13878

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Cicerone, K. D., Langenbahn, D. M., Braden, C., Malec, J. F., Kalmar, K., Fraas, M., Felicetti, T., Laatsch, L., Harley, J. P., Bergquist, T., Azulay, J., Cantor, J., & Ashman, T. (2011). Evidence-based cognitive rehabilitation: Updated review of the literature from 2003 through 2008. *Archives of Physical Medicine and Rehabilitation*, *92*(4), 519–530. https://doi.org/10.1016/j.apmr.2010.11.015

Cohen, M. L., Tulsky, D. S., Holdnack, J. A., Carlozzi, N. E., Wong, A., Magasi, S., Heaton, R. K., & Heinemann, A. W. (2017). Cognition among community-dwelling individuals with spinal cord injury. *Rehabilitation Psychology*, *62*(4), 425–434. https://doi.org/10.1037/rep0000140

Cook, S., & Marsiske, M. (2006). Subjective memory beliefs and cognitive performance in normal and mildly impaired older adults. *Aging & Mental Health*, *10*(4), 413–423. https://doi.org/10.1080/13607860600638487

Critchley, H. D. (2005). Neural mechanisms of autonomic, affective, and cognitive integration. *The Journal of Comparative Neurology*, *493*(1), 154–166. https://doi.org/10.1002/cne.20749

Davidoff, G. N., Roth, E. J., & Richards, J. S. (1992). Cognitive deficits in spinal cord injury: Epidemiology and outcome. *Archives of Physical Medicine and Rehabilitation*, *73*(3), 275–284.

Davidoff, G., Morris, J., Roth, E., & Bleiberg, J. (1985). Cognitive dysfunction and mild closed head injury in traumatic spinal cord injury. *Archives of Physical Medicine and Rehabilitation*, *66*(8), 489–491.

Delis, D., Kaplan, E., & Kramer, J. (2001). *Delis Kaplan Executive Function System (D-KEFS)*. The Psychological Corporation.

Delis, D., Kramer, A., Kaplan, E., & Ober, B. (2000). *California Verbal learning Test - Second Edition (CVLT-II)*. The Psychological Corporation.

DeLuca, J. (2008). How fast, how slow and how come. In J. DeLuca & J. H. Kalmar (Eds.), *Information processing speed in clinical populations* (pp. 265–273). Taylor and Francis.

DeLuca, J., & Kalmar, J. H. (Eds.). (2008). *Information processing speed in clinical populations*. Taylor & Francis.

Derouesné, C., Lacomblez, L., Thibault, S., & LePoncin, M. (1999). Memory complaints in young and elderly subjects. *International Journal of Geriatric Psychiatry*, *14*(4), 291–301. https://doi.org/10.1002/(SICI)1099-1166(199904)14:4<291::AID-GPS902>3.0.CO;2-7

Diehr, M. C., Heaton, R. K., Miller, W., & Grant, I. (1998). The Paced Auditory Serial Addition Task (PASAT): Norms for age, education, and ethnicity. *Assessment*, *5*(4), 375–387. https://doi.org/10.1177/107319119800500407

Dijkers, M., Bryce, T., & Zanca, J. (2009). Prevalence of chronic pain after traumatic spinal cord injury: A systematic review. *Journal of Rehabilitation Research and Development*, *46*(1), 13–29. https://doi.org/10.1682/JRRD.2008.04.0053

Dillon, H. R., Lichstein, K. L., Dautovich, N. D., Taylor, D. J., Riedel, B. W., & Bush, A. J. (2015). Variability in self-reported normal sleep across the adult age span. *The Journals of Gerontology: Series B, Psychological Sciences and Social Sciences*, *70*(1), 46–56. https://doi.org/10.1093/geronb/gbu035

Distel, D. F., Amodeo, M., Joshi, S., & Abramoff, B. A. (2020). Cognitive dysfunction in persons with chronic spinal cord injuries. *Physical Medicine and Rehabilitation Clinics of North America*, *31*(3), 345–368. https://doi.org/10.1016/j.pmr.2020.04.001

Donders, J., Tulsky, D. S., & Zhu, J. (2001). Criterion validity of new WAIS-II subtest scores after traumatic brain injury. *Journal of the International Neuropsychological Society*, *7*(7), 892–898. https://doi.org/10.1017/S1355617701777132

Dowler, R. N., Harrington, D. L., Haaland, K. Y., Swanda, R. M., Fee, F., & Fiedler, K. (1997). Profiles of cognitive functioning in chronic spinal cord injury and the role of moderating variables. *Journal of the International Neuropsychological Society*, *3*(5), 464–472. https://doi.org/10.1017/S1355617797004645

Dowler, R. N., O'Brien, S. A., Haaland, K. Y., Harrington, D. L., Feel, F., & Fiedler, K. (1995). Neuropsychological functioning following a spinal cord injury. *Applied Neuropsychology*, *2*(3–4), 124–129. https://doi.org/10.1080/09084282.1995.9645349

Dryden, D. M., Saunders, L. D., Rowe, B. H., May, L. A., Yiannakoulias, N., Svenson, L. W., Schopflocher, D. P., & Voaklander, D. C. (2005). Depression following traumatic spinal cord injury. *Neuroepidemiology*, *25*(2), 55–61. https://doi.org/10.1159/000086284

Dzierzewski, J. M., Dautovich, N., & Ravyts, S. (2018). Sleep and cognition in older adults. *Sleep Medicine Clinics*, *13*(1), 93–106. https://doi.org/10.1016/j.jsmc.2017.09.009

Empatica. (2020). *E4 wristband*. https://www.empatica.com/research/e4/

Fujiki, A., Sakabe, M., & Yoshioka, R. (2013). High prevalence of cyclical variation in heart rate before nocturnal episodes of paroxysmal atrial fibrillation. *Internal Medicine*, *52*(19), 2169–2172. https://doi.org/10.2169/internalmedicine.52.0787

Gao, C., Chapagain, N. Y., & Scullin, M. K. (2019). Sleep duration and sleep quality in caregivers of patients with dementia: A systematic review and meta-analysis. *JAMA Network Open*, *2*(8), e199891. https://doi.org/10.1001/jamanetworkopen.2019.9891

Geoffroy, P. A., Boudebesse, C., Bellivier, F., Lajnef, M., Henry, C., Leboyer, M., Scott, J., & Etain, B. (2014). Sleep in remitted bipolar disorder: A naturalistic case-control study using actigraphy. *Journal of Affective Disorders*, *158*, 1–7. https://doi.org/10.1016/j.jad.2014.01.012

Giannoccaro, M. P., Moghadam, K. K., Pizza, F., Boriani, S., Maraldi, N. M., Avoni, P., Morreale, A., Liguori, R., & Plazzi, G. (2013). Sleep disorders in patients with spinal cord injury. *Sleep Medicine Reviews*, *17*(6), 399–409. https://doi.org/10.1016/j.smrv.2012.12.005

Goel, N. (2017). Neurobehavioral effects and biomarkers of sleep loss in healthy adults. *Current Neurology and Neuroscience Reports*, *17*(11), 89. https://doi.org/10.1007/s11910-017-0799-x

Gontkovsky, S. T., & Beatty, W. W. (2006). Practical methods for the clinical assessment of information processing speed. *Int Journal of Neuroscience*, *116*(11), 1317–1325. https://doi.org/10.1080/00207450500516537

Hagen, E. M., Eide, G. E., Rekand, T., Gilhus, N. E., & Gronning, M. (2010). Traumatic spinal cord injury and concomitant brain injury: A cohort study. *Acta Neurologica Scandinavica*, *122*(190), 51–57. https://doi.org/10.1111/j.1600-0404.2010.01376.x

Hall, M., Thayer, J. F., Germain, A., Moul, D., Vasko, R., Puhl, M., Miewald, J., & Buysse, D. J. (2007). Psychological stress is associated with heightened physiological arousal during NREM sleep in primary insomnia. *Behavioral Sleep Medicine*, *5*(3), 178–193. https://doi.org/10.1080/15402000701263221

Hassanijirdehi, M., Khak, M., Afshari-Mirak, S., Holakouie-Naieni, K., Saadat, S., Taheri, T., & Rahimi-Movaghar, V. (2015). Evaluation of pain and its effect on quality of life and functioning in men with spinal cord injury. *The Korean Journal of Pain*, *28*(2), 129–136. https://doi.org/10.3344/kjp.2015.28.2.129

Heaton, R. K., Miller, S. W., Taylor, J. T., & Grant, I. (2004). *Revised comprehensive norms for an expanded Halstead-Reitan Battery: Demographically adjusted neuropsychological norms for African American and Caucasian adults*. Psychological Assessment Resources, Inc.

Hess, D. W., Marwitz, J. H., & Kreutzer, J. S. (2003). Neuropsychological impairments after spinal cord injury: A comparative study with mild traumatic brain injury. *Rehabilitation Psychology*, *48*(3), 151–156. https://doi.org/10.1037/0090-5550.48.3.151

Hultén, V. D. T., Biering-Sørensen, F., Jørgensen, N. R., & Jennum, P. J. (2018). A review of sleep research in patients with spinal cord injury. *The Journal of Spinal Cord Medicine*, *43*(6), 775–796. https://doi.org/10.1080/10790268.2018.1543925

Hutchinson, A. D., Hosking, J. R., Kichenadasse, G., Mattiske, J. K., & Wilson, C. (2012). Objective and subjective cognitive impairment following chemotherapy for cancer: A systematic review. *Cancer Treatment Reviews*, *38*(7), 926–934. https://doi.org/10.1016/j.ctrv.2012.05.002

January, A. M., Zebracki, K., Chlan, K. M., & Vogel, L. C. (2015). Sleep, well-being, and psychological symptoms in adults with pediatric-onset spinal cord injury. *Rehabilitation Psychology*, *60*(4), 328–334. https://doi.org/10.1037/rep0000061

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Johns, M. W. (1991). A new method for measuring daytime sleepiness - the Epworth Sleepiness Scale. *Sleep*, *14*(6), 540–545. https://doi.org/10.1093/sleep/14.6.540

Johns, M. W. (1992). Reliability and factor analysis of the Epworth Sleepiness Scale. *Sleep*, *15*(4), 376–381. https://doi.org/10.1093/sleep/15.4.376

Jungwirth, S., Fischer, P., Weissgram, S., Kirchmeyr, W., Bauer, P., & Tragl, K. H. (2004). Subjective memory complaints and objective memory impairment in the Vienna-Transdanube aging community. *Journal of the American Geriatrics Society*, *52*(2), 263–268. https://doi.org/10.1111/j.1532-5415.2004.52066.x

Killgore, W. D. S. (2010). Effects of sleep deprivation on cognition. In G. A. Kerkhof & H. P. A. van Dongen (Eds.), *Progress in Brain Research* (Vol. 185, pp. 105–129). Elsevier.

Kirshblum, S. C., Waring, W., Biering-Sorensen, F., Burns, S. P., Johansen, M., Schmidt-Read, M., Donovan, W., Graves, D., Jha, A., Jones, L., Mulcahey, M. J., & Krassioukov, A. (2011). Reference for the 2011 revision of the International Standards for Neurological Classification of Spinal Cord Injury. *The Journal of Spinal Cord Medicine*, *34*(6), 547–554. https://doi.org/10.1179/107902611X13186000420242

Klumpers, U. M., Veltman, D. J., van Tol, M. J., Kloet, R. W., Boellaard, R., Lammertsma, A. A., & Hoogendijk, W. J. (2015). Neurophysiological effects of sleep deprivation in healthy adults, a pilot study. *PLoS ONE*, *10*(1), e0116906. https://doi.org/10.1371/journal.pone.0116906

Knutson, K. L., Rathouz, P. J., Yan, L. L., Liu, K., & Lauderdale, D. S. (2007). Intra-individual daily and yearly variability in actigraphically recorded sleep measures: The CARDIA study. *Sleep*, *30*(6), 793–796. https://doi.org/10.1093/sleep/30.6.793

Kramer, C. J., Kerkhof, G. A., & Hofman, W. F. (1999). Age differences in sleep-wake behavior under natural conditions. *Personality and Individual Differences*, *27*(5), 853–860. https://doi.org/10.1016/S0191-8869(99)00034-3

Kratz, A. L., Kalpakjian, C. Z., & Hanks, R. A. (2017). Are intensive data collection methods in pain research feasible in those with physical disability? A study in persons with chronic pain and spinal cord injury. *Quality of Life Research*, *26*(3), 587–600. https://doi.org/10.1007/s11136-016-1494-0

Krause, J. S., Saunders, L. L., & Newman, S. (2010). Posttraumatic stress disorder and spinal cord injury. *Archives of Physical Medicine and Rehabilitation*, *91*(8), 1182–1187. https://doi.org/10.1016/j.apmr.2010.05.012

Kurihara, Y., & Watanabe, K. (2012). Sleep-stage decision algorithm by using heartbeat and body-movement signals. *IEEE Transactions on Systems, Man, and Cybernetics. Part A, Systems and Humans*, *42*(6), 1450–1459. https://doi.org/10.1109/TSMCA.2012.2192264

Lai, J. S., Wagner, L. I., Jacobsen, P. B., & Cella, D. (2014). Self-reported cognitive concerns and abilities: Two sides of one coin? *Psycho-Oncology*, *23*(10), 1133–1141. https://doi.org/10.1002/pon.3522

Landry, G. J., Best, J. R., & Liu-Ambrose, T. (2015). Measuring sleep quality in older adults: A comparison using subjective and objective methods. *Frontiers in Aging Neuroscience*, *7*, 166. https://doi.org/10.3389/fnagi.2015.00166

Lautenschlager, N. T., Flicker, L., Vasikaran, S., Leedman, P., & Almeida, O. P. (2005). Subjective memory complaints with and without objective memory impairment: Relationship with risk factors for dementia. *The American Journal of Geriatric Psychiatry*, *13*(8), 731–734. https://doi.org/10.1097/00019442-200508000-00013

Lazzaro, I., Tran, Y., Wijesuriya, N., & Craig, A. (2013). Central correlates of impaired information processing in people with spinal cord injury. *Journal of Clinical Neurophysiology*, *30*(1), 59–65. https://doi.org/10.1097/WNP.0b013e31827edb0c

Lemola, S., Ledermann, T., & Friedman, E. M. (2013). Variability of sleep duration is related to subjective sleep quality and subjective well-being: An actigraphy study. *PLoS ONE*, *8*(8), e71292. https://doi.org/10.1371/journal.pone.0071292

Lezak, M. D., Howieson, D. B., Loring, D. W., Hannay, H. J., & Fischer, J. S. (2004). *Neuropsychological assessment* (4th ed.). Oxford University Press.

Lineweaver, T. T., Naugle, R. I., Cafaro, A. M., Bingaman, W., & Lüders, H. O. (2004). Patients' perceptions of memory functioning before and after surgical intervention to treat medically refractory epilepsy. *Epilepsia*, *45*(12), 1604–1612. https://doi.org/10.1111/j.0013-9580.2004.54503.x

Macciocchi, S. N., Bowman, B., Coker, J., Apple, D., & Leslie, D. (2004). Effect of co-morbid traumatic brain injury on functional outcome of persons with spinal cord injuries. *American Journal of Physical Medicine & Rehabilitation*, *83*(1), 22–26. https://doi.org/10.1097/01.PHM.0000104661.86307.91

Macciocchi, S. N., Seel, R. T., & Thompson, N. (2013). The impact of mild traumatic brain injury on cognitive functioning following co-occurring spinal cord injury. *Archives of Clinical Neuropsychology*, *28*(7), 684–691. https://doi.org/10.1093/arclin/act049

Macciocchi, S., Seel, R. T., Thompson, N., Byams, R., & Bowman, B. (2008). Spinal cord injury and co-occurring traumatic brain injury: Assessment and incidence. *Archives of Physical Medicine and Rehabilitation*, *89*(7), 1350–1357. https://doi.org/10.1016/j.apmr.2007.11.055

Macciocchi, S., Seel, R. T., Warshowsky, A., Thompson, N., & Barlow, K. (2012). Co-occurring traumatic brain injury and acute spinal cord injury rehabilitation outcomes. *Archives of Physical Medicine and Rehabilitation*, *93*(10), 1788–1794. https://doi.org/10.1016/j.apmr.2012.01.022

Manber, R., Bootzin, R. R., Acebo, C., & Carskadon, M. A. (1996). The effects of regularizing sleep-wake schedules on daytime sleepiness. *Sleep*, *19*(5), 432–441. https://doi.org/10.1093/sleep/19.5.432

Masri, R., & Keller, A. (2012). Chronic pain following spinal cord injury. *Advances in Experimental Medicine and Biology*, *760*, 74–88. https://doi.org/10.1007/978-1-4614-4090-1_5

Mayes, S. D., & Calhoun, S. L. (2007). Learning, attention, writing, and processing speed in typical children and children with ADHD, autism, anxiety, depression, and oppositional-defiant disorder. *Child Neuropsychol*, *13*(6), 469–493. https://doi.org/10.1080/09297040601112773

McCrae, C. S., Vatthauer, K. E., Dzierzewski, J. M., & Marsiske, M. (2012). Habitual sleep, reasoning, and processing speed in older adults with sleep complaints. *Cognitive Therapy and Research*, *36*(2), 156–164. https://doi.org/10.1007/s10608-011-9425-4

McSorley, V. E., Bin, Y. S., & Lauderdale, D. S. (2019). Associations of sleep characteristics with cognitive function and decline among older adults. *American Journal of Epidemiology*, *188*(6), 1066–1075. https://doi.org/10.1093/aje/kwz037

Mezick, E. J., Matthews, K. A., Hall, M., Kamarck, T. W., Buysse, D. J., Owens, J. F., & Reis, S. E. (2009). Intra-individual variability in sleep duration and fragmentation: Associations with stress. *Psychoneuroendocrinology*, *34*(9), 1346–1354. https://doi.org/10.1016/j.psyneuen.2009.04.005

Migliorini, C., Sinclair, A., Brown, D., Tonge, B., & New, P. (2015). Prevalence of mood disturbance in Australian adults with chronic spinal cord injury. *Internal Medicine Journal*, *45*(10), 1014–1019. https://doi.org/10.1111/imj.12825

Minors, D., Atkinson, G., Bent, N., Rabbitt, P., & Waterhouse, J. (1998). The effects of age upon some aspects of lifestyle and implications for studies on circadian rhythmicity. *Age and Ageing*, *27*(1), 67–72. https://doi.org/10.1093/ageing/27.1.67

Monk, T. H., Reynolds, C. F. I. I. I., Buysse, D. J., Hoch, C. C., Jarrett, D. B., Jennings, J. R., & Kupfer, D. J. (1991). Circadian characteristics of healthy 80-year-olds and their relationship to objectively recorded sleep. *Journal of Gerontology*, *46*(5), M171–M175. https://doi.org/10.1093/geronj/46.5.M171

Nguyen, A. T., Baltzan, M. A., Small, D., Wolkove, N., Guillon, S., & Palayew, M. (2006). Clinical reproducibility of the Epworth Sleepiness Scale. *Journal of Clinical Sleep Medicine*, *2*(2), 170–174. https://doi.org/10.5664/jcsm.26512

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Norrbrink Budh, C., Hultling, C., & Lundeberg, T. (2005). Quality of sleep in individuals with spinal cord injury: A comparison between patients with and without pain. *Spinal Cord*, *43*(2), 85–95. https://doi.org/10.1038/sj.sc.3101680

North, N. T. (1999). The psychological effects of spinal cord injury: A review. *Spinal Cord*, *37*(10), 671–679. https://doi.org/10.1038/sj.sc.3100913

Onton, J. A., Kang, D. Y., & Coleman, T. P. (2016). Visualization of whole-night sleep EEG from 2-channel mobile recording device reveals distinct deep sleep stages with differential electrodermal activity. *Frontiers in Human Neuroscience*, *10*, 605. https://doi.org/10.3389/fnhum.2016.00605

Onton, J. A., Matthews, S. C., Kang, D. Y., & Coleman, T. P. (2018). In-home sleep recordings in military veterans with posttraumatic stress disorder reveal less rem and deep sleep < 1 Hz. *Frontiers in Human Neuroscience*, *12*, 196. https://doi.org/10.3389/fnhum.2018.00196

Palatini, P., & Julius, S. (1997). Heart rate and the cardiovascular risk. *Journal of Hypertension*, *15*(1), 3–17. https://doi.org/10.1097/00004872-199715010-00001

Paragliola, G., & Coronato, A. (2017). A deep learning-based approach for the recognition of sleep disorders in patients with cognitive diseases: A case study. In M. Ganzha, L. Maciaszek, & M. Paprzycki (Eds.), *Position Papers of the 2017 Federated Conference on Computer Science and Information Systems* (Vol. 12, pp. 43–48). ACSIS. https://doi.org/10.15439/2017F532

Patel, S. R., Hayes, A. L., Blackwell, T., Evans, D. S., Ancoli-Israel, S., Wing, Y. K., Stone, K. L., & the Osteoporotic Fractures in Men (MrOS) & the Study of Osteoporotic Fractures (SOF) Research Groups. (2014). The association between sleep patterns and obesity in older adults. *International Journal of Obesity*, *38*(9), 1159–1164. https://doi.org/10.1038/ijo.2014.13

Podewils, L. J., McLay, R. N., Rebok, G. W., & Lyketsos, C. G. (2003). Relationship of self-perceptions of memory and worry to objective measures of memory and cognition in the general population. *Psychosomatics*, *44*(6), 461–470. https://doi.org/10.1176/appi.psy.44.6.461

Raikes, A. C., & Schaefer, S. Y. (2016). Phasic Electrodermal Activity During the Standardized Assessment of Concussion (SAC). *Journal of Athletic Training*, *51*(7), 533–539. https://doi.org/10.4085/1062-6050-51.8.09

Reese, C. M., & Cherry, K. E. (2006). Effects of age and ability on self-reported memory functioning and knowledge of memory aging. *The Journal of Genetic Psychology*, *167*(2), 221–240. https://doi.org/10.3200/GNTP.167.2.221-240

Rintala, D. H., Loubser, P. G., Castro, J., Hart, K. A., & Fuhrer, M. J. (1998). Chronic pain in a community-based sample of men with spinal cord injury: Prevalence, severity, and relationship with impairment, disability, handicap, and subjective well-being. *Archives of Physical Medicine and Rehabilitation*, *79*(6), 604–614. https://doi.org/10.1016/S0003-9993(98)90032-6

Roane, B. M., Seifer, R., Sharkey, K. M., Van Reen, E., Bond, T. L., Raffray, T., & Carskadon, M. A. (2015). What role does sleep play in weight gain in the first semester of university? *Behavioral Sleep Medicine*, *13*(6), 491–505. https://doi.org/10.1080/15402002.2014.940109

Roth, E., Davidoff, G., Thomas, P., Doljanac, R., Dijkers, M., Berent, S., Morris, J., & Yarkony, G. (1989). A controlled study of neuropsychological deficits in acute spinal cord injury patients. *Paraplegia*, *27*(6), 480–489. https://doi.org/10.1038/sc.1989.75

Sachdeva, R., Gao, F., Chan, C. C. H., & Krassioukov, A. V. (2018). Cognitive function after spinal cord injury: A systematic review. *Neurology*, *91*(13), 611–621. https://doi.org/10.1212/WNL.0000000000006244

Sadeghi, R., Banerjee, T., Hughes, J. C., & Lawhorne, L. W. (2019). Sleep quality prediction in caregivers using physiological signals. *Computers in Biology and Medicine*, *110*, 276–288. https://doi.org/10.1016/j.compbiomed.2019.05.010

Sankari, A., Vaughan, S., Bascom, A., Martin, J. L., & Badr, M. S. (2019). Sleep-disordered breathing and spinal cord injury: A state-of-the-art review. *Chest*, *155*(2), 438–445. https://doi.org/10.1016/j.chest.2018.10.002

Sano, A., Picard, R. W., & Stickgold, R. (2014). Quantitative analysis of wrist electrodermal activity during sleep. *International Journal of Psychophysiology*, *94*(3), 382–389. https://doi.org/10.1016/j.ijpsycho.2014.09.011

Sawrie, S. M., Martin, R. C., Kuzniecky, R., Faught, E., Morawetz, R., Jamil, F., Viikinsalo, M., & Gilliam, F. (1999). Subjective versus objective memory change after temporal lobe epilepsy surgery. *Neurology*, *53*(7), 1511–1517. https://doi.org/10.1212/WNL.53.7.1511

Schilero, G. J., Bauman, W. A., & Radulovic, M. (2018). Traumatic spinal cord injury: Pulmonary physiologic principles and management. *Clinics in Chest Medicine*, *39*(2), 411–425. https://doi.org/10.1016/j.ccm.2018.02.002

Schmidt, I. W., Berg, I. J., & Deelman, B. G. (2001). Relations between subjective evaluations of memory and objective memory performance. *Perceptual and Motor Skills*, *93*(3), 761–776. https://doi.org/10.2466/pms.2001.93.3.761

Sharma, B., Bradbury, C., Mikulis, D., & Green, R. (2014). Missed diagnosis of traumatic brain injury in patients with traumatic spinal cord injury. *Journal of Rehabilitation Medicine*, *46*(4), 370–373. https://doi.org/10.2340/16501977-1261

Short, M. A., & Chee, M. W. L. (2019). Adolescent sleep restriction effects on cognition and mood. *Progress in Brain Research*, *246*, 55–71. https://doi.org/10.1016/bs.pbr.2019.02.008

Silvani, A. (2019). Sleep disorders, nocturnal blood pressure, and cardiovascular risk: A translational perspective. *Autonomic Neuroscience*, *218*, 31–42. https://doi.org/10.1016/j.autneu.2019.02.006

Spong, J., Graco, M., Brown, D. J., Schembri, R., & Berlowitz, D. J. (2015). Subjective sleep disturbances and quality of life in chronic tetraplegia. *Spinal Cord*, *53*(8), 636–640. https://doi.org/10.1038/sc.2015.68

Stein, P. K., & Kleiger, R. E. (1999). Insights from the study of heart rate variability. *Annual Review of Medicine*, *50*, 249–261. https://doi.org/10.1146/annurev.med.50.1.249

Stein, P. K., & Pu, Y. (2012). Heart rate variability, sleep and sleep disorders. *Sleep Medicine Reviews*, *16*(1), 47–66. https://doi.org/10.1016/j.smrv.2011.02.005

Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation and clinical use. *Circulation*, *93*, 1043–1065. https://doi.org/10.1161/01.CIR.93.5.1043

Tsuji, H., Venditti, F. J., Jr., Manders, E. S., Evans, J. C., Larson, M. G., Feldman, C. L., & Levy, D. (1994). Reduced heart rate variability and mortality risk in an elderly cohort. The Framingham Heart Study. *Circulation*, *90*(2), 878–883. https://doi.org/10.1161/01.CIR.90.2.878

Tulsky, D. S., Carlozzi, N. E., Chevalier, N., Espy, K. A., Beaumont, J. L., & Mungas, D. (2013). V. NIH Toolbox Cognition Battery (CB): Measuring working memory. *Monographs of the Society for Research in Child Development*, *78*(4), 70–87. https://doi.org/10.1111/mono.12035

Tulsky, D. S., Carlozzi, N., Chiaravalloti, N. D., Beaumont, J. L., Kisala, P. A., Mungas, D., Conway, K., & Gershon, R. (2014). NIH Toolbox Cognition Battery (NIHTB-CB): List sorting test to measure working memory. *Journal of the International Neuropsychological Society*, *20*(6), 599–610. https://doi.org/10.1017/S135561771400040X

Ullrich, P. M., Spungen, A. M., Atkinson, D., Bombardier, C. H., Chen, Y., Erosa, N. A., Groer, S., Ottomanelli, L., & Tulsky, D. S. (2012). Activity and participation after spinal cord injury: State-of-the-art report. *Journal of Rehabilitation Research and Development*, *49*(1), 155–174. https://doi.org/10.1682/JRRD.2010.06.0108

Vanderlind, W. M., Beevers, C. G., Sherman, S. M., Trujillo, L. T., McGeary, J. E., Matthews, M. D., Maddox, W. T., & Schnyer, D. M. (2014). Sleep and sadness: Exploring the relation among sleep, cognitive control, and depressive symptoms in young adults. *Sleep Medicine*, *15*(1), 144–149. https://doi.org/10.1016/j.sleep.2013.10.006

Vega, R., Miró, J., Esteve, R., Ramírez-Maestre, C., López-Martínez, A. E., & Jensen, M. P. (2019). Sleep disturbance in individuals with physical disabilities and chronic pain: The role of physical, emotional and cognitive factors. *Disability and Health Journal*, *12*(4), 588–593. https://doi.org/10.1016/j.dhjo.2019.04.001

Weintraub, S., Dikmen, S. S., Heaton, R. K., Tulsky, D. S., Zelazo, P. D., Bauer, P. J., Carlozzi, N. E., Slotkin, J., Blitz, D., Wallner-Allen, K., Fox, N. A., Beaumont, J. L., Mungas, D., Nowinski, C. J., Richler, J., Deocampo, J. A., Anderson, J. E., Manly, J. J., Borosh, B., . . . Gershon, R. C. (2013). Cognition assessment using the NIH Toolbox. *Neurology*, *80*(11), S54–S64. https://doi.org/10.1212/WNL.0b013e3182872ded

Weintraub, S., Dikmen, S. S., Heaton, R. K., Tulsky, D. S., Zelazo, P. D., Slotkin, J., Carlozzi, N. E., Bauer, P. J., Wallner-Allen, K., Fox, N., Havlik, R., Beaumont, J. L., Mungas, D., Manly, J. J., Moy, C., Conway, K., Edwards, E., Nowinski, C. J., & Gershon, R. (2014). The cognition battery of the NIH toolbox for assessment of neurological and behavioral function: Validation in an adult sample. *Journal of the International Neuropsychological Society*, *20*(6), 567–578. https://doi.org/10.1017/S1355617714000320

Whiteside, D. M., Kealey, T., Semla, M., Luu, H., Rice, L., Basso, M. R., & Roper, B. (2016). Verbal fluency: Language or executive function measure? *Applied Neuropsychology: Adult*, *23*(1), 29–34. https://doi.org/10.1080/23279095.2015.1004574

Widerström-Noga, E. G., Felipe-Cuervo, E., & Yezierski, R. P. (2001). Chronic pain after spinal injury: Interference with sleep and daily activities. *Archives of Physical Medicine and Rehabilitation*, *82*(11), 1571–1577. https://doi.org/10.1053/apmr.2001.26068

Wilmot, C. B., Cope, D. N., Hall, K. M., & Acker, M. (1985). Occult head injury: Its incidence in spinal cord injury. *Archives of Physical Medicine and Rehabilitation*, *66*(4), 227–231. https://doi.org/10.1016/0003-9993(85)90148-0

Yu, L., Buysse, D. J., Germain, A., Moul, D. E., Stover, A., Dodds, N. E., Johnston, K. L., & Pilkonis, P. A. (2011). Development of short forms from the PROMIS™ sleep disturbance and sleep-related impairment item banks. *Behavioral Sleep Medicine*, *10*(1), 6–24. https://doi.org/10.1080/15402002.2012.636266

Zandi, T. (2004). Relationship between subjective memory complaints, objective memory performance, and depression among older adults. *American Journal of Alzheimer's Disease and Other Dementias*, *19*(6), 353–360. https://doi.org/10.1177/153331750401900610

Received December 23, 2020
Revision received August 13, 2021
Accepted August 19, 2021 ■

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.