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ORIGINAL RESEARCH

# Daily Variation in Sleep Quality is Associated With Health-Related Quality of Life in People With Spinal Cord Injury

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**Abstract**

**Objective:** Although sleep difficulties are common after spinal cord injury (SCI), little is known about how day-to-day fluctuations in sleep quality affects health-related quality of life (HRQOL) among these individuals. We examined the effect of sleep quality on same-day HRQOL using ecological momentary assessment methods over a 7-day period.

**Design:** Repeated-measures study involving 7 days of home monitoring; participants completed HRQOL measures each night and ecological momentary assessment ratings 3 times throughout the day; multilevel models were used to analyze data.

**Setting:** Two academic medical centers.

**Participants:** A total of 170 individuals with SCI (N=170).

**Interventions:** Not applicable.

**Main Outcome Measures:** Daily sleep quality was rated on a scale of 0 (worst) to 10 (best) each morning. Participants completed end-of-day diaries each night that included several HRQOL measures (Sleep Disturbance, Sleep-related Impairment, Fatigue, Cognitive Abilities, Pain Intensity, Pain Interference, Ability to Participate in Social Roles and Activities, Depression, Anxiety) and ecological momentary assessment ratings of HRQOL (pain, fatigue, subjective thinking) 3 times throughout each day.

**Results:** Multilevel models indicated that fluctuations in sleep quality (as determined by end-of-day ratings) were significantly related to next-day ratings of HRQOL; sleep quality was related to other reports of sleep (Sleep Disturbance; Sleep-related Impairment; Fatigue) but not to other aspects of HRQOL. For ecological momentary assessment ratings, nights of poor sleep were related to worse pain, fatigue, and thinking. Generally, sleep quality showed consistent associations with fatigue and thinking across the day, but the association between sleep quality and these ecological momentary assessment ratings weakened over the course of the day.

**Conclusions:** Findings highlight the important association between sleep and HRQOL for people with SCI. Future work targeting sleep quality improvement may have positive downstream effects for improving HRQOL in people with SCI.

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The global prevalence of spinal cord injury (SCI) ranges from 250 per million (Rhone-Alpes Region, France) to 906 per million (United States).[1] SCI is associated with broad and unique physiological changes, as well as secondary complications that significantly affect the health-related quality of life (HRQOL), or the mental, physical, or social well-being,[2] of these individuals.[3,4]

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Sleep difficulties are common after SCI and can include poor sleep quality, greater difficulty falling asleep, more frequent awakenings, and less satisfying sleep.[4-8] In fact, there is evidence to suggest that sleep disorders are more common in SCI than in the general population. This includes high rates of sleep disordered breathing (including objective sleep apnea), periodic leg movements (including restless leg syndrome), circadian rhythm sleep-wake disorder, and insomnia in people with SCI.[5] Not surprisingly, there is evidence to suggest that poor sleep is linked to different aspects of HRQOL in SCI including physical (ie, pain, fatigue) and mental health (ie, depressed mood, anxiety).[4-7,9,10]

Regarding physical health, current evidence across clinical and healthy samples suggests that sleep disturbance plays a major role in the development and maintenance of pain[4] and that poor sleep is associated with greater pain intensity.[6,7,9] In particular, pain can have a devastating effect on HRQOL, mental and physical health, physical functioning, and social participation in people with SCI.[11-13] Pain also appears to be exacerbated by and related to sleep disturbance in SCI.[4,6,7,9] Fatigue is also common in people with SCI,[14,15] but little is known about the day-to-day and moment-to-moment experience of fatigue in persons with SCI.

For mental health, studies in a mixed physical disability sample (that included persons with SCI) and in people with SCI have demonstrated that both anxiety and depression have significant associations with concurrent sleep disturbance/difficulties[4,10] and are evident over a 24-month time frame.[10] Furthermore, there is evidence that sleep is associated with cognition in other samples (both healthy samples and clinical samples).[16,17] Although we are unaware of studies that have examined associations between sleep and cognition in SCI, studies of cognition in SCI report that there are problems with attention and concentration, processing speed, learning, memory, and executive functioning[18,19] and suggest that these cognitive problems are associated with worse self-care and community reintegration.[18]

In addition, although we know that there are many barriers to social and community participation for people with SCI,[20] we are unaware of any studies that have examined the relationship of sleep and social participation.

Our understanding of the relationship between sleep and HRQOL in SCI is also hindered by methodological limitations. Many of the existing studies in SCI are limited by small sample sizes and other methodological shortcomings. Most studies in SCI use a onetime assessment of HRQOL; the use of in situ assessment methods, such as ecological momentary assessment, is extremely limited in SCI research. Thus, much of the current body of evidence on sleep and HRQOL cannot speak to day-to-day experiences of symptoms and functioning, the covariance of symptoms with functioning, or within-person processes that can bring clarity to the relationship between sleep and HRQOL. A clear understanding of how sleep is associated with the day-to-day fluctuations in pain, fatigue, anxiety, depression, cognitive function, and social participation is necessary to understand how sleep affects the daily lives of people with SCI.

*List of abbreviations:*

**HRQOL** health-related quality of life
**PROMIS** Patient-Reported Outcome Measurement Information System
**SCI** spinal cord injury

To address current gaps in our understanding of how day-to-day fluctuations in sleep quality affect HRQOL, we used a data collection methodology that combined ecological momentary assessment (real-time self-report) and end-of-day diaries (proximal self-report of same-day experiences) to assess sleep and HRQOL data over 7 days. These methods are feasible in people with disability,[21-23] minimize recall bias, increase measurement reliability, and capture within-people variability in real time in the natural environment.[22,24] The primary aim of this analysis was to assess how within-people changes in sleep quality affect next-day HRQOL of individuals with SCI, including their pain, fatigue, pain, mental health (anxiety, depression), cognitive function, and social participation. We also examined momentary associations between sleep quality and next-day real-time ratings of pain, fatigue, and subjective reports of thinking clarity.

# Methods

## Participants

### Inclusion criteria

Participants were adults (18y or older) who experienced a medically documented SCI.[25] Additional inclusion criteria included ability to comprehend and speak English, ability to provide informed consent, ability to operate the study wristband monitor (either independently or have someone available to assist with its operation), and willingness to complete all study assessments. 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 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent was obtained from all participants included in the study.

### Exclusion criteria

Persons who were currently receiving inpatient care or intensive outpatient physical therapy were excluded.

### Classification of SCI

Participants were classified as having paraplegia/tetraplegia and complete/incomplete injury according to International Standards for Neurological Classification of SCI.[26]

Participants were recruited at 2 academic medical centers. Participants were recruited from already established research registries at both sites, from medical record review, and from clinic and community settings (eg, study flyers, websites, community events). Participants were contacted in person, by mail, by phone, or by email and were provided with information about the research study. All data were collected in accordance with each site's local Institutional Review Board.

## Study procedures

The study consisted of a baseline visit, 7 days of home monitoring, and a follow-up visit. Over the home monitoring period, participants wore the E4 wristband[a] (described below) and completed the ecological momentary assessment and end-of-day assessments daily (see study schematic, fig 1).

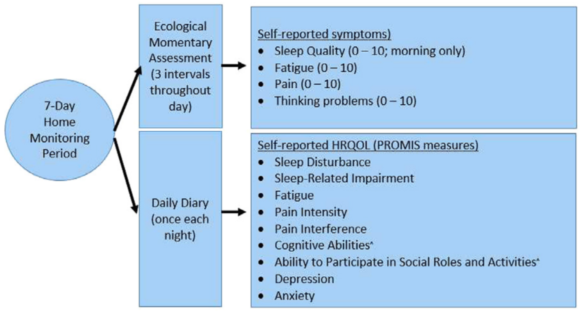


**Fig 1** Study design.

## Demographic variables

At the baseline visit, participants completed a self-report demographic survey of age, sex, education, ethnicity, race, marital status, living situation, household income, work status, mobility, and injury (level, completeness, cause).

## Ecological momentary assessments

Participants completed ecological momentary assessments 3 times each day (morning, afternoon, evening) on a cell phone or on a paper diary (for those without internet/reliable cell service) during the 7-day monitoring period. The timing of the morning assessment was based on the participants' self-reported wake time. The 2 remaining assessments occurred at 4-hour successive intervals after the morning assessment. Participants reported ratings of pain, fatigue, and subjective thinking problems for all ecological momentary assessments. The morning ecological momentary assessment included 3 additional questions regarding the time the participant went to bed the previous night, the time the participant woke up, and how refreshed the participant felt on waking (sleep quality: higher scores indicate more refreshed sleep). A scale of 0-10 was used for all questions that required the participants to rate their experience (see below for the pain, fatigue, and subjective thinking questions).

### Pain

What is your level of pain right now? Please rate on a scale from 0-10 where 0=no pain and 10=worst pain imaginable.

### Fatigue

What is your level of fatigue right now? Please rate on a scale of 0-10, where 0=no fatigue and 10=extremely severe fatigue.

### Thinking

How is your thinking right now? Please rate on a scale of 0-10, where 0=no thinking problems (clear and sharp) to 10=extremely severe thinking problems (unclear and foggy).

The pain and fatigue items were adapted from the widely used Brief Pain Inventory[27] and the Brief Fatigue Inventory,[28] respectively. These items have data supporting their reliability in other ecological momentary assessment studies, including in people with SCI.[22,29] The thinking item was developed to be concordant with the other 2 items to limit burden and allow for straightforward statistical comparisons.

## End-of-day assessments

At the end of each day of the 7-day home monitoring period, participants were prompted to complete the daily end-of-day diaries, which measured the participants' daily HRQOL. This assessment was composed of 9 Patient-Reported Outcome Measurement Information System (PROMIS) short form surveys[30,31] adapted for daily use and measures of daily intake of caffeine, nicotine, alcohol, and sleep aids. The measures included were PROMIS Sleep Disturbance (perception of sleep quality, sleep depth, and restoration related to sleep), PROMIS Sleep-related Impairment (examines difficulties when awake resulting from impaired sleep and feelings of tiredness and alertness), PROMIS Fatigue (duration, intensity, and frequency of fatigue, as well as the effect of fatigue on daily life activities), PROMIS Pain Intensity (measures pain severity), PROMIS Pain Interference (assesses the effects of pain on a range of daily life activities), PROMIS Cognitive Function Abilities (evaluates one's perception of their ability to perform memory, thinking, and tracking tasks), PROMIS Ability to Participate in Social Roles and Activities (gauges one's involve in social activities), PROMIS Depression (explores feelings of sadness and hopelessness), and PROMIS Anxiety (examines fear, anxiousness, hyperarousal, and potential anxiety-related symptoms). Each short form ranged from 3-8 questions. The short forms were also modified to capture daily experiences by changing the instructions' time frame from "In the past 7 days . . ." to "Think about how you feel today . . . ." PROMIS items were rated on a 5-point Likert-type scale, and responses were summed and converted to a T score (mean, 50± 10). A higher T score demonstrated worse outcomes for all of the PROMIS measures used except for the PROMIS Cognitive Function Abilities and PROMIS Abilities to Participate in Social Roles and Activities, where a higher T score demonstrated better outcomes. Although the original PROMIS measures have extensive data to support their reliability and validity in chronic conditions,[30,31] the internal consistency of these adapted versions in our sample ranged from very good to excellent (Cronbach $\alpha$ ranged from 0.87 for Sleep Disturbance to 0.94 for Cognitive Abilities), which is consistent with other published findings that report the use of a recall period vs no recall period has "little to no effect" on response scores.[32]

## Sleep quality

Sleep quality was assessed with a single item, "How refreshed did you feel when you woke up this morning?" The item was rated using a scale of 0-10, where 0=totally unrefreshed (low energy) and 10=totally refreshed (energetic, ready to start the day). It was asked each day of the 7-day home monitoring period during the morning set of ecological momentary assessment questions. The morning questions were scheduled to be administered at a self-reported wake time to minimize the recall bias for the participants' assessments of their sleep quality. This item was adapted from the Consensus Sleep Diary item on refreshed sleep[33] to be concordant with the other ecological momentary assessment items and to allow for straightforward statistical comparisons.

## Objective sleep

Study participants wore the E4 wristband during the home monitoring period. This E4 collects physiological data that are highly correlated with sleep[34-36]: heart rate variability, electrodermal activity, body movement (accelerometer data), and skin temperature data.[37] We examined sleep duration (denoted by participants marking bedtime and wake times) as well as a measure of heart rate variability, blood volume pulse (ie, the mean of the mean time between systolic peaks and diastolic peaks in a pulse wave in 5-minute windows, which provides a measure of heart rate variability related to emotional arousal), and electrodermal activity (the skewness of the maximum frequency of the phasic components of the electrodermal activity signal in 5-minute windows, which provides a marker of sympathetic nervous system arousal a marker of sympathetic nervous system arousal[38]). The E4 wristband does not have established algorithms for evaluating sleep in the general population or in individuals with SCI; thus findings for these variables should be considered preliminary and should be interpreted with caution.

## Data analyses

### Preliminary analyses

Descriptive statistics were calculated to check for assumptions underlying the primary analyses.

### Primary analyses

We assessed the between- and within-people effects of sleep (sleep quality, sleep duration, and proxy measures of heartrate variability and electrodermal activity) on HRQOL. For the analyses of end-of-day assessments of PROMIS domains, restricted maximum likelihood multilevel models with random effects for participant were used to examine between- and within-patient effects. In addition, temporal autocorrelation was handled using an autoregressive-1 structure, and restricted maximum likelihood estimation was used with the Kenward-Roger method for degrees of freedom and SEs. In these linear models, the end-of-day PROMIS scores from each day were outcomes. Between-participant effects were examined using a "weekly average" of sleep quality; within-participant effects were analyzed with a day-to-day variability term calculated as the sleep quality score from that day minus the individual's weekly average. Separate models were run for each sleep variable as well as for each PROMIS domain, and analyses adjusted for age, sex, education, and injury classification. On any given day, significant between-person effects indicate a person with worse sleep over the course of the week (relative to a person with better sleep over the course of the week) has worse HRQOL. Significant within-person effects indicate a person with lower sleep on a given day has worse HRQOL on that day regardless of what their average sleep was throughout the week.

A separate strategy was used for the ecological momentary assessment measures of pain, fatigue, and thinking problems measured in the morning, early afternoon, and late afternoon. These restricted maximum likelihood multilevel mixed models included random effects for participant and day. Main effects were included for sleep and time (ie, morning vs early afternoon vs late afternoon). A sleep quality-by-time interaction was also included to assess if the effect of sleep quality on HRQOL varied throughout the day. Separate models were conducted for the 4 different sleep variables. These models also controlled for age, sex, education, and injury classification. Statistical analyses were performed using SAS version 9.4.[b]

## Sample size considerations

The study sample size of 170 had 80% power to detect Pearson correlation coefficient of 0.21, with 2-sided $\alpha$=0.05. Thus, this study was powered to detect small relationships (ie, $\rho \sim 0.21$) between sleep quality and HRQOL.

# Results

Table 1 provides descriptive data the sample (N=170) as well as for the ecological momentary and end-of-day assessments for each day of the home monitoring period. Mean ecological momentary assessment scores are shown in figure 2. For the end-of-day analyses of the 170 people included in this analysis, there were a total of 1190 potential study visits (7 per participant). There was a total of 858 completed visits (72% completion). Visits without the end-of-day assessment for HRQOL or first morning assessment for sleep quality were excluded. For the ecological momentary assessment analyses, there were a total of 3570 potential assessments (21 per participant) and a total of 2967 completed assessments (83% completion). Among these included visits, there were no missing data for variables of interest (ie, age, sex, education, injury classification). Rates for missing data were comparable with other studies and ranged from ~20%-25% on any given day, with the higher rates (ie, ~25%) occurring on the last day of the study; missing data were distributed equally across different disease classification groups.

End-of-day assessment results are shown in tables 2-5. For both of these tables, each column contains estimates from a linear mixed model where the PROMIS domain for that column is the outcome; estimates for fixed effects are shown in rows (ie, difference in PROMIS domain per 1-point increase in weekly average of sleep quality). Estimates that are statistically significant are indicated with an asterisk. Regarding sleep quality (see tables 2 and 4), the end-of-day assessments indicated that better sleep quality was associated with better HRQOL for all of the assessed domains (between-participants' effects); within an individual, sleep quality was related to other reports of sleep (Sleep Disturbance, Sleep-related Impairment, Fatigue) and cognition (Cognitive Abilities) but not to any other aspects of HRQOL (within-participants' effects). Random-effect estimates for these end-of-day analyses indicated that there was greater between-than within-person variability for most domains (eg, Depression 52.91% between vs 14.46% within); sleep domains showed the reverse (Sleep Disturbance: 38.83% within vs 16.00% between; Sleep-related Impairment: 43.86% within vs 30.52% between). There were generally no significant associations between the objective sleep variables and HRQOL (see tables 3 and 5); the only exceptions were significant within- and between-participants effects between sleep duration and sleep-related impairment, as well as the significant positive association between sleep duration and social participation; better average sleep duration was associated with less sleep-related impairment and greater social participation (between-participants' effects), and within an individual, a night of more sleep was associated with less sleep-related impairment the following day (within-participants' effects).

For the ecological momentary assessment assessments of sleep quality (table 6), better sleep quality was associated with less pain intensity, less fatigue, and better subjective thinking. In general, the relationships between sleep quality and these real-time reports of daytime symptoms (pain, fatigue, subjective thinking) were

**Table 1** Demographic data and descriptive data for end-of-day and ecological momentary assessment data (N=170)

| Variable | Distribution |
|---|---|
| Age (y), mean ± SD (median) | 49.3±14.77 (49.5) |
| Female, n (%) | 58 (34) |
| Education, n (%) | |
| Grades 9-12, without graduating | 4 (2) |
| GED or high school graduate | 16 (9) |
| Some college credit, but <1 y | 34 (20) |
| Associate's degree (eg, AA, AS) | 27 (16) |
| Bachelor's degree (eg, BA, AB, BS) | 53 (31) |
| Master's degree (eg, MA, MS, MEng, Med, MSW, MBA) | 20 (12) |
| Professional or doctorate degree (eg, MD, DDS, DVM, JD, LLB, PhD, EdD) | 9 (5) |
| Vocational degree/certificate | 6 (4) |
| Unknown | 1 (1) |
| Injury classification, n (%) | |
| Paraplegia | 66 (39) |
| Tetraplegia | 74 (44) |
| Unknown/missing | 30 (18) |
| Weekly average for end-of-day assessments, mean ± SD* | |
| PROMIS Sleep Disturbance | 48.7±6.18 |
| PROMIS Sleep-related Impairment | 48.7±8.24 |
| PROMIS Fatigue | 48.4±8.19 |
| PROMIS Pain Intensity | 44.6±7.92 |
| PROMIS Pain Interference | 50.7±8.10 |
| PROMIS Social Participation | 51.0±8.90 |
| PROMIS Depression | 50.0±8.10 |
| PROMIS Anxiety | 50.0±8.36 |
| PROMIS Cognitive Abilities | 52.4±8.68 |
| Daily average for ecological momentary assessments, mean ± SD† | |
| Pain | 4.1±5.75 |
| Fatigue | 2.7±1.67 |
| Thinking problems | 1.6±1.61 |

Abbreviation: GED, General Equivalency Diploma.
* Scores are on a T metric (mean, 50±10).
† Ratings are on a scale of 0-10. For * and †, higher scores indicate more of the named construct (ie, higher scores for negatively worded concepts indicate poorer health-related quality of life, whereas higher scores for positively worded concepts indicate better health-related quality of life).

strongest in the morning but attenuated over the course of the day (fig 3). Random-effect estimates for these ecological momentary assessments of sleep quality (see table 6) indicated strongest effects between participants and stronger effects for time of day (within a day) relative to day within a week. Regarding the objective sleep variables and HRQOL (table 7), longer sleep duration was associated with less pain intensity, less fatigue, and better subjective thinking regardless of time of day; there were no significant effects for the other objective sleep variables and HRQOL over the course of the day.

## Discussion

The primary aim of this article was to examine the effect of sleep quality on HRQOL (fatigue, pain, anxiety, depression, cognitive function, social participation) in people with SCI. We used both end-of-day and ecological momentary assessments to examine the relationship between sleep quality and different aspects of HRQOL both over the course of a week and over the course of a day (including whether or not some times of day are more affected than others).

Not surprisingly, over the course of the week, better sleep quality and longer sleep duration was associated with better HRQOL. This finding is consistent with numerous reports in the literature that have demonstrated a negative relationship between sleep quality and different aspects of HRQOL. Specifically, findings are consistent with previous studies in people with SCI[4,9,39,40] as well as in several other clinical and nonclinical populations (eg, fibromyalgia,[41,42] low back pain[43], information technology and extended care nursing home employees,[44] university students,[45] older adults[46]).

When we examined day-to-day associations between sleep quality and HRQOL, we found that sleep quality and duration was related to other measures of sleep and/or fatigue but not to other aspects of HRQOL (ie, pain, depression, anxiety, social participation, cognition). When these findings are considered in the context of the existing literature, the relationships between sleep quality/duration and *next-day sleep and/or fatigue* are largely consistent with other published literature in other populations (ie, chronic fatigue syndrome,[47] irritable bowel syndrome,[48] restless leg syndrome,[49] older adults[50]). Yet, the absence of relationships between sleep and *next-day pain intensity and pain interference* in people with SCI is largely inconsistent with published findings in other

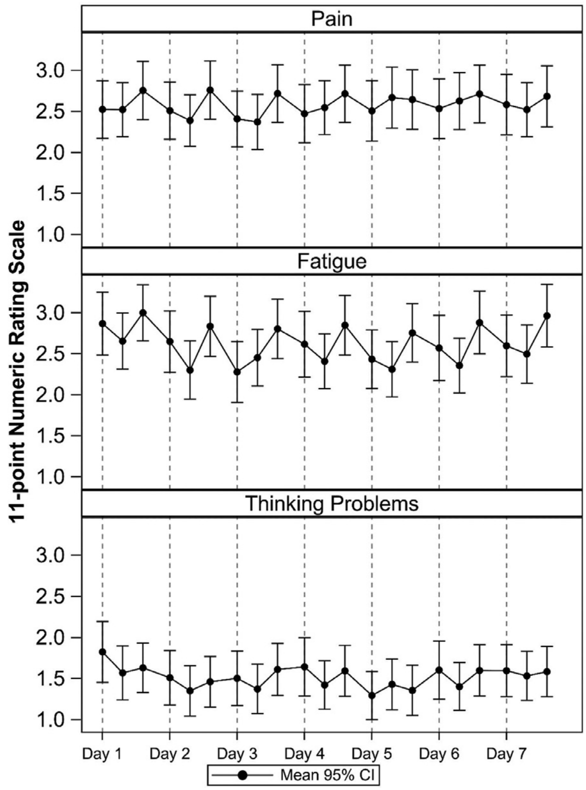


**Fig 2** Average pain, fatigue, and thinking problem scores over 7 days. CI, confidence interval.

populations (eg, irritable bowel syndrome,[48] osteoarthritis,[51] and chronic low back pain[43]).

Regarding mental HRQOL and sleep quality, we found that better sleep quality is related to less depressive and anxiety symptoms in our sample of people with SCI. The literature in other clinical populations is mixed. Some studies have found relationships between sleep quality and anxiety (eg, young women,[52] Parkinson disease,[53] irritable bowel syndrome[48]) or depression (eg, young women[52]), whereas others have not found relationships with either anxiety (eg, older adults[50]) or depression (eg, older adults,[50] irritable bowel syndrome[48]). In addition, we did not see relationships between objective sleep variables and mental HRQOL. Thus, more research is needed to better understand the relationship between sleep quality and anxiety/depression more generally and why this relationship is present in some clinical populations (including SCI) but not others.

The absence of relationships between sleep and self-reported cognition in people with SCI is consistent with findings in older adults[50] and Parkinson disease[53] but inconsistent with reports in restless leg syndrome.[49] The association between sleep and social participation was present for sleep duration but absent for sleep quality. In the broader literature, an association between sleep and social participation has been reported for restless leg syndrome[49] but not for Parkinson disease.[53] Given the mixed findings both within this study and in the literature and the results of our analyses, future work should further explore the relationships between sleep quality and social participation in people with SCI.

When diurnal patterns were examined, we found that the relationship between sleep quality and daytime symptoms (pain, fatigue, thinking) was strongest in the morning but attenuated over

**Table 2** Effect of sleep quality on physical HRQOL

| Variable | PROMIS Sleep Disturbance β (95% CI) | PROMIS Sleep-related Impairment β (95% CI) | PROMIS Fatigue β (95% CI) | PROMIS Pain Intensity β (95% CI) | PROMIS Pain Interference β (95% CI) |
|---|---|---|---|---|---|
| Intercept | 63.63 | 64.99 | 63.51 | 57.39 | 60.05 |
| Sleep quality | | | | | |
| Weekly average (per 1 point) | −2.26 (−2.76 to −1.77)* | −2.82 (−3.45 to −2.19)* | −2.47 (−3.13 to −1.81)* | −1.83 (−2.52 to −1.14)* | −1.91 (−2.63 to −1.19)* |
| Day-to-day variability (per 1 point) | −0.90 (−1.11 to −0.69)* | −0.66 (−0.88 to −0.43)* | −0.51 (−0.70 to −0.31)* | −0.06 (−0.19 to 0.06) | −0.15 (−0.30 to 0.00) |
| Covariates | | | | | |
| Age (per 1y) | 0.00 (−0.06 to 0.05) | −0.02 (−0.09 to 0.05) | −0.03 (−0.10 to 0.05) | 0.00 (−0.07 to 0.08) | 0.06 (−0.02 to 0.14) |
| Sex (female vs male) | −1.04 (−2.70 to 0.62) | 0.24 (−1.89 to 2.36) | 0.62 (−1.61 to 2.86) | −1.65 (−4.00 to 0.70) | −0.20 (−2.64 to 2.24) |
| Education (college vs <college) | −0.09 (−1.81 to 1.64) | 2.27 (0.07 to 4.47)† | 1.35 (−0.96 to 3.65) | −1.09 (−3.51 to 1.33) | −0.59 (−3.11 to 1.92) |
| Injury classification (tetraplegia vs paraplegia) | −1.59 (−3.39 to 0.21) | −1.93 (−4.23 to 0.36) | −1.67 (−4.08 to 0.74) | −1.43 (−3.94 to 1.09) | −1.63 (−4.25 to 0.99) |
| Injury classification (unknown/missing vs paraplegia) | −0.25 (−2.47 to 1.96) | 1.39 (−1.44 to 4.22) | 1.77 (−1.20 to 4.75) | −1.10 (−4.22 to 2.03) | 0.25 (−3.00 to 3.49) |
| Random effects (% of covariance estimates) | | | | | |
| Participant | 16.00 | 30.52 | 35.22 | 45.73 | 49.27 |
| Day | 0.11 | 0.12 | 0.22 | 0.22 | 0.04 |
| Residual | 38.83 | 43.86 | 36.26 | 14.44 | 19.48 |

NOTE. Higher scores indicate more of the named construct (ie, higher scores for negatively worded concepts indicate poorer health-related quality of life, whereas higher scores for positively worded concepts indicate better health-related quality of life).
Abbreviation: CI, confidence interval.
* $P<.0001$.
† $P<.05$.

**Table 3** Effect of objective sleep variables (as measured by the E4 wristband) on physical HRQOL

| Variable | PROMIS Sleep Disturbance β (95% CI) | PROMIS Sleep-related Impairment β (95% CI) | PROMIS Fatigue β (95% CI) | PROMIS Pain Intensity β (95% CI) | PROMIS Pain Interference β (95% CI) |
|---|---|---|---|---|---|
| Sleep duration | | | | | |
| Weekly average | −0.11 (−1.03 to 0.81) | −1.27 (−2.46 to −0.07)* | −0.71 (−1.85 to 0.42) | 0.17 (−0.93 to 1.28) | −0.53 (−1.67 to 0.62) |
| Day-to-day variability | −0.31 (−0.71 to 0.10) | −0.72 (−1.13 to −0.31)* | −0.31 (−0.68 to 0.06) | 0.00 (−0.22 to 0.22) | 0.05 (−0.23 to 0.33) |
| Heartrate variability signal | | | | | |
| Weekly average | −0.07 (−9.49 to 9.35) | 1.02 (−11.32 to 13.37) | 1.25 (−10.37 to 12.86) | −9.77 (−20.82 to 1.29) | −3.99 (−15.60 to 7.62) |
| Day-to-day variability | 5.07 (−1.80 to 11.95) | 1.55 (−5.63 to 8.73) | −0.99 (−7.31 to 5.33) | 0.52 (−3.25 to 4.29) | −2.78 (−7.54 to 1.98) |
| Electrodermal activity signal | | | | | |
| Weekly average | −0.08 (−0.77 to 0.61) | −0.05 (−0.95 to 0.84) | −0.14 (−0.98 to 0.70) | 0.23 (−0.57 to 1.03) | −0.56 (−1.39 to 0.27) |
| Day-to-day variability | 0.11 (−0.22 to 0.43) | 0.14 (−0.21 to 0.48) | 0.22 (−0.09 to 0.52) | 0.09 (−0.09 to 0.28) | 0.15 (−0.08 to 0.38) |

NOTE. Higher scores indicate more of the named construct (ie, higher scores for negatively worded concepts indicate poorer health-related quality of life, whereas higher scores for positively worded concepts indicate better health-related quality of life).
Abbreviation: CI, confidence interval.
* P<.05.

**Table 4** Effect of sleep quality on mental and social HRQOL

| Variable | PROMIS Depression β (95% CI) | PROMIS Anxiety β (95% CI) | PROMIS Cognitive Abilities β (95% CI) | PROMIS Social Participation β (95% CI) |
|---|---|---|---|---|
| Intercept | 65.24 | 64.78 | 40.96 | 44.95 |
| Sleep quality | | | | |
| Weekly average (per 1 point) | −1.66 (−2.40 to −0.91)* | −1.72 (−2.47 to −0.97)* | 2.29 (1.57 to 3.02)* | 2.14 (1.36 to 2.92)* |
| Day-to-day variability (per 1 point) | −0.06 (−0.18 to 0.07) | −0.11 (−0.24 to 0.02) | 0.28 (0.12-0.45)* | 0.06 (−0.08 to 0.20) |
| Covariates | | | | |
| Age (per 1y) | −0.10 (−0.19 to −0.02)† | −0.09 (−0.18 to −0.01)† | −0.05 (−0.13 to 0.03) | −0.12 (−0.20 to −0.03)† |
| Sex (female vs male) | −1.27 (−3.81 to 1.27) | 0.02 (−2.53 to 2.57) | −0.45 (−2.92 to 2.02) | −0.21 (−2.87 to 2.46) |
| Education (college vs <college) | −0.35 (−2.99 to 2.29) | 0.03 (−2.61 to 2.67) | −0.45 (−3.00 to 2.10) | −1.10 (−3.84 to 1.64) |
| Injury classification (tetraplegia vs paraplegia) | 0.20 (−2.53 to 2.93) | −1.14 (−3.88 to 1.60) | 2.19 (−0.46 to 4.84) | −0.42 (−3.27 to 2.43) |
| Injury classification (unknown/missing vs paraplegia) | 1.42 (−1.95 to 4.79) | 2.29 (−1.10 to 5.67) | −1.68 (−4.96 to 1.61) | −0.11 (−3.64 to 3.43) |
| Random effects (% of covariance estimates) | | | | |
| Participant | 52.91 | 53.89 | 48.49 | 59.19 |
| Day | 0.37 | 0.25 | 0.19 | 0.18 |
| Residual | 14.46 | 16.15 | 24.42 | 17.23 |

NOTE. Higher scores indicate more of the named construct (ie, higher scores for negatively worded concepts indicate poorer health-related quality of life, whereas higher scores for positively worded concepts indicate better health-related quality of life).
Abbreviation: CI, confidence interval.
* $P<.0001$.
† $P<.05$.

**Table 5** Effect of objective sleep variables (as measured by the E4 wristband) on mental and social HRQOL

| Variable | PROMIS Depression β (95% CI) | PROMIS Anxiety β (95% CI) | PROMIS Cognitive Abilities β (95% CI) | PROMIS Social Participation β (95% CI) |
|---|---|---|---|---|
| Sleep duration | | | | |
| Weekly average | 0.60 (−0.55 to 1.75) | 0.67 (−0.46 to 1.80) | 0.65 (−0.59 to 1.89) | 1.23 (0.03-2.43)* |
| Day-to-day variability | −0.09 (−0.33 to 0.15) | −0.13 (−0.37 to 0.10) | 0.17 (−0.13 to 0.46) | 0.23 (−0.02 to 0.47) |
| Heartrate variability signal | | | | |
| Weekly average | 2.60 (−9.07 to 14.26) | 1.25 (−10.22 to 12.71) | −3.37 (−15.97 to 9.23) | 1.83 (−10.45 to 14.11) |
| Day-to-day variability | 0.30 (−3.79 to 4.39) | 3.46 (−0.57 to 7.50) | −1.05 (−6.08 to 3.97) | 2.30 (−1.83 to 6.44) |
| Electrodermal activity signal | | | | |
| Weekly average | 0.72 (−0.10 to 1.55) | 0.01 (−0.82 to 0.83) | 0.48 (−0.43 to 1.38) | 0.65 (−0.22 to 1.53) |
| Day-to-day variability | 0.11 (−0.09 to 0.31) | 0.13 (−0.07 to 0.32) | −0.15 (−0.39 to 0.10) | −0.14 (−0.34 to 0.06) |

Abbreviation: CI, confidence interval.
* $P<.05$.

the course of the day. This finding is consistent with previous research in other populations that have reported that *pain* is heightened after a night of poor sleep but that the effect dissipates across the course of a day.[43,51,54] This finding is also consistent with research in other populations that have reported that *fatigue* is heightened after a night of poor sleep but that the effect dissipates across the course of a day.[50,51] The findings for these diurnal patterns highlight the importance of considering the timing of self-reported assessments when designing observational studies and clinical trials in people with SCI.

The patterns of findings between sleep and HRQOL was not consistent across the self-reported sleep variables (sleep quality) and the objective sleep variables (measured by the E4 device). Although these discrepancies may be because of method variance (ie, self-report correlates more highly with self-report vs objective measures), we suspect that this is more likely a limitation of the lack of established sleep algorithms for this device and/or challenges that a wrist-worn device may have in capturing important sleep variables in a population with limited mobility and neurophysiological changes that are associated with this type of injury.

## Study limitations

Although these are the first findings to examine diurnal relationships between sleep quality and HRQOL in people with SCI, these findings need to be interpreted within the context of the study

**Table 6** Effect of sleep quality on HRQOL throughout the day

| Variable | Pain β (95% CI) | Fatigue β (95% CI) | Thinking Problems β (95% CI) |
|---|---|---|---|
| Intercept | 4.00 | 4.21 | 2.12 |
| Main effects | | | |
| Sleep quality (per 1 point) | −0.08 (−0.12 to −0.05)* | −0.26 (−0.30 to −0.22)* | −0.15 (−0.19 to −0.12)* |
| Time: early afternoon vs morning | −0.29 (−0.53 to −0.05)† | −1.03 (−1.33 to −0.74)* | −0.49 (−0.72 to −0.26)* |
| Time: late afternoon vs morning | −0.07 (−0.32 to 0.17) | −0.64 (−0.94 to −0.34)* | −0.47 (−0.70 to −0.24)* |
| Sleep quality × time interaction | | | |
| Early afternoon vs morning | 0.05 (0.01-0.09)† | 0.15 (0.10-0.19)* | 0.06 (0.03-0.10)† |
| Late afternoon vs morning | 0.05 (0.01-0.08)† | 0.16 (0.11-0.20)* | 0.08 (0.04-0.11)* |
| Covariates | | | |
| Age (per 1y) | 0.00 (−0.02 to 0.01) | 0.00 (−0.02 to 0.01) | 0.01 (−0.01 to 0.02) |
| Sex (female vs male) | −0.30 (−0.89 to 0.29) | 0.51 (0.02-1.00)† | 0.36 (−0.14 to 0.85) |
| Education (college vs <college) | −0.41 (−1.01 to 0.19) | 0.12 (−0.38 to 0.62) | 0.24 (−0.26 to 0.74) |
| Injury classification (tetraplegia vs paraplegia) | −0.74 (−1.35 to −0.12)† | −0.47 (−0.98 to 0.05) | −0.33 (−0.85 to 0.18) |
| Injury classification (unknown/missing vs paraplegia) | −0.20 (−0.99 to 0.59) | 0.05 (−0.61 to 0.71) | 0.15 (−0.51 to 0.81) |
| Random effects (% of covariance estimates) | | | |
| Participant | 3.20 | 2.09 | 2.18 |
| Day | 0.15 | 0.59 | 0.39 |
| Residual | 1.16 | 1.72 | 1.05 |

NOTE. Higher scores indicate more of the named construct (ie, higher scores for negatively worded concepts indicate poorer health-related quality of life, whereas higher scores for positively worded concepts indicate better health-related quality of life).
Abbreviation: CI, confidence interval.
* $P<.0001$.
† $P<.05$.

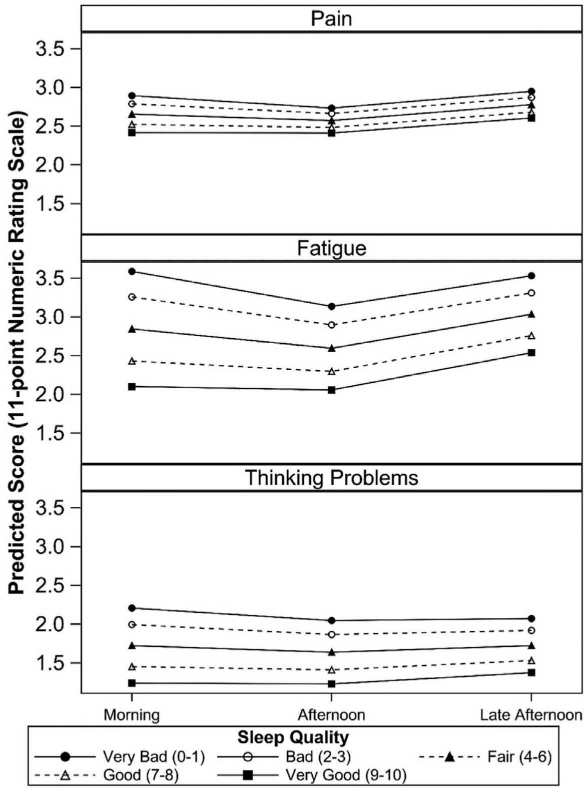


**Fig 3** Interactions between time of day and symptoms.

limitations. First, sleep quality was assessed via self-report. An examination of objective measures of sleep quality may yield different results, as has been demonstrated in previous studies in other clinical populations.[55] In addition, our sample was generally high functioning and well-educated relative to the broader population with SCI, limiting the generalizability to those with more severe injuries and those that are less well educated. Furthermore, although our sample demonstrated substantial within- and between-people variability for the variables of interest, it is possible that our findings may be different in a sample that includes more individuals with more impaired sleep. In addition, our study did not evaluate the absence/presence of sleep disorders. Future research should also examine the relationship between sleep quality and HRQOL for people with SCI and different clinical sleep diagnoses. In addition, future work should consider a more rigorous sleep assessment that includes traditional objective measures of sleep (ie, polysomnography) or using wrist-worn devices that have established clinical utility in people in the general population, if not also in people with SCI. Furthermore, ecological momentary assessment is a relatively intense data collection procedure that can be burdensome on the participant, and this study design has also been associated with behavioral activity (ie, the tendency for an individual to change one's behavior when they are being monitored).[21,23,56,57] Although these concerns are valid, given that it does not take very long for participants to habituate to the device, we hope that the overall effect is minimal. In addition, we believe the benefits of this type of study design outweigh the weaknesses. Specifically, benefits—which include the ability to examine temporal relationships among symptoms, a data collection approach that minimizes recall bias, and a study design that

**Table 7** Effect of objective sleep variables (as measured by the E4 wristband) on HRQOL throughout the day

| Variable | | Pain β (95% CI) | Fatigue β (95% CI) | Thinking Problems β (95% CI) |
|---|---|---|---|---|
| Sleep duration | Main effects | | | |
| | Sleep quality (per 1 point) | −0.06 (−0.12 to −0.01)* | −0.20 (−0.28 to −0.12)† | −0.08 (−0.14 to −0.02)* |
| | Time: early afternoon vs morning | −0.42 (−0.98 to 0.13) | −0.68 (−1.46 to 0.09) | 0.04 (−0.54 to 0.62) |
| | Time: late afternoon vs morning | −0.40 (−0.96 to 0.16) | −0.39 (−1.16 to 0.39) | −0.03 (−0.62 to 0.55) |
| | Sleep quality × time interaction | | | |
| | Early afternoon vs morning | 0.05 (−0.02 to 0.12) | 0.06 (−0.04 to 0.16) | −0.02 (−0.10 to 0.05) |
| | Late afternoon vs morning | 0.08 (0.00-0.15)* | 0.08 (−0.02 to 0.18) | −0.00 (−0.08 to 0.07) |
| Heartrate variability signal | Main effects | | | |
| | Sleep quality (per 1 point) | −0.59 (−1.43 to 0.25) | −0.31 (−1.55 to 0.93) | 0.51 (−0.46 to 1.48) |
| | Time: early afternoon vs morning | −0.71 (−1.45 to 0.03) | −0.84 (−1.92 to 0.24) | −0.06 (−0.86 to 0.74) |
| | Time: late afternoon vs morning | −0.21 (−0.96 to 0.54) | −0.33 (−1.43 to 0.76) | −0.27 (−1.10 to 0.56) |
| | Sleep quality × time interaction | | | |
| | Early afternoon vs morning | 0.81 (−0.09 to 1.72) | 0.77 (−0.55 to 2.09) | −0.09 (−1.07 to 0.88) |
| | Late afternoon vs morning | 0.48 (−0.43 to 1.40) | 0.69 (−0.64 to 2.02) | 0.28 (−0.73 to 1.30) |
| Electrodermal activity signal | Main effects | | | |
| | Sleep quality (per 1 point) | −0.01 (−0.05 to 0.04) | 0.03 (−0.03 to 0.10) | −0.00 (−0.05 to 0.04) |
| | Time: early afternoon vs morning | −0.09 (−0.33 to 0.14) | −0.21 (−0.55 to 0.12) | −0.14 (−0.38 to 0.10) |
| | Time: late afternoon vs morning | 0.17 (−0.07 to 0.41) | 0.44 (0.11-0.78)* | −0.04 (−0.29 to 0.20) |
| | Sleep quality × time interaction | | | |
| | Early afternoon vs morning | 0.01 (−0.05 to 0.06) | −0.00 (−0.08 to 0.07) | −0.00 (−0.06 to 0.06) |
| | Late afternoon vs morning | 0.00 (−0.05 to 0.06) | −0.06 (−0.14 to 0.02) | 0.00 (−0.05 to 0.06) |

Abbreviation: CI, confidence interval.
* $P<.05$.
† $P<.0001$.

maximizes ecological validity—likely outweigh the behavioral activation that may accompany this type of intensive study design.[56] Missing data for this type of intensive study design are common and this, as well as the potential that data are not missing at random, is also a study limitation. Regardless, our overall completion rate (72%) is consistent with completion rates for other ecological momentary assessment rates in studies in SCI (which range from 65.2-87.8).[21,23]

## Conclusions

Regardless of these limitations, our findings suggest that future work targeting improvement in sleep quality may have positive downstream effects for improving HRQOL in people with SCI. In particular, our findings support the potential utility of time-based interventions for improving sleep quality and the effect on subsequent daily functioning and highlight the importance of time of day when asking participants to provide momentary assessments of fatigue, pain, and thinking.

## Suppliers

a. E4 wristband; Empatica.
b. SAS version 9.4; SAS Institute.

## Keywords

Ecological momentary assessment; Quality of life; Rehabilitation; Sleep; Spinal cord injuries

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## Sleep and HRQOL Annotated Code for Upload

/*Code for "Daily variation in sleep quality is associated with health-related quality of life in people with spinal cord injury" Carlozzi et al Archives of Physical Medicine and Rehabilitation
Datasets:

-daily: long dataset where each row is a subject-day (maximum of 7 days). :_Mean variables are subject-level means of values across all days and are used to test between-person effects,

and :_Diff variables measure day-to-day variation (daily measure - subject-specific mean) used to test within-peron effects

-multiday: long dataset where each row is a subject-day-time (maximum of 21 assessments, 3 times per day: morning, afternoon and evening)
*/

/*Table 2A The effect of sleep quality on physical health-related quality of life (HRQOL)*/ proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model SleepDistSF_Tscore=SleepQual_Mean SleepQual_Diff Age Sex college Injury_Classification/solution ddfm=kenwardro-ger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model SleepImpSF_Tscore=SleepQual_Mean SleepQual_Diff Age Sex college Injury_Classification/solution ddfm=kenwardro-ger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model FatigueSF_Tscore=SleepQual_Mean SleepQual_Diff Age Sex college Injury_Classification/solution ddfm=kenwardro-ger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model PainIntensitySF_Tscore=SleepQual_Mean SleepQual_-Diff Age Sex college Injury_Classification/solution ddfm=ken-wardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model PainInterferenceSF_Tscore=SleepQual_Mean Sleep-Qual_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit;

/*Table 2B The effect of objective sleep variables (as measured by the E4 wristband) on physical health-related quality of life (HRQOL)*/ proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model SleepDistSF_Tscore=SleepDur_Mean SleepDur_Diff Age Sex college Injury_Classification/solution ddfm=kenwardro-ger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model SleepImpSF_Tscore=SleepDur_Mean SleepDur_Diff Age Sex college Injury_Classification/solution ddfm=kenwardro-ger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model FatigueSF_Tscore=SleepDur_Mean SleepDur_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model PainIntensitySF_Tscore=SleepDur_Mean SleepDur_-Diff Age Sex college Injury_Classification/solution ddfm=ken-wardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model PainInterferenceSF_Tscore=SleepDur_Mean Sleep-Dur_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model SleepDistSF_Tscore=HRV_Mean HRV_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");

model SleepImpSF_Tscore=HRV_Mean HRV_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model FatigueSF_Tscore=HRV_Mean HRV_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model PainIntensitySF_Tscore=HRV_Mean HRV_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model PainInterferenceSF_Tscore=HRV_Mean HRV_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model SleepDistSF_Tscore=Electrodermal_Mean Electrodermal_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model SleepImpSF_Tscore=Electrodermal_Mean Electrodermal_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model FatigueSF_Tscore=Electrodermal_Mean Electrodermal_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model PainIntensitySF_Tscore=Electrodermal_Mean Electrodermal_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model PainInterferenceSF_Tscore=Electrodermal_Mean Electrodermal_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit;

/*Table 3A The effect of sleep quality on mental and social health-related quality of life (HRQOL)*/ proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model DepressionSF_Tscore=SleepQual_Mean SleepQual_-Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model AnxietySF_Tscore=SleepQual_Mean SleepQual_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model CogAbilitiesSF_Tscore=SleepQual_Mean SleepQual_-Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model SocialParticipationSF_Tscore=SleepQual_Mean SleepQual_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit;

/*Table 3B The effect of objective sleep variables (as measured by the E4 wristband) on mental and social health-related quality of life (HRQOL)*/ proc mixed data=daily namelen=50 cl;
class study_id day Sex(ref="Male") college(ref="0") Injury_-Classification(ref="Paraplegia");
model DepressionSF_Tscore=SleepDur_Mean SleepDur_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;
random intercept/subject=study_id ;
repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model AnxietySF_Tscore=SleepDur_Mean SleepDur_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model CogAbilitiesSF_Tscore=SleepDur_Mean SleepDur_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model SocialParticipationSF_Tscore=SleepDur_Mean SleepDur_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model DepressionSF_Tscore=HRV_Mean HRV_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model AnxietySF_Tscore=HRV_Mean HRV_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model CogAbilitiesSF_Tscore=HRV_Mean HRV_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model SocialParticipationSF_Tscore=HRV_Mean HRV_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model DepressionSF_Tscore=Electrodermal_Mean Electrodermal_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model AnxietySF_Tscore=Electrodermal_Mean Electrodermal_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model CogAbilitiesSF_Tscore=Electrodermal_Mean Electrodermal_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=daily namelen=50 cl;

class study_id day Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model SocialParticipationSF_Tscore=Electrodermal_Mean Electrodermal_Diff Age Sex college Injury_Classification/solution ddfm=kenwardroger;

random intercept/subject=study_id ;

repeated day/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit;

/*Table 4A The effect of sleep quality on health-related quality of life (HRQOL) throughout the day*/ proc mixed data=multiday namelen=50 cl;

class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model Pain=SleepQual time SleepQual*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;

random intercept /subject=study_id;

repeated day(time)/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=multiday namelen=50 cl;

class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model Fatigue=SleepQual time SleepQual*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;

random intercept /subject=study_id;

repeated day(time)/subject=study_id type=ar(1);

ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=multiday namelen=50 cl;

class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");

model Cognitive=SleepQual time SleepQual*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;

random intercept /subject=study_id;

repeated day(time)/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit;

/*Table 4B The effect of objective sleep variables (as measured by the E4 wristband) on health-related quality of life (HRQOL) throughout the day*/ proc mixed data=multiday namelen=50 cl;
class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");
model Pain=SleepDur time SleepDur*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;
random intercept /subject=study_id;
repeated day(time)/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=multiday namelen=50 cl;
class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");
model Fatigue=SleepDur time SleepDur*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;
random intercept /subject=study_id;
repeated day(time)/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=multiday namelen=50 cl;
class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");
model Cognitive=SleepDur time SleepDur*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;
random intercept /subject=study_id;
repeated day(time)/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=multiday namelen=50 cl;
class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");
model Pain=HRV time HRV*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;
random intercept /subject=study_id;
repeated day(time)/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=multiday namelen=50 cl;
class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");
model Fatigue=HRV time HRV*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;
random intercept /subject=study_id;
repeated day(time)/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=multiday namelen=50 cl;
class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");
model Cognitive=HRV time HRV*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;
random intercept /subject=study_id;
repeated day(time)/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=multiday namelen=50 cl;
class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");
model Pain=Electrodermal time Electrodermal*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;
random intercept /subject=study_id;
repeated day(time)/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=multiday namelen=50 cl;
class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");
model Fatigue=Electrodermal time Electrodermal*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;
random intercept /subject=study_id;
repeated day(time)/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit; proc mixed data=multiday namelen=50 cl;
class study_id day time(ref="Morning") Sex(ref="Male") college(ref="0") Injury_Classification(ref="Paraplegia");
model Cognitive=Electrodermal time Electrodermal*time Age Sex college Injury_Classification/solution DDFM=KENWARDROGER;
random intercept /subject=study_id;
repeated day(time)/subject=study_id type=ar(1);
ods output SolutionF=SolutionF CovParms = covp; quit;