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Duration of sleep contributes to next-day pain report in the general population ☆

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Abstract

Cross-sectional research in clinical samples, as well as experimental studies in healthy adults, suggests that the experiences of pain and sleep are bi-directionally connected. However, whether sleep and pain experiences are prospectively linked to one another on a day-to-day basis in the general population has not previously been reported. This study utilizes data from a naturalistic, micro-longitudinal, telephone study using a representative national sample of 971 adults. Participants underwent daily assessment of hours slept and the reported frequency of pain symptoms over the course of one week. Sleep duration on most nights (78.0%) was between 6 and 9 h, and on average, daily pain was reported with mild frequency. Results suggested that hours of reported sleep on the previous night was a highly significant predictor of the current day's pain frequency ($Z = -7.9$, $p < .0001$, in the structural equation model); obtaining either less than 6 or more than 9 h of sleep was associated with greater next-day pain. In addition, pain prospectively predicted sleep duration, though the magnitude of the association in this direction was somewhat less strong ($Z = -3.1$, $p = .002$, in the structural equation model). Collectively, these findings indicate that night-to-night changes in sleep affect pain report, illuminating the importance of considering sleep when assessing and treating pain.

Keywords: Pain; Sleep

1. Introduction

Persistent pain is a critical national health problem, accounting for hundreds of billions of dollars in healthcare costs, lost productivity, diminished quality of life, and early mortality [9,12,20,33]. Given pain's adverse impact, the identification of risk factors for developing painful conditions, or of factors that magnify adverse pain-related outcomes has become increasingly important. Of particular interest are modifiable risk factors that might serve as intervention targets; one such potentially important factor is sleep [29]. Recent reviews have highlighted the contribution of disturbed sleep to the experience of pain, although the paucity of longitudinal data renders many conclusions speculative [14,29].

Collectively, a handful of laboratory studies have indicated that sleep deprivation produces hyperalgesic responses in humans [16] and may impair the functioning of endogenous pain-inhibitory systems [27]. Moreover, several sleep diary studies in individuals with

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intractable pain have found evidence for a bi-directional relationship between sequential measures of pain and sleep; that is, increased daytime pain is linked with poor subsequent nighttime sleep and poor sleep is, in turn, associated with augmented next-day pain [1,25]. Finally, two longer-term prospective studies have suggested that prolonged nighttime awakenings in patients with rheumatoid arthritis are associated with increased joint-pain severity measured 6 months later [5], and that subjective sleep problems increased risk for developing widespread pain within 15 months in the general population [8].

Summarizing the research in this area to date, it is quite clear that pain impairs sleep quality (e.g., over 50% of pain patients report significant sleep disturbance [29]), and the investigations cited above indicate that disturbed sleep likely magnifies the experience of pain. What is currently missing from the literature is a large-scale study of the prospective daily associations between sleep and pain in the general population. Furthermore, within-person statistical methods (e.g., [6,18,24]), which simultaneously evaluate whether night-to-night changes in an individual's sleep predict day-to-day changes in pain and vice versa, and which also evaluate the relative strength of each directional prediction, are needed. While the question of whether there is a bi-directional linkage between pain and sleep appears conceptually simple, it requires large sample sizes and relatively complex statistical modeling to adequately address. If nightly fluctuations in sleep substantially shape pain reports, sleep could be an influential (and currently under-recognized) factor to consider in physicians' routine assessment and treatment of many persistent painful conditions, as well as in epidemiologic research investigating individual differences in pain report. In the present report, a micro-longitudinal study of adults in the U.S. population, we assess the association between nightly sleep duration and next-day pain report, assessed by daily telephone interview over the course of approximately one week.

2. Methods

2.1. Participants

The sample was derived from the National Study of Daily Experiences (NSDE), a sub-study within the Midlife in the United States Survey (MIDUS), a nationally representative telephone and mail survey in the United States [21]. A representative subset of 1031 participants (562 women, 469 men) in the original MIDUS study agreed to participate in the NSDE. Additional demographic characteristics of this sample included: a mean reported age of 47 years old, 90% of the sample reported their race as 'white', and 81% of the sample reported that they were married. Over eight consecutive evenings, NSDE respondents completed short telephone interviews about their daily experiences as previously described [2,3,7].

2.2. Measures

Daily pain was assessed each evening by asking respondents to estimate the frequency of their pain symptoms over the past day using a 5-point scale: 0 = *none of the time*, 1 = *a little*, 2= *some*, 3 = *most*, and 4 = *all of the time*. Similarly, respondents indicated the amount of sleep they had obtained (in hours and minutes) during the previous sleep period. Such measures of self-reported sleep duration, while lacking the richness of questionnaires that query sleep quality, satisfaction with sleep, etc., are rather standard indices in epidemiological studies [13]. A variety of other demographic and health-related variables were assessed in the MIDUS [22] and NSDE [2,3,7]: among other items, participants indicated their height and weight (for calculating BMI), use of "prescription medication" in the past month, whether or not they experienced "chronic sleeping problems" or an "emotional disorder" such as anxiety or depression, and whether they suffered from arthritis, recurrent back pain, or migraine headaches. Finally, an index was compiled of the number of "chronic conditions" reported (these included, out of 29 conditions: asthma, cancer, diabetes, hypertension, ulcers, etc.).

2.3. Analysis

The relationship between sleep and pain is presented in four ways: First, we provide the raw data for reported pain as a function of hours previously slept, using all available data from each subject across all study nights (see Table 1). Second, we generated a structural equation model (SEM) to simultaneously evaluate the prospective effects of sleep on pain and the prospective effects of pain on sleep (see Fig. 1 for the model's structure). In this model, sleep on a given night is predicted by sleep on the previous night and by pain on the preceding day (i.e., answering the question of whether the amount of pain experienced during a day predicts changes in the amount of sleep from the night before), and pain on a given day is predicted by pain on the previous day and by sleep on the preceding night (i.e., answering the question of whether the amount of sleep predicts changes in the reported pain level from the day before). Third, to examine the potentially nonlinear association between sleep and pain we used Generalized Additive Modeling (GAM) [34]. We modeled the effect of "yesterday's" pain and the previous night's sleep on "today's" pain. Models representing this effect were of the form:

Table 1
Mean pain reported by previous hours of sleep reported

Hours of sleep	Next-day pain (0–4)	SD	*n*
0–3	1.36	1.51	75
4	1.13	1.36	166
5	0.94	1.29	434
6	0.79	1.11	1138
7	0.73	1.11	1568
8	0.75	1.13	1557
9	0.71	1.09	339
10	1.24	1.40	119
11+	1.78	1.59	66

SD, standard deviation.

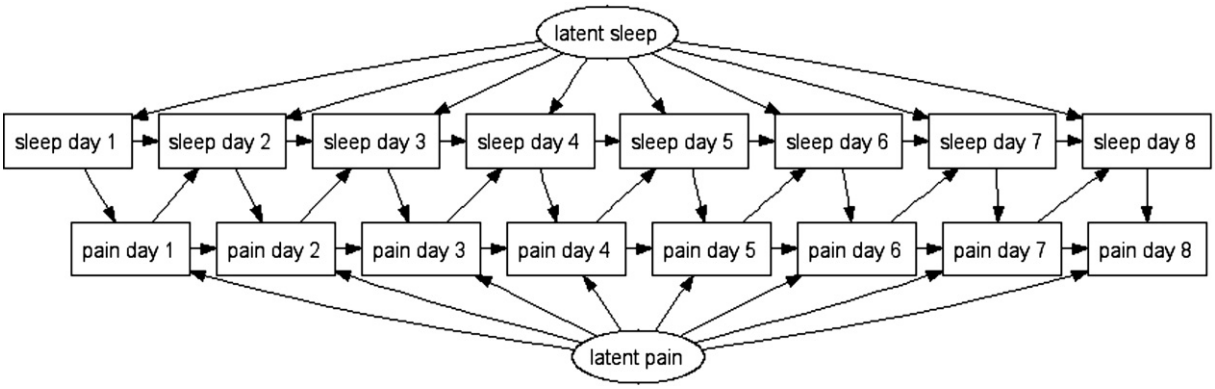

Fig. 1. Depiction of structural equation model evaluating the prospective associations between sleep and pain.

$$g[E(Y_i)] = \beta_0 + \beta_1 \text{previous days pain}_i + f(\text{previous nights sleep}_i) + \beta X + b_i$$

where Y_i follows an exponential distribution, X represents relevant covariates, and b_i is distributed normally with mean 0 and variance σ^2. In our models, previous night's sleep was modeled as a nonparametric function, and covariates included gender, age, BMI, number of chronic conditions, report of "chronic sleeping problems", report of an emotional disorder, 30-day use of prescription medications, and the presence of a persistent pain condition (arthritis, back pain, or migraine). Models included subject-specific random intercepts to account for correlation between observations. The model was fitted using partially iterative least squares, assumptions of randomly-missing data, and is shown with 95% confidence intervals [19]. Finally, we generated a general linear model (using the same covariates), in which we analyzed adjacent days' data to assess changes in sleep duration over two consecutive nights as a predictor of changes in pain on subsequent days. For the purpose of classifying changes in sleep, we categorized sleep duration as <6 h, 6–9 h, or >9 h. Data are presented as an estimated percentage change in pain from the previous day, as a function of night-to-night changes in sleep category.

3. Results

Data were complete for 5462 observations from 971 subjects. Table 1 presents the raw pain data, organized as a function of the amount of previous sleep (see Table 1). As expected, most of the observed values (78.0%) for sleep were between 6 and 9 h. Reported pain levels clearly increased as the number of hours of sleep dropped below 6, or rose above 9.

For the structural equation model, presented in Fig. 1, the adjusted-goodness-of fit index was 0.98, indicating very good model fit. The model includes six pathways of interest (all of which are estimated simultaneously): sleep predicting subsequent sleep, pain predicting subsequent pain, sleep predicting subsequent pain, pain predicting subsequent sleep, and finally the paths from the latent pain and sleep factors to their constituent variables. Results for the model are presented in Table 2. Of interest, significant effects of previous sleep on next-day pain, and of previous pain on subsequent sleep were found. Interestingly, the relationship was somewhat stronger for the prospective association of sleep with subsequent pain (Beta = −.08, Z-value = −7.9, $p < .0001$) compared to the prospective association of pain with later sleep (Beta = −.04, Z-value = −3.1, $p = .002$).

The generalized additive model revealed a significant curvilinear association between sleep and subsequent pain ($p < .001$), even after including the following covariates: pain on the previous day, age, sex, BMI, number of chronic conditions, use of prescription medications, chronic sleep difficulties, the presence of an emotional disorder, and the presence of a persistent pain condition. The results of the model are presented in Table 3, which lists estimates and significance values for each of the covariates, and in Fig. 2, which displays the association (curvilinear) between the prior night's sleep duration and subsequent pain. In terms of the covariates, the previous day's pain was the strongest predictor of today's pain. Other covariates significantly ($p < .05$) associated

Table 2
Results for the structural equation model shown in Fig. 1

Pathway	Estimate	Standard error	Z	p
Sleep → subsequent sleep	.15	.01	11.4	<.001
Pain → subsequent pain	.18	.01	13.9	<.001
Sleep → subsequent pain	−.08	.01	−7.9	<.001
Pain → subsequent sleep	−.04	.01	−3.1	.002
Latent sleep → individual sleep nights	.45	.02	27.5	<.001
Latent pain → individual pain days	.57	.02	32.6	<.001

Table 3
Results for the generalized additive model predicting daily pain (see Fig. 2)

Variable	Estimate	Standard error	*t*	*p*
Previous night sleep	NA[a]	NA[a]	NA[a]	<.001
Gender	.03	.03	0.7	.47
Age	−.01	.002	−3.7	<.001
BMI	.01	.003	2.3	.02
# Chronic conditions	.03	.01	2.7	.007
Chronic sleep problems	.06	.06	0.9	.38
Emotional disorder	.14	.05	2.7	.008
Prescription medication	.01	.003	2.6	.01
Persistent pain condition	.28	.05	6.3	<.001
Previous day pain	.35	.01	26.3	<.001

[a] Estimates not available since Previous night's sleep was modeled as a nonparametric (curvilinear) function – see Fig. 2 for a graphical depiction; BMI, body mass index.

with higher ratings of daily pain were: younger age, higher BMI, larger numbers of co-morbid chronic conditions, the presence of an emotional disorder, the use of prescription medication, and the presence of a persistent pain condition.

Finally, the general linear model evaluating night-to-night changes in sleep revealed that transitioning from a night of "normal" sleep duration (i.e., 6–9 h) to a night of either <6 h or >9 h of sleep was associated with a substantial increase in pain frequency, compared to the reference category of two consecutive nights of 6–9 h of sleep (see Table 4). Similarly, two consecutive nights of either <6 h or >9 h of sleep were also associated with pain increases relative to the reference category.

4. Discussion

Amid growing interest in the complex interplay of pain and sleep, several recent studies have noted that individuals who suffer from sleep disturbance are at elevated risk for the future development of pain complaints over time frames from as short as 1 year to as long as 28 years [8,11,23,26]. Moreover, our recent reports from our group (Smith et al. [30]) and others [4] have indicated that the development of symptoms of insomnia (i.e., disrupted sleep) in the aftermath of an acute, painful injury, is associated with the persistence of post-injury pain. In that context, this is the first micro-longitudinal study in the general population to evaluate the associations between sleep and pain on a day-to-day basis.

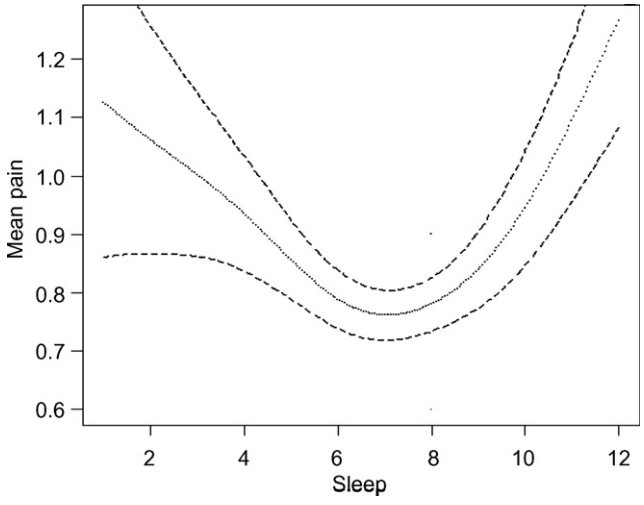

Fig. 2. Generalized additive model depicting the curvilinear relationship between previous hours of sleep and the reported frequency of subsequent pain (95% confidence intervals added).

The results of the present study suggest a significant curvilinear prospective association of sleep duration with subsequent daily pain report; individuals sleeping for less than 6 h, or for 9 h or more, reported more frequent pain complaints the following day. Evaluating the extremes of sleep duration, using raw data (see Table 1), sleeping for three hours or less was associated with an 81% increase in pain frequency relative to sleeping 6–9 h, and sleeping for more than 11 h was associated with a 137% increase in pain frequency. Such findings complement the macro-longitudinal studies cited above, and indicate that reciprocal inter-relationships between sleep and pain may unfold over both short and long-time horizons. Overall, the curvilinear sleep–pain association that we observed seems to parallel large epidemiologic studies noting that either relatively short or relatively long sleep durations are associated with early mortality [10,13]. It is of interest to note that this relationship was observed in models that controlled for a large number of covariates (e.g., the presence of other medical conditions, the presence of chronic disorders of sleep, pain, and emotional functioning). Of these covariates, younger age, a higher BMI, more co-morbid chronic conditions, the presence of an emotional disorder, the use of prescription medication, and the presence of a persistent pain condition were all associated with higher daily ratings of pain in the GAM model. Moreover, it is interesting to note that structural equation modeling that simultaneously evaluated the temporal

Table 4
Mean day-to-day changes in pain report as a function of night-to-night changes in reported sleep time

Changes in hours of sleep	% Change in pain from yesterday to today	*n*	*p*
Prior sleep between 6 and 9 h, last night's sleep also 6–9 h	+4.2	4185	N/A (reference)
Prior sleep between 6 and 9 h, last night's sleep <6 h	+31.9	319	.005
Prior sleep between 6 and 9 h, last night's sleep >9 h	+29.7	129	.02
Prior sleep >9 h, last night's sleep between 6 and 9 h	−12.3	97	.33
Prior sleep <6 h, last night's sleep between 6 and 9 h	−17.9	302	.18
Prior sleep <6 h, last night's sleep also <6 h	+9.5	342	.02
Prior sleep >9 h, last night's sleep also >9 h	+12.0	62	.01

Note. Model adjusted for: age, sex, BMI, number of chronic conditions, use of prescription medications, chronic sleep difficulties, the presence of an emotional disorder, and the presence of a persistent pain condition. *p*-Values are for the comparison with the reference condition (''prior sleep between 6 and 9 h, last night's sleep also 6 and 9 h").

pathways of current sleep predicting next-day pain and current pain predicting next-night sleep suggested that while both pathways are important, the strength of the prospective association of current sleep with next-day pain appeared to be of somewhat greater magnitude.

Previous reports have anticipated the findings detailed here, indicating that a disturbed night's sleep correlated with increased next-day aches and pains [32], and noting day-to-day relationships between sleep and pain in select diagnostic groups such as fibromyalgia [1], and hospitalized burn patients [25]. Moreover, laboratory-based sleep deprivation studies have also suggested that reductions in total sleep time are accompanied by increased sensitivity to noxious stimuli [15,17], and by decrements in endogenous pain-inhibitory processes [27]. Thus, this study's observed association of reduced sleep time with subsequent increases in pain report corresponds well with existing data and hypotheses. The prospective link between longer sleep duration and elevated next-day pain is somewhat more complex to explain, but it may reflect the effects of an acute condition associated with both lengthened sleep and physical discomfort, such as infection. Alternatively, a relatively long sleep period may indicate poor sleep continuity (e.g., fragmented, or overly ''light" sleep), which has been associated with enhanced pain perception in some laboratory studies of experimental sleep fragmentation [27]. In our prior laboratory-based study, the total amount of sleep time was less important than the continuity of sleep in shaping next-day pain responses [27], and it may be the case that subjects in the current study who reported getting more than 9 h of sleep on a given night had experienced intermittent, fragmented periods of sleep interspersed with longer-than-usual amounts of wake time.

Collectively, some potentially important implications arise from the observed prospective associations. First, sleep disturbance, manifested as either reduced or increased sleep duration, may serve as a marker identifying individuals at elevated risk for poor pain-related outcomes. Second, sleep disturbance may be part of the etiopathogenesis of some pain syndromes [16,29,31], and as such may represent an important target for putative analgesic treatments. Our group and others have argued that this reciprocal sleep–pain relationship may reflect a neurobiologic overlap between brainstem descending pain-modulatory systems and ascending arousal systems regulating consciousness [27–29]. At present, however, whether or not the down-stream effects of poor sleep can be reversed or prevented by sleep-improving interventions remains a largely unexplored question. Third, day-to-day fluctuations in sleep may be an important factor for health professionals to evaluate in their assessment of patients in pain. Consider, for example, the hypothetical case of a patient with longstanding, stable, moderately-severe knee pain. If this patient happened to sleep poorly for several nights before his follow-up appointment, he would be expected to report somewhat more pain than usual to his physician, which might trigger costly assessment procedures on the presumption of worsening ''disease" pathology. Similarly, if a new therapy had recently been implemented, this bout of acute sleep disruption might detract from its apparent analgesic effects. Fourth, sleep disturbance may be a valuable target for non-pharmacologic intervention in the multi-modal treatment of pain. A substantial literature suggests that behavioral factors are frequently involved as perpetuators of sleep problems in patients with pain, and the current findings (as well as previous results from several trials) of non-pharmacologic interventions for insomnia; see [29] hint that interventions addressing these behavioral factors (e.g., cognitive-behavioral therapy) may lead to improvements in daytime pain.

Overall, a number of qualifications and limitations should be highlighted when interpreting the findings of the present study. First, the study utilized a non-randomized, observational design, which should prevent readers from drawing causal conclusions (i.e., on the basis of these findings, it should not be concluded that lengthening an individual's sleep period to >9 h would likely increase that person's report of pain). Second, these findings are based on single-item measures of daily pain and nightly sleep. While many epidemiological studies have used similar items, it would be preferable to obtain multidimensional measures of sleep and pain

in future studies; for example, items assessing not only the frequency but also the severity, quality, spatial extent, source, and impact of pain would provide valuable information. Third, and relatedly, the assessment of sleep in this study was based solely on self-report of total sleep time. Future studies in this area would benefit from evaluating self-report of other aspects of sleep (e.g., perceived sleep quality, sleep onset latency, etc.), as well as from objective measurement of sleep continuity and sleep architecture. Finally, we do not have data on the specific mechanisms by which sleep duration prospectively influences pain reports, and we are left to speculate about the processes that might be involved. In spite of these limitations, however, this investigation provides a rigorous evaluation of the bi-directional inter-relationships between sleep and pain in a large sample of the general population. Moreover, despite the rather crude assessment of sleep and pain (i.e., using single-item measures), these findings hint that at least a brief assessment of sleep may substantively contribute to assessments of pain complaints in a variety of populations.

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