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Intraindividual variability in sleep and perceived stress in young adults

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ABSTRACT

Objectives: Research suggests strong associations between habitual sleep parameters (eg, mean duration, timing, efficiency), perceived stress, and insomnia symptoms. The associations between intraindividual variability (IIV; night-to-night within-person variation) in sleep, perceived stress, and insomnia have not been explored. This study examined associations between IIV in subjectively and objectively determined sleep parameters and to perceived stress in young adults with and without insomnia.
Design: Prospective longitudinal.
Setting and participants: Participants were 149 college students (mean age = 20.2 [SD = 2.4], 59% female) either with insomnia (n = 81; 54%) or without insomnia (n = 68; 46%).
Measurements: Participants completed 1 week of daily sleep diaries and actigraphy (to assess total sleep time [TST], sleep efficiency [SE], and circadian midpoint [CM]), the Perceived Stress Scale, and a diagnostic interview for determination of insomnia as part of a parent study.
Results: Greater IIV in actigraphy-determined TST (but not SE or CM) was independently associated with greater perceived stress, regardless of insomnia status. Greater IIV in sleep diary–determined TST, SE, or CM was not associated with perceived stress. Insomnia status was the most robust predictor of elevated perceived stress. There was a significant interaction between IIV in sleep diary–determined TST and insomnia status on perceived stress: Only in those *without* insomnia was greater IIV in sleep diary–determined TST associated with higher perceived stress.
Conclusion: Maintaining a more consistent sleep duration may be associated with lower stress in college students. Future research is needed to clarify the directionality and implications of this association for treatment.

College students are prone to elevated levels of stress due to intense academic demands, transition to independence, and unique social and financial pressures. Previous studies have shown approximately 73% of college students report any current psychological distress, and 26% report at least moderate levels of stress.[1,2] Disturbed sleep may be one important yet understudied correlate of perceived stress in college students. Experimental studies have shown sleep loss and poor sleep quality impair emotion regulation,[3,4] increase pain,[5,6] increase susceptibility to illness,[7] and impair attention and memory.[8] These sleep-related consequences may directly or indirectly lead to increases in perceived stress in young adults, which could potentially contribute to downstream effects such as worse academic performance, dropout, and mental and physical health consequences.

To date, most studies examining associations between sleep parameters and perceived stress have used a cross-sectional design and relied on retrospective questionnaires (which may not validly or reliably capture sleep) or have focused on older populations (which likely does not generalize to young adults' sleep).[9–12] In cross-sectional studies of young adults and college students, higher perceived stress has been associated with greater subjective insomnia symptoms,[9] daytime sleepiness and fatigue,[13] more restless sleep,[14] more trouble falling asleep,[14] more early morning awakenings,[14] lower self-reported sleep quality[13,15] and shorter subjective sleep duration.[13] College students have also reported their

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sleep quality worsens and sleep duration shortens prior to high stress periods (eg, final examinations) and then improves after the stressor ends,[13] suggesting a close potential link between stress and sleep disturbances. Taken together, these studies provide some evidence for associations between habitual sleep and stress among young adults.

Young adults with insomnia may be particularly likely to experience increased stress in the face of disturbed sleep due to increased self-monitoring of sleep loss and its consequences on mental and physical well-being.[16,17] Approximately 10% of college students suffer from chronic insomnia, and those with insomnia report worse sleep, fatigue, depression, anxiety, stress, and quality of life, and greater hypnotic and stimulant use for sleep problems.[9] However, to our knowledge, no studies have examined the associations between sleep and perceived stress in college students with and without insomnia using rigorous and comprehensive measures of sleep (eg, via both prospective sleep diaries and actigraphy). An additional limitation of previous studies was that insomnia was not diagnosed with a structured clinical interview, which is the gold standard for establishing an insomnia diagnosis and is typically more reliable and valid than retrospective self-report questionnaires.[18]

Furthermore, a substantial limitation of the existing literature on sleep, stress, and insomnia is that most studies have only examined average (ie, habitual) sleep or used single-night or long-term retrospective assessments of sleep, as opposed to prospective intraindividual variability (IIV) in sleep.[9,12,15,19] IIV characterizes night-to-night within-person fluctuations in sleep and appears to be an important marker of physical and mental health above habitual sleep patterns.[20] College students in particular are likely to have high IIV in sleep duration, efficiency, and timing.[21]

Presently, only a few studies have examined associations between IIV in sleep and perceived stress. For example, greater IIV in actigraphy-determined sleep duration and sleep fragmentation has been associated with higher levels of perceived stress,[10] and greater IIV in actigraphy-determined sleep onset latency and time in bed has been associated with greater negative mood in adolescents.[22] A study of college students demonstrated high sleep variability and high stress contributed to psychological maladjustment.[19] Furthermore, compared to people without insomnia, people with insomnia tend to report greater IIV in sleep, as well as higher levels of perceived stress and more average sleep disturbances.[11,12,23] Therefore, it is plausible that the associations between stress and IIV in sleep may be different for those with vs without insomnia. However, these associations may depend on whether sleep is measured subjectively or objectively.[24]

To our knowledge, no studies have examined associations between IIV in sleep (both subjective and objective) and perceived stress in college students with and without insomnia. A better understanding of the psychological correlates of IIV in sleep in young adults with and without insomnia may have implications for interventions to address these factors proactively before maladaptive patterns may become entrenched later in adulthood.

The current study

We examined associations between average and IIV in sleep diary and actigraphy-assessed sleep parameters (ie, duration, efficiency, and timing) and perceived stress in college students with or without insomnia. We hypothesized shorter average total sleep time (TST) (both sleep diary and actigraphy determined), lower average sleep efficiency (SE) (ie, TST divided by time in bed), and later average sleep timing (ie, circadian midpoint [CM] or the midpoint between bedtime and risetime) would be associated with greater perceived stress, regardless of insomnia status. We also hypothesized greater IIV in these same sleep parameters (both sleep diary and actigraphy determined) would be positively associated with perceived stress. Finally, we examined insomnia status as a moderator of the association between IIV in sleep and perceived stress and hypothesized young adults with insomnia would experience stronger positive associations between IIV in sleep and perceived stress compared to young adults without insomnia.

Methods

Participants and recruitment

The study was approved by the university's institutional review board for human participants. Participants were initially recruited to participate in a parent study on the role of insomnia in antibody response to the influenza vaccine response in college students.[7] Participants were recruited using announcements in class and flyers around campus. A total of 1088 participants underwent phone screening to determine initial eligibility. To pass the initial screening, participants had to be 18-29 years old and enrolled at the university at which the study was conducted. Participants also had to have a usual bedtime between 10:00 PM and 1:00 AM or rise time between 4:00 AM and 10:00 AM. If they were in the insomnia group, they also had to have difficulty falling or staying asleep ≥3 nights a week, for ≥3 months, with daytime complaints; if they were in the no-insomnia group, they had to have an average sleep duration >7.5 hours. Participants were excluded if they had received the influenza vaccine the previous year (to lessen the likelihood of baseline influenza antibodies to any repetitive viral strains in the vaccine); had another sleep disorder, Axis I or II psychiatric disorder (based on *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition*, criteria), or serious chronic medical condition (eg, cancer, HIV, pain, immune, Guillain-Barre syndrome); were taking any medications that could alter immune responses (eg, steroids, opioids); were pregnant or nursing; or had egg or mercury allergies (due to the influenza vaccine administered as part of the larger study).

A total of 331 (30%) volunteers passed initial screening, were sent the packet of questionnaires, and were scheduled for in-person meetings for consenting and diagnostic interviews. A total of 171 (52%) participants passed this stage and were scheduled for a psychological history and physical and laboratory assessments to ensure no underlying conditions or substances were present that may have affected sleep or vaccine response. Of those, 149 (87%) participants passed and were included in the current study. The final sample consisted of N = 149 college students with insomnia (n = 81; 54%) and without insomnia (n = 68; 46%). The mean age of the sample was 20.2 years (SD = 2.4), and 59.1% (n = 88) of participants were female, 28.9% (n = 43) were Hispanic/Latino, 65.8% were Caucasian or white, 11.4% were African American or black, and 3.3% (n = 5) were Asian.

Procedure

After providing informed consent, participants underwent a screening process to ensure they met inclusion and exclusion criteria by completing the Insomnia Severity Index (ISI), Epworth Sleepiness Scale (ESS), Pittsburgh Sleep Quality Index (PSQI), Morningness-Eveningness Questionnaire (MEQ), and a structured clinical interview for sleep disorders (SCISD)[18] to determine insomnia status. Participants without insomnia were screened to ensure they did not have any clinically significant sleep disturbances (ie, PSQI ≤5, MEQ 31-69, ISI <15, ESS <15), and all participants were interviewed to verify the absence of any psychiatric or sleep disorders that were exclusionary. Participants then were asked to complete daily sleep diaries and wear an Actiwatch for 7 days.

Measures

Sleep diary

Prospective sleep diaries (using a modified version of the Consensus Sleep Diary[25]) were used to assess subjective measures of TST, SE, and CM. Sleep diaries are significantly correlated with polysomnography (PSG) on wake time after sleep onset (WASO), TST, and SE in people with insomnia.[26,27] Sleep diaries are considered the gold standard of subjective sleep measurement because they provide greater accuracy compared to single-point retrospective estimates of sleep.[28] In the current study, participants were asked to make daily diary entries for 7 days with an estimate of their sleep the night before (eg, bedtime, waketime, risetime, sleep onset latency [SOL]). TST was calculated by taking the amount of time elapsed from the time participants reported falling asleep (ie, bedtime − SOL) to waketime. SE was calculated by taking TST divided by time in bed (TIB; ie, time elapsed from bedtime to risetime) and multiplied by 100. CM was calculated by taking the midpoint between bedtime and risetime, converted to a numeric value (eg, if bedtime was 12 AM and risetime was 6 AM, CM was 3 AM). To ensure diaries were completed daily, participants were asked to call in each morning to an answering machine and provide their sleep diary data from the night before. Rates of missing sleep diary data were low (28 missing diaries out of 1043 possible diaries or 2.7% missing data), suggesting good adherence (97%) to the daily diary protocol.

Actigraphy

Actigraphy data were obtained using Actiwatch Spectrums produced by Philips Respironics (Bend, OR) worn on the nondominant wrist for 7 days and nights. Data were recorded in 30-second epochs and scored using the software provided by the manufacturer (Actiware v5.5). The Actiwatch collects data on gross motor activity using an accelerometer and 3-band light sensor. Sleep and wake patterns are determined by comparing activity counts for a given epoch of time and the epochs surrounding that sample to a wake threshold so that a certain amount of activity is required to score the epoch as wake. Actigraphy is highly correlated with PSG on measures of TST, SOL, WASO, and SE ($r = .78.98$) among normal sleepers[29] and demonstrates more modest correlations with PSG on measures of TST, SOL, WASO, and SE among individuals with insomnia.[27,30] Actigraphy was scored using medium sensitivity (ie, 40 activity counts) as the wake threshold. The sleep onset and sleep offset settings were both set to the default setting: 10 immobile minutes. Two trained scorers set intervals based on a laboratory-developed scoring hierarchy, and discrepancies were resolved independently by a third scorer. Percent agreement between the 2 initial scorers was high (89.4%).

Perceived stress

The Perceived Stress Scale (PSS) is a 14-item self-report measure that assesses the stress domains of lack of control, unpredictability, burden overload, and stressful life circumstances.[31] Participants specify the frequency of certain feelings and thoughts using a 5-point scale (0 = never to 4 = very often) with a total score range of 0-56 (greater perceived stress reflected by higher scores). The PSS has shown good reliability in college student samples with an internal consistency α coefficient of .88 in a previous study[9] and .89 in the current sample.

Insomnia

All participants who proceeded to the diagnostic evaluation phase of the study were interviewed by trained interviewers with the Structured Clinical Interview for Sleep Disorders (SCISD)[18] to assess for current sleep disorders as defined by the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (*DSM-5*).[32] (At the time this study was conducted, the *DSM-5* had not yet been released; however, *DSM-5* criteria for insomnia were obtained through personal correspondence with the head of the *DSM-5* insomnia diagnosis subcommittee). This measure was specifically designed to allow an independent evaluator with a master's degree or higher, and minimal training in sleep disorders and administration, to obtain reliable sleep disorder diagnoses in adults. This measure has been validated in a recent study.[18] Insomnia diagnosis was confirmed as needed by one of the authors (who is a licensed clinical psychologist and board certified in both sleep medicine and behavioral sleep medicine).

Data analysis plan

Analyses were performed in R (RStudio, Version 1.0.153), an open-source statistical program.[33] Measures of IIV in sleep (ie, sleep diary– and actigraphy-determined TST, SE, and CM) were calculated using the R package *varian*,[34] which computes the intraindividual standard deviation (iSD) across a repeated measures construct. Hierarchical regressions were conducted using the R package *apaTables*.[35] In the first step, a model examining the intraindividual mean (iM) and intraindividual standard deviation (iSD) of TST, SE, and CM and insomnia status were examined as predictors of the total score on the PSS. Then, a model with all predictors in step 1 plus the interactions between insomnia status (0 = no insomnia, 1 = insomnia) and the iSDs of TST, SE, and CM was examined. Separate models were

Table 1
Sample descriptives for sleep diary and actigraphy sleep parameters and perceived stress by insomnia status

	Entire sample (N = 149)		No insomnia (n = 81)		Insomnia (n = 68)			
	Mean	SD	Mean	SD	Mean	SD	*t* value	*P* value
Sleep diary parameters								
SE iM	87.43	9.57	92.31	4.51	82.07	10.70	7.35	**<.001**
TST iM	423.90	63.28	449.07	47.57	394.80	67.35	5.56	**<.001**
CM iM	5.60	1.66	2.32	2.01	2.58	2.09	−0.63	.53
TST iSD	90.52	53.21	84.32	34.80	98.87	69.23	−1.56	.12
SE iSD	7.48	6.02	5.46	4.25	9.75	6.96	−4.39	**<.001**
CM iSD	2.42	2.05	2.32	2.01	2.58	2.09	−0.75	.45
Actigraphy parameters								
SE iM	83.25	5.55	82.85	6.42	83.66	4.41	−0.90	.37
TST iM	404.88	38.23	404.09	39.68	403.99	36.60	0.02	.99
CM iM	5.01	1.32	4.83	1.02	5.24	1.61	−1.81	.07
TST iSD	81.90	35.99	77.97	39.08	87.36	32.32	−1.60	.11
SE iSD	5.87	3.84	5.86	4.12	5.83	3.56	0.03	.97
CM iSD	1.06	0.76	0.97	0.42	1.17	1.02	−1.54	.13
PSS total	15.43	6.47	12.35	5.10	19.10	6.03	−7.31	**<.001**

Bold *P* values signify significant differences ($P < .05$) between those with and without insomnia.

conducted for sleep diaries and actigraphy. Significant interactions were graphed by insomnia status using the R package *ggplot*.[36] Semipartial correlation coefficient squared (sr^2; ie, the unique contribution to the total variance in the dependent variable explained by each independent variable, after accounting for the variance explained by the other IVs) was used as a measure of effect size. The following Cohen (1988)[37] heuristics were used: small effect size, $sr^2 = .02$; medium effect size, $sr^2 = .13$; and large effect size, $sr^2 = .26$.

Results

Descriptive results

Descriptives for all variables by insomnia status are presented in Table 1. Participants with insomnia reported significantly greater perceived stress, shorter habitual sleep diary–determined TST, lower habitual sleep diary–determined SE, and greater IIV in sleep diary–determined SE (Table 2). Insomnia status was not associated with actigraphy-determined habitual or IIV in TST, SE, or CM (Table 2).

Main effects of IIV in sleep parameters and insomnia status on perceived stress

Sleep diaries

The overall main effects model of insomnia status and habitual and IIV in sleep diary–determined TST, SE, and CM on perceived stress was significant ($F_{7,138} = 8.01$, $P < .0001$). These variables explained 29% of the variance in perceived stress ($R^2 = .29$). Neither habitual or IIV in sleep-diary determined TST, SE, or CM was independently associated with perceived stress (top portion of Table 3). Only insomnia status was independently associated with

Table 2
Bivariate correlations

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Insomnia status													
2. PSS	.52** [.39 to .63]												
3. SE iM acti	.07 [−.09 to .23]	.11 [−.05 to .27]											
4. TST iM acti	−.00 [−.16 to .16]	.03 [−.14 to .19]	.40** [.26 to .52]										
5. CM iM acti	.15 [−.01 to .31]	.01 [−.15 to .17]	.04 [−.12 to .20]	.03 [−.13 to .18]									
6. SE iSD acti	−.00 [−.16 to .16]	.04 [−.12 to .20]	−.52** [−.63 to −.40]	−.32** [−.46 to −.17]	−.06 [−.22 to .10]								
7. TST iSD acti	.13 [−.03 to .28]	.17* [.01 to .32]	−.05 [−.20 to .11]	.02 [−.14 to .18]	.38** [.23 to .51]	.25** [.09 to .39]							
8. CM iSD acti	.13 [−.03 to .29]	−.08 [−.24 to .08]	.01 [−.15 to .16]	.07 [−.09 to .23]	.66** [.56-.74]	−.02 [−.18 to .14]	.39** [.24 to .52]						
9. SE iM diary	−.54** [−.65 to −.42]	−.32** [−.46 to −.16]	.09 [−.07 to .25]	.03 [−.13 to .19]	−.01 [−.17 to .15]	−.08 [−.24 to .08]	−.02 [−.18 to .14]	−.03 [−.19 to .13]					
10. TST iM diary	−.43** [−.55 to −.29]	−.28** [−.42 to −.12]	−.12 [−.28 to .04]	.46** [.32 to .57]	.04 [−.12 to .20]	−.06 [−.22 to .10]	.00 [−.16 to .16]	.11 [−.05 to .26]	.76** [.68 to .82]				
11. CM iM diary	.05 [−.11 to .21]	.11 [−.06 to .26]	−.02 [−.17 to .14]	−.01 [−.17 to .15]	.38** [.23 to .51]	−.07 [−.23 to .09]	.02 [−.14 to .18]	.22** [.07 to .37]	.07 [−.09 to .23]	.07 [−.09 to .23]			
12. SE iSD diary	.36** [.20 to .49]	.20* [.04 to .35]	−.12 [−.28 to .04]	−.12 [−.28 to .04]	.04 [−.12 to .20]	.25** [.09 to .39]	.14 [−.02 to .30]	.05 [−.11 to .21]	−.76** [−.82 to −.68]	−.59** [−.69 to −.48]	−.14 [−.30 to .02]		
13. TST iSD diary	.14 [−.03 to .29]	.04 [−.13 to .20]	−.02 [−.18 to .15]	.10 [−.06 to .26]	.58** [.46 to .68]	.02 [−.14 to .18]	.60** [.49 to .70]	.77** [.69 to .83]	−.10 [−.26 to .06]	.09 [−.07 to .24]	.19* [.03 to .34]	.28** [.13 to .42]	
14. CM iSD diary	.06 [−.10 to .22]	.06 [−.10 to .22]	−.06 [−.21 to .11]	.02 [−.14 to .18]	−.12 [−.28 to .04]	.00 [−.16 to .16]	−.05 [−.21 to .11]	.16 [−.00 to .31]	−.05 [−.21 to .11]	.01 [−.15 to .17]	.69** [.59 to .76]	−.10 [−.25 to .07]	.09 [−.07 to .25]

Values in square brackets indicate the 95% CI for each correlation. Insomnia status (0 = no insomnia, 1 = insomnia). Acti, actigraphy measures, Diary, sleep diary measures.
* $P < .05$.
** $P < .01$.

Table 3
Insomnia status, IIV, and average sleep diary sleep parameters on perceived stress

Predictor	b	b 95% CI [LL-UL]	beta	beta 95% CI [LL-UL]	sr^2	sr^2 95% CI [LL-UL]	r	Fit	Difference
(Intercept)	16.49	[−2.48 to 35.46]							
Insomnia	6.26**	[4.00 to 8.52]	0.48	[0.31 to 0.65]	.15	[.05 to .25]	.52**		
TST iSD	−0.01	[−0.03 to 0.01]	−0.04	[−0.21 to 0.12]	.00	[−.01 to .01]	.04		
SE iSD	−0.01	[−0.28 to 0.25]	−0.01	[−0.26 to 0.23]	.00	[−.00 to .00]	.20*		
CM iSD	−0.17	[−0.80 to 0.47]	−0.05	[−0.25 to 0.15]	.00	[−.01 to .01]	.06		
SE iM	−0.04	[−0.25 to 0.17]	−0.05	[−0.33 to 0.23]	.00	[−.01 to .01]	−.33**		
TST iM	−0.01	[−0.03 to 0.02]	−0.05	[−0.27 to 0.17]	.00	[−.01 to .01]	−.28**	R^2 = .289**	
CM iM	0.49	[−0.32 to 1.30]	0.12	[−0.08 to 0.33]	.01	[−.02 to .03]	.11	95% CI [.14 to .37]	
(Intercept)	12.64	[−6.57 to 31.84]							
Insomnia	11.02**	[5.99 to 16.05]	0.84	[0.46 to 1.23]	.09	[.01-.17]	.52**		
TST iSD	0.04	[−0.00 to 0.07]	0.29	[−0.03 to 0.61]	.02	[−.02 to .05]	.04		
SE iSD	−0.02	[−0.37 to 0.34]	−0.02	[−0.34 to 0.31]	.00	[−.00 to .00]	.20*		
CM iSD	−0.12	[−0.90 to 0.66]	−0.04	[−0.28 to 0.21]	.00	[−.01 to .01]	.06		
SE iM	−0.04	[−0.25 to 0.16]	−0.06	[−0.34 to 0.22]	.00	[−.01 to .01]	−.33**		
TST iM	−0.00	[−0.03 to 0.02]	−0.03	[−0.25 to 0.18]	.00	[−.01 to .01]	−.28**		
CM iM	0.49	[−0.31 to 1.29]	0.12	[−0.08 to 0.33]	.01	[−.02 to .03]	.11		
Insomnia × TST iSD	−0.05*	[−0.10 to −0.01]	−0.56	[−1.02 to −0.11]	.03	[−.02 to .08]	.30**		
Insomnia × SE iSD	−0.01	[−0.39 to 0.38]	−0.01	[−0.40 to 0.39]	.00	[−.00 to .00]	.37**	R^2 = .323**	ΔR^2 = .034
Insomnia × CM iSD	0.03	[−0.90 to 0.96]	0.01	[−0.26 to 0.28]	.00	[−.00 to .00]	.37**	95% CI [.15-.39]	95% CI [−.01 to .08]

A significant *b* weight indicates the beta-weight and semipartial correlation are also significant. *b* represents unstandardized regression weights; *beta* indicates the standardized regression weights; sr^2 represents the semipartial correlation squared; *r* represents the zero-order correlation. *LL*, lower limit of a CI; UL, upper limit of CI.
* $P < .05$.
** $P < .01$.

perceived stress: those with insomnia had a 6.27-unit increase in perceived stress compared to those without insomnia (95% confidence interval [CI] 4.00-8.52, $sr^2 = .15$; top portion of Table 3).

Actigraphy

The overall main effects model of insomnia status and habitual and IIV in actigraphy-determined TST, SE, and CM on perceived stress was significant, $F_{7,141} = 10.08$, $P < .0001$. These variables explained 33% of the variance in perceived stress ($R^2 = .33$). Habitual TST, SE, and CM were not independently associated with perceived stress. Greater IIV in actigraphy-determined TST and lower IIV in CM were independently associated with greater perceived stress (top portion of Table 4). Insomnia status also was independently associated with perceived stress: those with insomnia had a 6.73-unit increase in perceived stress compared to those without insomnia (95% CI 4.94-8.53, $sr^2 = .26$; top portion of Table 4).

Interactions between IIV in sleep parameters and insomnia status on perceived stress

Insomnia status moderated the effect of IIV in sleep diary–determined TST and perceived stress ($\beta = -0.05$, 95% CI −0.10 to −0.01, $sr^2 = .03$, $P < .05$; see bottom portion of Table 3): Those without insomnia had a positive association between IIV in TST and

Table 4
Insomnia status, IIV, and average actigraphy sleep parameters on perceived stress

Predictor	b	b 95% CI [LL-UL]	beta	beta 95% CI [LL-UL]	sr^2	sr^2 95% CI [LL-UL]	r	Fit	Difference
(Intercept)	0.17	[−17.56 to 17.90]							
Insomnia	6.73**	[4.94 to 8.53]	0.52	[0.38 to 0.66]	.26	[.14 to .38]	.52**		
TST iSD	0.03*	[0.00-0.06]	0.18	[0.02-0.34]	.02	[−.02 to .06]	.17*		
SE iSD	0.08	[−0.21 to 0.36]	0.05	[−0.12 to 0.22]	.00	[−.01 to .01]	.04		
CM iSD	−1.91*	[−3.49 to −0.33]	−0.23	[−0.41 to −0.04]	.03	[−.02 to .07]	−.08		
SE iM	0.12	[−0.07 to 0.31]	0.11	[−0.06 to 0.27]	.01	[−.02 to .03]	.11		
TST iM	0.00	[−0.02 to 0.03]	0.01	[−0.14 to 0.16]	.00	[−.00 to .00]	.03	R^2 = .333**	
CM iM	0.05	[−0.85 to 0.95]	0.01	[−0.18 to 0.20]	.00	[−.00 to .00]	.01	95% CI [.18 to .41]	
(Intercept)	−1.87	[−20.16 to 16.42]							
Insomnia	7.44**	[2.06 to 12.82]	0.57	[0.16 to 0.99]	.04	[−.01 to .08]	.52**		
TST iSD	0.03	[−0.01 to 0.06]	0.14	[−0.07 to 0.35]	.01	[−.02 to .03]	.17*		
SE iSD	0.02	[−0.33 to 0.37]	0.01	[−0.20 to 0.22]	.00	[−.00 to .00]	.04		
CM iSD	−0.11	[−3.33 to 3.11]	−0.01	[−0.39 to 0.37]	.00	[−.00 to .00]	−.08		
SE iM	0.13	[−0.07 to 0.32]	0.11	[−0.06 to 0.28]	.01	[−.02 to .03]	.11		
TST iM	0.00	[−0.02 to 0.03]	0.02	[−0.14 to 0.17]	.00	[−.00 to .00]	.03		
CM iM	0.14	[−0.79 to 1.07]	0.03	[−0.16 to 0.22]	.00	[−.01 to .01]	.01		
Insomnia × TST iSD	0.01	[−0.05 to 0.07]	0.05	[−0.40 to 0.50]	.00	[−.00 to .00]	.48**		
Insomnia × SE iSD	0.16	[−0.33 to 0.65]	0.09	[−0.19 to 0.38]	.00	[−.01 to .01]	.45**	R^2 = .343**	ΔR^2 = .010
Insomnia × CM iSD	−2.20	[−5.79 to 1.40]	−0.31	[−0.81 to 0.20]	.01	[−.01 to .03]	.20*	95% CI [.17 to .41]	95% CI [−.02 to .04]

A significant *b* weight indicates the beta-weight and semipartial correlation are also significant. *b* represents unstandardized regression weights; *beta* indicates the standardized regression weights; sr^2 represents the semipartial correlation squared; *r* represents the zero-order correlation.
* $P < .05$.
** $P < .01$.

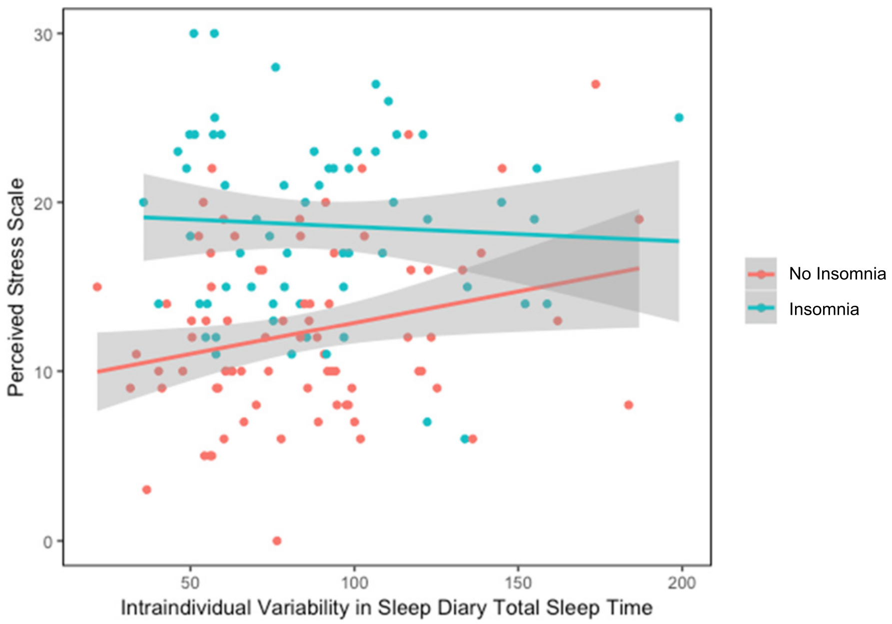

Fig. 1. Moderated effect of insomnia status on the association between IIV in sleep diary TST and perceived stress. Note. Gray bands represent 95% CIs.

perceived stress ($\beta = 0.04$, SE = 0.02, $P = .07$), whereas those with insomnia had a negative association between IIV in TST and perceived stress ($\beta = -0.02$, SE = 0.01, $P = .12$; Fig. 1). Insomnia status did not moderate the effect of IIV in sleep diary–determined SE or CM on perceived stress, or the effect of IIV in actigraphy-determined TST, SE, or CM on perceived stress.

Discussion

The current study examined the association among both subjective and objective measures of IIV in sleep and perceived stress in young adults with and without insomnia. Greater IIV in sleep diary–determined TST, SE, and CM was not associated with perceived stress, whereas greater IIV in actigraphy-determined TST (but not SE or CM) was associated with greater perceived stress. Insomnia status was the most robust predictor of perceived stress, and on average, students with insomnia reported greater perceived stress, shorter habitual subjective TST, lower habitual subjective SE, and greater IIV in subjective SE. Insomnia status also moderated the association between IIV in subjective TST and PSS such that only among those students *without* insomnia was higher IIV in sleep-diary TST associated with higher perceived stress. These results highlight the importance of assessing IIV in subjective and objective sleep parameters in future sleep health research.

In the current study, greater IIV in actigraphy-determined TST was associated with increased perceived stress. However, after controlling for mean TST and insomnia status, this effect was attenuated. These results replicated findings from 2 similar studies which showed greater IIV in actigraphy-determined TST, sleep fragmentation, time in bed, and SOL was associated with more negative mood and stressful life events in adults and adolescents.[10,22] Together, these findings suggest obtaining inconsistent TST from night-to-night may be associated with impairments in mood and the ability to cope with daily stressors.

Interestingly, we did not observe any significant findings between IIV in sleep diary TST, SE, or CM with perceived stress, or between IIV in actigraphy SE or CM with perceived stress. This may be attributed to a relative restriction of range in IIV in SE or CM compared to IIV in TST. It is also possible that inconsistency in the amount of TST obtained from night to night is simply more stressful for college students than inconsistency in CM (ie, sleep timing) or SE (ie, sleep fragmentation).

There also is now consensus that sleep diaries and actigraphy can be considered complementary but partially distinct measures.[27,38] Sleep diaries capture an individual's perceptual awareness of sleep/wake, whereas actigraphy captures behavioral quiescence. Actigraphy also may be less biased in estimating IIV in TST than sleep diaries. Previous studies have shown actigraphy is less biased than are sleep diaries for estimating *average* TST.[27] Comparatively little work has been done to estimate the validity of actigraphy and sleep diaries for estimating IIV in TST. In the current study, IIV in actigraphy- and sleep diary–determined TST was only moderately correlated ($r = 0.60$). Together, this evidence suggests sleep diaries and actigraphy may be somewhat discrete measures that can each be useful in understanding unique associations between sleep, insomnia, and health.

Overall, our results indicated insomnia status was the most robust predictor of perceived stress (explaining 26% of the unique variance in perceived stress). This is unsurprising given previous research showing insomnia is strongly associated with increased stress reactivity and higher levels of perceived stress.[16] Those with insomnia also tend to exhibit greater “sleep reactivity” or pronounced sleep disturbances in the face of stress.[39] This may be due to increased cortical arousal and hyperactivation of the hypothalamic pituitary adrenal (HPA) axis and sympathetic nervous system (SNS). It is possible that those with insomnia who experience increased sleep reactivity also may feel more impacted by stressful events, which in turn lead to increases in perceived sleep disturbances.

Insomnia status was not associated with any of the objective sleep parameters in the current study. There are a number of potential explanations for these findings. First, although diagnostic criteria for insomnia do not require objective sleep disturbances (eg, long SOL, low SE, short TST) to be present, insomnia with and without objective sleep disturbances may constitute 2 different subtypes of insomnia. Each of these subtypes may be differentially associated with health correlates. For example, those who report insomnia symptoms *without* objective sleep disturbances (sometimes called *paradoxical insomnia*) often exhibit increased sensitivity to external stimuli and cognitive-emotional and cortical arousal but typically not increased risk for morbidity and mortality.[40] In contrast, those who report insomnia *with* objective sleep disturbances often exhibit greater cognitive-emotional and cortical arousal, activation of the SNS and HPA axis, and a higher risk for morbidity and mortality.[40,41] Therefore, those with insomnia with objective sleep disturbances may exhibit a more severe phenotype[40]; future studies should examine insomnia phenotype as a moderator of IIV in sleep and perceived stress associations.

Another explanation for the null results with insomnia and actigraphy sleep parameters may be that actigraphy cannot fully differentiate between time in bed actually asleep vs time in bed awake but not moving and therefore may underestimate actual sleep disturbances. Future studies should use additional objective measures of sleep that can differentiate between these 2 states, such as at-home electroencephalography or PSG, to measure how IIV in sleep may be related to stress. Assessing more objective biomarkers of stress, such as cortisol, heart rate variability, or blood pressure, may also be useful in disentangling the association between sleep and stress. For example, one previous study demonstrated that greater IIV in sleep fragmentation was associated with higher levels of nocturnal norepinephrine,[10] and another found that greater IIV in sleep timing and TST (but not mean sleep) was associated with flatter diurnal cortisol slopes and higher allostatic load.[42] Both of these studies suggest that greater IIV in sleep may be associated with dysregulated HPA axis and SNS functioning.

Our results also indicated a significant moderation effect between IIV in TST and stress by insomnia status: for people *without* insomnia, greater IIV in sleep diary–determined TST was associated with *greater* perceived stress, whereas for people *with* insomnia, IIV in sleep diary–determined TST was associated with *lower* perceived stress. Although this was a small effect ($sr^2 = .03$), these results tentatively suggest that greater IIV in perceived TST may actually be more stressful for those *without* insomnia. This finding may be attributed to the fact that those with insomnia are likely more accustomed to experiencing greater IIV in sleep and higher average levels of perceived stress; therefore, IIV in sleep may be less salient or impactful for those with insomnia.

Although this study did not examine directionality of the association among insomnia, IIV in sleep, and perceived stress, it is highly likely that a bidirectional or cyclical association exists. The intrusion of stressful life events may make it more difficult to maintain a consistent sleep schedule, and the inability to maintain a consistent sleep schedule may serve as a stressor itself. Night-to-night variability in sleep timing may stem from daytime stressors or nighttime rumination, or greater fluctuations in the sleep window may produce greater daytime impairment and perceived stress. Other studies have indeed shown that the association among stress, rumination, and sleep quality is bidirectional and may result in a vicious cycle.[43] Future longer-term, prospective longitudinal studies are needed to examine if the association between IIV in sleep and stress also is bidirectional.

Limitations and future directions

Although this study had multiple strengths (eg, use of a clinical sample determined through a structured clinical interview, use of actigraphy, examining both means and IIV in sleep), there are some limitations that warrant future research. First, we only used 7 days of sleep diaries and actigraphy. Although 7 days may be sufficient to achieve adequate reliability in some measures of mean sleep (eg, TST), other measures of mean sleep (ie, SOL, a component of SE) may require 14 or more days of data to ensure adequate reliability.[44] To date, nothing is known about how many days are needed to ensure reliability of IIV in sleep data. However, adding more days of assessment should always be weighed against participant burden. Second, although actigraphy has been validated for the assessment of TST and SE in those with insomnia,[27] as previously discussed, it may underestimate the amount of time individuals spent awake in bed. Future studies should use ambulatory electroencephalography or PSG as an alternative way to assess sleep naturalistically. Third, other variables, such as chronotype and race/ethnicity, may modify the associations we observed and should be examined in future research. Fourth, we chose to exclude individuals with comorbid Axis I conditions to improve the internal validity of the parent study, but in doing so, we may have limited the generalizability of our results (as most individuals with insomnia have comorbid Axis I disorders). Finally, this study only assessed perceived stress at 1 time point, but it may also be useful to examine the daily, within-person associations between insomnia symptoms, objective and subjective sleep, and perceived stress using repeated measures designs.

Potential clinical implications

Regardless of insomnia diagnosis, our results suggest that maintaining a more consistent sleep schedule may be associated with lower stress in college students. For those college students with insomnia, mindfulness-based stress reduction (MBSR) or cognitive behavioral therapy for insomnia (CBT-I) may be useful treatment strategies to help address sleep state misperception and coping with perceived stress.[45] Both CBT-I and MBSR emphasize the importance of coping with underlying stressors that might affect sleep. CBT-I in particular also emphasizes maintaining a consistent sleep schedule, as well as engaging in stimulus control (ie, only using the bed for sleep), sleep hygiene (eg, not using caffeine before bedtime, avoiding bright light in the evening), and sleep restriction (restricting sleep so that sleep is more consolidated), which may help reduce IIV in sleep. CBT-I has been shown to be an effective long-term treatment for insomnia and also to reduce IIV in subjective SOL, waketime, bedtime, TST, and WASO.[46]

Conclusions

Given the high levels of perceived stress that college students face, understanding the sources of their stress is of critical importance for improving their health and well-being. Results from this study suggest that insomnia appears to be associated with subjective differences in average and IIV in sleep and is a strong predictor of greater perceived stress in college students. Greater IIV in actigraphy-determined TST may also be associated with increased perceived stress. Maintaining a consistent sleep schedule and targeting insomnia symptoms via MBSR or CBT-I may be effective ways to reduce perceived stress in college students. Future research should examine the cyclical or bidirectional nature of these associations.

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References

1. Saleh D, Camart N, Romo L. Predictors of stress in college students. *Front Psychol*. 2017;8:19.

2. Beiter R, Nash R, McCrady M, et al. The prevalence and correlates of depression, anxiety, and stress in a sample of college students. *J Affect Disord*. 2015;173:90–96.
3. Yoo S-S, Gujar N, Hu P, Jolesz FA, Walker MP. The human emotional brain without sleep—a prefrontal amygdala disconnect. *Curr Biol*. 2007;17(20):R877–R878.
4. Walker MP, van Der Helm E. Overnight therapy? The role of sleep in emotional brain processing. *Psychol Bull*. 2009;135(5):731.
5. Smith MT, Edwards RR, McCann UD, Haythornthwaite JA. The effects of sleep deprivation on pain inhibition and spontaneous pain in women. *Sleep*. 2007;30(4):494–505.
6. Irwin MR, Olmstead R, Carrillo C, et al. Sleep loss exacerbates fatigue, depression, and pain in rheumatoid arthritis. *Sleep*. 2012;35.
7. Taylor DJ, Kelly K, Kohut ML, Song KS. Is insomnia a risk factor for decreased influenza vaccine response? *Behav Sleep Med*. 2017;15(4):270–287.
8. Lim J, Dinges DF. A meta-analysis of the impact of short-term sleep deprivation on cognitive variables. *Psychol Bull*. 2010;136(3):375.
9. Taylor DJ, Bramoweth AD, Grieser EA, Tatum JI, Roane BM. Epidemiology of insomnia in college students: relationship with mental health, quality of life, and substance use difficulties. *Behav Ther*. 2013;44(3):339–348.
10. Mezick EJ, Matthews KA, Hall M, et al. Intra-individual variability in sleep duration and fragmentation: associations with stress. *Psychoneuroendocrinology*. 2009;34(9):1346–1354.
11. Buysse DJ, Cheng Y, Germain A, et al. Night-to-night sleep variability in older adults with and without chronic insomnia. *Sleep Med*. 2010;11(1):56–64.
12. Fernandez-Mendoza J, Vela-Bueno A, Vgontzas AN, et al. Cognitive-emotional hyperarousal as a premorbid characteristic of individuals vulnerable to insomnia. *Psychosom Med*. 2010;72(4):397–403.
13. Campbell R, Soenens B, Beyers W, Vansteenkiste M. University students' sleep during an exam period: the role of basic psychological needs and stress. *Motivation and Emotion*. 2018;42(5):671–681.
14. Wiklund M, Malmgren-Olsson EB, Ohman A, Bergstrom E, Fjellman-Wiklund A. Subjective health complaints in older adolescents are related to perceived stress, anxiety and gender—a cross-sectional school study in Northern Sweden. *BMC Public Health*. 2012;12(993):1471–2458.
15. Lund HG, Reider BD, Whiting AB, Prichard JR. Sleep patterns and predictors of disturbed sleep in a large population of college students. *J Adolesc Health*. 2010;46(2):124–132.
16. Drake CL, Pillai V, Roth T. Stress and sleep reactivity: a prospective investigation of the stress-diathesis model of insomnia. *Sleep*. 2014;37(8):1295–1304.
17. Kalmbach DA, Cuamatzi-Castelan AS, Tonnu CV, et al. Hyperarousal and sleep reactivity in insomnia: current insights. *Nat Sci Sleep*. 2018;10:193–201.
18. Taylor DJ, Wilkerson AK, Pruiksma KE, et al. Reliability of the structured clinical interview for DSM-5 sleep disorders module. *J Clin Sleep Med*. 2018;14(3):459–464.
19. Lev Ari L, Shulman S. Pathways of sleep, affect, and stress constellations during the first year of college: transition difficulties of emerging adults. *Journal of Youth Studies*. 2012;15(3):273–292.
20. Bei B, Wiley JF, Trinder J, Manber R. Beyond the mean: a systematic review on the correlates of daily intraindividual variability of sleep/wake patterns. *Sleep Med Rev*. 2016;28:108–124.
21. Carney CE, Edinger JD, Meyer B, Lindman L, Istre T. Daily activities and sleep quality in college students. *Chronobiol Int*. 2006;23(3):623–637.
22. Bei B, Manber R, Allen NB, Trinder J, Wiley JF. Too long, too short, or too variable? Sleep intraindividual variability and its associations with perceived sleep quality and mood in adolescents during naturalistically unconstrained sleep. *Sleep*. 2017;40(2).
23. Molzof HE, Emert SE, Tutek J, et al. Intraindividual sleep variability and its association with insomnia identity and poor sleep. *Sleep Med*. 2018;52:58–66.
24. Manconi M, Ferri R, Sagrada C, et al. Measuring the error in sleep estimation in normal subjects and in patients with insomnia. *J Sleep Res*. 2010;19(3):478–486.
25. Carney CE, Buysse DJ, Ancoli-Israel S, et al. The consensus sleep diary: standardizing prospective sleep self-monitoring. *Sleep*. 2012;35(2):287–302.
26. Lichstein KL, Rosenthal TL. Insomniacs' perceptions of cognitive versus somatic determinants of sleep disturbance. *J Abnorm Psychol*. 1980;89(1):105–107.
27. Williams JM, Taylor DJ, Slavish DC, et al. Validity of actigraphy in young adults with insomnia. *Behav Sleep Med*. 2018:1–16.
28. Coursey RD, Frankel BL, Gaarder KR, Mott DE. A comparison of relaxation techniques with electrosleep therapy for chronic, sleep-onset insomnia a sleep-EEG study. *Biofeedback Self Regul*. 1980;5(1):57–73.
29. Sánchez-Ortuño MM, Carney CE, Edinger JD, Wyatt JK, Harris A. Moving beyond average values: assessing the night-to-night instability of sleep and arousal in DSM-IV-TR insomnia subtypes. *Sleep*. 2011;34(4):531–539.
30. Lichstein KL, Stone KC, Donaldson J, et al. Actigraphy validation with insomnia. *Sleep*. 2006;29(2):232–239.
31. Cohen S, Kamarck T, Mermelstein R. A global measure of perceived stress. *J Health Soc Behav*. 1983;24:385–396.
32. American Psychological Association. Diagnostic and Statistical Manual of Mental Disorders (4th Ed., Text Rev.*)*. Washington, DC2000.
33. R: A Language and Environment for Statistical Computing [Computer Program]. Vienna, Austria: R Foundation for Statistical Computing; 2013.
34. varian: variability analysis in R [computer program]. Version 0.2.22016.
35. apaTables: create American Psychological Association (APA) style tables [computer program]. Version 1.5.12017.
36. ggplot2: Elegant Graphics for Data Analysis. [Computer Program]. New York: Springer-Verlag 2016.
37. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed.. Lawrence Earlbaum Associates: Hillsdale, NJ; 1988.
38. Tryon WW. Issues of validity in actigraphic sleep assessment. *Sleep*. 2004;27(1):158–165.
39. Drake CL, Friedman NP, Wright KP, Roth T. Sleep reactivity and insomnia: genetic and environmental influences. *Sleep*. 2011;34(9):1179–1188.
40. Vgontzas AN, Fernandez-Mendoza J, Liao D, Bixler EO. Insomnia with objective short sleep duration: the most biologically severe phenotype of the disorder. *Sleep Med Rev*. 2013;17(4):241–254.
41. Fernandez-Mendoza J, Vgontzas AN, Liao D, et al. Insomnia with objective short sleep duration and incident hypertension: the Penn State cohort. *Hypertension*. 2012;60(4):929–935.
42. Bei B, Seeman TE, Carroll JE, Wiley JF. Sleep and physiological dysregulation: a closer look at sleep intraindividual variability. *Sleep.* 2017;zsx109.
43. Van Laethem M, Beckers DGJ, Kompier MAJ, Kecklund G, van den Bossche SNJ, Geurts SAE. Bidirectional relations between work-related stress, sleep quality and perseverative cognition. *J Psychosom Res*. 2015;79(5):391–398.
44. Wohlgemuth WK, Edinger JD, Fins AI, Sullivan RJ. How many nights are enough? The short-term stability of sleep parameters in elderly insomniacs and normal sleepers. *Psychophysiology*. 1999;36(2):233–244.
45. Taylor DJ, Zimmerman MR, Gardner CE, et al. A pilot randomized controlled trial of the effects of cognitive-behavioral therapy for insomnia on sleep and daytime functioning in college students. *Behav Ther*. 2014;45(3):376–389.
46. Suh S, Nowakowski S, Bernert RA, et al. Clinical significance of night-to-night sleep variability in insomnia. *Sleep Med*. 2012;13(5):469–475.