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Sleep Disturbance and Older Adults' Inflammatory Responses to Acute Stress

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Abstract

Objectives—Poor sleep diminishes mental and physical health. The objective of this study was to examine associations between sleep disturbance and interleukin-6 (IL-6) responses to acute mental stress in older adults.

Design—Observational study of community-dwelling, healthy older adults.

Setting—Participants completed the study in a clinical research laboratory of a mid-sized university.

Participants—Generally healthy, community-dwelling men and women 50 years of age and older.

Measurements—IL-6 and negative affect at rest and following a series of challenging cognitive tests; sleep quality; depressive symptoms; perceived stress; loneliness.

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Results—Participants categorized as poor sleepers based on Pittsburgh Sleep Quality Index scores had significantly larger IL-6 responses to the cognitive stressors compared to good sleepers. The association between poor sleep and heightened IL-6 response to acute stress was not explained by other psychosocial factors previously linked to immune dysregulation, including depressive symptoms, perceived stress, and loneliness.

Conclusions—Findings add to the growing evidence for poor sleep as an independent risk factor for poor mental and physical health. Older adults may be particularly vulnerable to effects of sleep disturbance due to significant age-related changes in both sleep and inflammatory regulation.

Keywords

sleep disturbance; stress; interleukin-6

Objective

Sleep disturbance is independently linked to quality of life decrements (1), psychiatric (2) and medical (3) morbidity, and inflammatory function (4). Normal sleep regulates and is regulated by inflammatory cytokines (5); not surprisingly, insomnia (6) and sleep disturbance (7-11) are related to inflammatory cytokine alterations, especially elevated levels of interleukin (IL)-6. Despite this evidence, relatively little is known regarding the pathways through which poor sleep impacts circulating levels of inflammatory cytokines.

Known links between stress and inflammatory processes provide a framework for considering how sleep disturbance impacts inflammation. Chronic stress has well-established deleterious physiological consequences, including heightened inflammation and decreased adaptive immune function (12). Chronic stress can also modulate physiological stress reactivity to discrete, acute stressors (e.g., (13, 14), and disrupt neuroendocrine regulation of inflammatory processes (15). In one study, chronic stress was associated with larger increases in circulating IL-6 in response to acute mental stressors (16). Sleep disturbance may also impact physiological stress and inflammatory reactivity in a manner similar to chronic stress (17) that, in turn, increases risk for heightened inflammation; however, the impact of sleep disturbance on inflammatory cytokine responses to acute stress is unknown.

Sleep disturbance may also indirectly impact acute stress reactivity by diminishing emotional and cognitive resources that, in turn, increase psychological stress and its inflammatory sequelae. Sleep disturbance is consistently associated with negative mood (18), and negative emotional arousal has been linked to increased inflammatory markers (19). Accordingly, poor sleep might relate to greater negative mood in response to acute stress that heightens inflammatory responses. Diminished cognitive resources may also confer risk for poor stress regulation and greater stress reactivity (20). Thus, cognitive deficits that may result from sleep disturbance (21) could also contribute to heightened physiological reactivity to mental stress.

The aim of the current study was to examine whether sleep disturbance in a healthy sample of older adults was associated with larger IL-6 responses to mental stressors. Age-related increases in sleep disturbance (22, 23), inflammatory dysregulation (24) and increases in chronic, low level inflammation due to immunosenescence (25) may render older adults particularly vulnerable to poor sleep and subsequent mental and physical health consequences. We also examined whether negative emotional arousal or diminished cognitive function would mediate the association between older adults' sleep and IL-6 responses. Finally, we examined whether loneliness and perceived stress, given their links to

both sleep (7) and elevated inflammatory markers (9, 26) would help explain associations between poor sleep and IL-6 responses in older adults.

Methods

Study Sample

Healthy men and postmenopausal women 50 years of age and older were recruited through community advertisements for a study of stress and memory. Exclusion criteria included: health problems having immunological or endocrinological components (e.g., cancer, recent surgeries, strokes, peripheral vascular disease, diabetes); smoking; diagnosis of dementia or evidence of cognitive impairment; more than 14 alcoholic drinks per week; more than 30% above ideal weight or no more than 10% below (27); needle or blood phobias; current use of psychotropic medications, including anti-depressants or anxiolytics.

The final sample included 45 women and 38 men who had complete data on key measures for the current analyses (from among 110 participants in the main study); their average age was 61.16 years (SD = 8.78; range = 50 – 87 years); 76 (91.6%) were White, non-Hispanic, 5 (6.0%) were Black or African American, 1 (1.2%) was Hispanic or Latino, and 1 (1.2%) was American Indian, Alaska Native. None reported use of sedatives or hypnotics, or other sleep medications, including nonprescription sleep aids. The internal review boards at Ohio University and the University of Rochester approved the study; all participants provided written informed consent prior to participation.

Study Sessions

At an initial session, participants provided informed consent, demographics information and had cognitive status confirmed using the Repeated Battery for the Assessment of Neuropsychological Status (RBANS; (28). Prior to a 3-hour study session approximately one week later, participants completed self-reports of sleep quality, perceived stress, loneliness, and medication use, and received a reminder call about study preparations (no anti-inflammatory medication and alcohol use for 24 hours, caffeine use for 2 hours, and food consumption for 30 minutes prior to their study sessions).

All study sessions started between 1:00 and 3:00 p.m. to control for diurnal variation in cognitive performance and biological indices. Participants completed questionnaires, and had height and weight measured and a venous cannula placed in their non-dominant arm by a research nurse. Participants then sat quietly for a 30-minute adaptation period, completed the affect measure, read materials for 10 minutes (unrelated to the current study), and were then administered a series of neuropsychological tests of verbal and working memory by testers trained in standardized procedures. Following the cognitive tests, participants reported on their current affect, sat quietly for a 60-minute recovery period, and reported their affect once again.

Blood was drawn through the cannula at the end of the adaptation period (baseline), immediately following cognitive testing, and at 20-, 40- and 60-minutes thereafter for the majority of older adults (n = 74; 89.2%). For 9 participants, venipuncture was preferred in lieu of the cannula. In light of consistent evidence for delayed IL-6 level increase in response to acute stressors (29), it was decided a priori to limit venipuncture to baseline, and 20- and 60-minutes after cognitive testing (2 of these 9 participants (2.4%) preferred venipuncture at baseline and 60-minutes post-cognitive testing only). Participants wore electrodes and a blood pressure cuff throughout the session to obtain cardiovascular measures, and provided multiple saliva samples before and after the cognitive testing; these measures are unrelated to the current study reported here. Participants were compensated up to \$90 for their participation.

Self-Report Measures

Sleep Quality—The Pittsburgh Sleep Quality Index (PSQI; (30)) is a well-validated and reliable 18-item scale that assesses sleep quality and sleep disturbances over a 1-month interval utilizing seven “component” scores consisting of subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances (e.g., awakened due to coughing or snoring, pain, etc), use of sleeping medications, and daytime dysfunction. These component scores are summed to yield one global sleep quality score that ranges from 0 to 21 (30). The PSQI has been validated in older adults (31), and a PSQI global score greater than 5 indicates clinical sleep impairment (30) with a sensitivity of 98.7% and specificity of 84.4% (32) in distinguishing individuals with and without insomnia. Using this cutoff, participants were categorized as either poor or good sleepers (i.e., a PSQI global score > 5 and ≤ 5, respectively).

Current negative affect—The Positive and Negative Affect Schedule (33) is a well-validated and reliable 20-item self-report measure of state mood, and research supports its use with older adults (34). In the present study, Cronbach's alpha was .65, .82, and .76 for the negative affect subscale completed at baseline, immediately post-cognitive tests, and 60-minutes post-cognitive testing, respectively.

Global perceived stress—The 10-item Perceived Stress Scale (PSS; (35)) measured the degree to which current life situations are appraised as stressful. The single factor PSS has satisfactory psychometric properties (35), and criterion validity in older adults (36). Cronbach's alpha for the current sample was .89.

Loneliness—The 20-item UCLA Loneliness Scale (UCLA-LS; (37)) measured perceived adequacy of interpersonal relationships. The UCLA-LS has demonstrated reliability and validity in elderly populations (37, 38). Cronbach's alpha was .91 for the current sample.

Depressive symptoms—The 30-item Geriatric Depression Scale (GDS; (39)) was used to measure depressive symptoms in older adults. The GDS is well-validated and reliable, and can correctly classify individuals diagnosed as depressed with clinical interviews (39). Cronbach's alpha for the present study was .91.

Neuropsychological Tests

The Auditory Verbal Learning Test (AVLT; (40)) is a common, well validated measure of verbal learning and recall, consisting of a 15-item word list practiced over five learning trials, immediate recall of the list after an intrusion list, and a 20-min delayed recall and recognition of the list. The immediate list recall and the 20-minute delayed recall served as the dependent variables for the present study.

The Auditory Consonant Trigram task (ACT; (40)) measures auditory working memory in which individuals recall a series of three-letter trigrams after a delay of variable length (9- to 36-sec), during which they complete a cognitively interfering task (mental subtraction). The dependent variables utilized in the present study were total number of letters correctly recalled across the 36-delay trials (the most difficult trials), and the total number of correct letters recalled across all trials.

IL-6 Assays

Blood was kept on ice, centrifuged at 4°C, and plasma stored at -80° C within 30 minutes following collection. Plasma IL-6 was assayed in duplicate using Quantikine High

Sensitivity Immunoassay kits (R&D Systems, Inc., Minneapolis, MN). Intra- and interassay coefficients of variation were < 10%.

Data Analysis

Preliminary IL-6 analyses—IL-6 levels were skewed and, therefore, log transformed (descriptive data are presented as non-transformed values (pg/ml)). Based on independent t-tests, IL-6 levels did not significantly differ between subjects whose blood was collected by catheter or venipuncture at common timepoints (all p 's > .30), and controlling for blood draw procedure did not alter findings. IL-6 change from baseline (calculated as IL-6 level at post-testing timepoint minus baseline) was more than twice as large at 60-minute post-testing ($M = 0.89$ pg/ml; $SD = 1.80$) compared to 20-minutes post-testing ($M = 0.40$ pg/ml; $SD = 0.89$; $t(75) = -3.23$, $p = .002$) among participants with data from all three timepoints. Thus, IL-6 change from baseline to the 60-minute recovery period was calculated (60-minute recovery IL-6 level minus baseline IL-6 level) and used as the key dependent variable in analyses.

Primary analyses—Characteristics of poor sleepers (PSQI > 5) and good sleepers (PSQI ≤ 5) were compared with t-tests for continuous variables and chi-square tests for categorical variables. IL-6 and negative affect changes from baseline were examined using paired t-tests comparing baseline and post-testing values. Pearson correlation coefficients were used to evaluate associations between potential covariates and variables of interest. Linear regression models were used to examine whether IL-6 and negative affect responses to the acute stressor, and cognitive measures, differed between sleep groups. If affective response or cognitive performance differed by sleep group, mediation analyses were planned (41). Regression models of IL-6 response were adjusted for age (25), body mass index ($BMI = \text{mass (kg)}/[\text{height (m)}]^2$) and depressive symptoms (42) to control for their influence on IL-6 production. Models of negative affect response were adjusted for GDS score, and age. GDS score, and education level were evaluated as potential covariates for analyses of cognitive performance. Finally, if poor sleepers also reported more stress or loneliness, each variable was included in subsequent regression models of IL-6 response to determine whether stress or loneliness explained potential associations between poor sleep and inflammatory responses. All tests were two-tailed with alpha set at .05.

Results

Sample Characteristics

More than a quarter of participants were categorized as poor sleepers (PSQI score > 5: $n = 22$; 26.5%). Descriptive statistics comparing sleep groups are presented in Table 1. Compared to good sleepers, poor sleepers reported significantly more depressive symptoms, but were on average non-depressed (GDS score of < 10 (39)). Poor sleepers also reported more loneliness and global perceived stress relative to good sleepers. Negative affect reported at baseline during the laboratory session did not differ between sleep groups. Poor sleepers did not differ from good sleepers on age, gender distribution, BMI, use of antihypertensive or statin medications, or baseline levels of IL-6.

IL-6 Response to Cognitive Testing

Across the sample, older adults showed modest but statistically significant increases in IL-6 from baseline ($M = 2.10$ pg/ml, $SD = 1.37$) to 60-min post-cognitive testing ($M = 2.92$ pg/ml, $SD = 1.85$; $t(81) = -5.56$, $p < .001$).

Baseline IL-6 levels were positively associated with age ($r(81) = .27$, $p = .01$), BMI ($r(81) = .25$, $p = .03$), and negatively correlated with IL-6 response ($r(81) = -.33$, $p = .002$).

Baseline IL-6 was not associated with GDS scores ($r(81) = -.14, p = .23$) or PSQI score ($r(81) = -.08, p = .49$), and did not differ by sleep group (Table 1). After adjustment for baseline IL-6 levels, age, BMI, and GDS score, poor sleepers had a significantly larger increase in IL-6 from baseline in response to the acute stressors compared to good sleepers (Table 2, Model 1; Figure 1).

Affective Response to Cognitive Testing

Negative affect also increased from baseline ($M = 10.84, SD = 1.64$) to immediately post-testing ($M = 12.98, SD = 3.56; t(78) = -6.31, p < .001$), but returned to baseline by the end of the 60-minute recovery period ($M = 10.85, SD = 2.14; t(78) = 0.00, p = 1.00$). Baseline negative affect was not associated with age ($r(78) = .05, p = .69$), BMI ($r(78) = .15, p = .18$), GDS scores ($r(78) = .17, p = .14$), negative affect response ($r(78) = .13, p = .25$) or PSQI scores ($r(78) = .13, p = .25$), and was not significantly different between sleep groups (Table 1). However, when regressing negative affect change onto sleep group and GDS score (model $R^2 = .31; F(2, 77) = 16.98; p < .001$), poor sleep was associated larger increases in negative affect in response to the cognitive testing ($B(SE) = 1.66(.67), t(77) = 2.48, p = .02$) after controlling for GDS score ($B(SE) = .24(.06), t(77) = 3.88, p < .001$; Figure 1).

Using mediation testing procedures (41), we next determined if the association between poor sleep and heightened IL-6 response was mediated by negative affect change by regressing IL-6 change onto sleep group and negative affect change while controlling for age, BMI, baseline IL-6, and GDS score. Mediation would be indicated if, in the full model, sleep group was no longer associated with IL-6 change while negative affect change significantly predicted IL-6. On the contrary, sleep group remained a significant predictor of IL-6 change after controlling for negative affect change in response to cognitive testing (Table 2, Model 2).

Cognitive Performance

Immediate and delayed recall scores from the AVLT were not associated with age (immediate: $r(81) = -.17$, delayed: $r(81) = -.17$), education (immediate: $r(81) = .18$, delayed: $r(81) = .12$), or GDS score (immediate: $r(81) = -.01$, delayed: $r(81) = -.09$; all p 's $> .11$). Poor sleepers did not differ from good sleepers on AVLT immediate recall (poor sleepers: $M(SD) = 8.32(2.15)$; good sleepers: $M(SD) = 8.59(2.77)$; $F(1, 82) = .17, p = .68, B(SE) = -.28(.65)$) or delayed recall (poor sleepers: $M(SD) = 7.32(3.09)$; good sleepers: $M(SD) = 8.15(3.03)$; $F(1, 82) = 1.20, p = .28, B(SE) = -.83(.76)$).

Total working memory scores from the ACT were related to both age ($r(80) = -.25, p = .03$) and education ($r(80) = .23, p = .04$), and working memory scores based on the 36-second delay trials were related to education ($r(80) = .23, p = .04$), but not age ($r(80) = -.18, p = .12$). Poor sleepers did not differ from good sleepers on total working memory scores after adjustment for age and education (full model $R^2 = .11, F(3, 81) = 3.02, p = .04$); sleep category: $B(SE) = -.71(2.06), t(78) = -.34, p = .73$; poor sleepers: $M_{adj}(SD) = 42.48(1.77)$; good sleepers: $M_{adj}(SD) = 43.18(1.05)$), or on working memory scores from 36-second delay trials after adjustment for education (full model $R^2 = .05, F(2, 81) = 2.13, p = .13$); sleep category: $B(SE) = -.20(.88), t(79) = -.23, p = .82$; poor sleepers: $M_{adj}(SD) = 8.35(.76)$; good sleepers: $M_{adj}(SD) = 8.55(.45)$).

Sleep, Loneliness and Perceived Stress

As shown in Table 1, poor sleepers reported significantly more loneliness and perceived stress relative to good sleepers. However, the relationship between poor sleep and greater IL-6 change withstood adjustment for perceived stress and loneliness (Table 2, Models 3 and 4).

Conclusion

Sleep disturbance is commonly reported in older adults (22); in our population, approximately 27% were classified as poor sleepers. As is also commonly reported, poor sleep was associated with higher depressive symptoms, higher loneliness and greater perceived stress. Notably, sleep disturbance was associated with heightened IL-6 responses to the cognitive stressors, and this association was independent of all variables examined, including negative affect. Our findings are suggestive of a greater acute inflammatory stress response in poor sleepers. The significance of the findings is underscored by their relevance to older adults for whom poor sleep-related inflammation is transposed onto immunosenescence and may contribute additively or synergistically to inflammatory-related mental and physical morbidity.

In the present study, baseline IL-6 levels did not distinguish between the two sleep groups. Other studies have linked sleep disturbance to higher IL-6 levels at rest in various samples (8-11), and others have found chronic stress to be associated with higher baseline IL-6 levels in older adult populations (43). It may be that our sample of healthy older adults has not yet reached the tipping point at which chronic stress/sleep disruption increases their risk for higher levels of inflammation. Others have similarly shown higher IL-6 responses to acute mental stress among depressed versus non-depressed adults in the absence of group differences in IL-6 levels at baseline (44). Notably, the findings here show that poor sleepers had post-testing levels of IL-6 that were on average greater than 3.19 pg/ml, a level found to increase risk for morbidity and mortality in older adults (45). It is likely that pre-stress levels of IL-6 were restored in these older adults, but an important question remains regarding the time course of recovery. Over time, repeated acute stressors—which can be considered discrete components of chronic stress—in addition to inflammatory effects of sleep disturbance itself—may eventually lead to higher baseline levels of IL-6. Longitudinal studies with similar populations to ours could illuminate the causality of the sleep disturbance-inflammation relationship.

The lack of association between self-reported sleep disturbance and memory performance adds to evidence suggesting that neuropsychological measures of verbal memory can show little difference between good and poor sleepers (46). Working memory performance was also similar between good and poor sleepers, adding to inconsistent findings (46). It is important to note that the majority of studies assessing neurocognitive function in the context of chronic sleep disturbance compare healthy controls with individuals meeting diagnostic criteria for primary insomnia. Whether heightened IL-6 response to acute mental stress is evident among individuals with primary insomnia remains to be determined. Further, the cognitive battery used in the current study measured aspects of executive function, whereas more consistent evidence supports diminished aspects of non-executive function, including attention and reaction time, in individuals with primary insomnia versus healthy controls (46). Experimental studies of sleep deprivation show similar effects of sleep disturbance on non-executive function, but also working memory (21). Nonetheless, it is unclear whether the effects of acute experimental sleep restriction are a good proxy for the long term effects of poor sleep, in general, or chronic insomnia, more specifically (46).

The present study documents that older adult poor sleepers have exaggerated IL-6 responses to an acute stress that appear independent of various psychosocial factors. Without the inclusion of young adults who are good versus poor sleepers, it is unclear whether the findings are generalizable, or if they are more specific to older adults. Regardless, since older adults are more vulnerable to both sleep disturbance and greater inflammation, it is important to understand the stress-related inflammatory sequelae of older adults' sleep disturbance. Although poor sleep, as indexed by PSQI scores, was associated with IL-6

responses after controlling for depressive symptoms, loneliness, and perceived stress, the reliance on self-reported sleep disturbance precludes any assumption about standard objective indices of sleep architecture or sleep continuity achieved by polysomnography. It is also possible that the effect size of negative affect, loneliness and perceived stress on these older adults' IL-6 responses is small relative to poor sleep. If so, the sample size may not have been adequate to detect even partial mediation by these psychological factors. Finally, our findings are limited to IL-6, which was chosen due to its strong link to age-related morbidity and mortality (25); however, sleep loss and stress affect multiple markers of inflammatory function (47). More comprehensive study of the inflammatory pathways affected by poor sleep and acute stressors is necessary and worthwhile.

As inflammation is a potent risk factor for psychiatric and physical morbidity and mortality in older adults, it is important to consider modifiable contributors to both basal and stress-induced levels of inflammatory cytokines. Sleep quality, a potentially important marker of successful aging (48), may be one such contributor. Our data suggest that sleep may be a plausible target for interventions designed to ameliorate inflammation and immunosenescence, as well as to improve quality of life for older adults.

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Figure 1. Increased interleukin-6 (IL-6) and negative affect in response to the cognitive testing in poor sleepers (solid line) relative to good sleepers (dotted line). Means and standard errors (bars) adjusted for age, BMI, and GDS score for IL-6, and GDS score for Positive and Negative Affect Scale (PANAS) negative affect score.

Table 1

Characteristics of Poor Sleepers (PSQI > 5) and Good Sleepers (PSQI ≤ 5)

	Poor sleepers (<i>n</i> = 22)	Good sleepers (<i>n</i> = 61)	<i>t</i> or χ^2	<i>df</i>	<i>p</i>
Age (years), <i>M</i> (<i>SD</i>)	60.81 (10.25)	61.28 (8.27)	.21	81	.83
Females, <i>n</i> (%)	15 (68.2)	30 (49.2)	2.35	1	.14
BMI, <i>M</i> (<i>SD</i>)	27.71 (4.26)	26.51 (4.30)	-1.12	81	.27
Global sleep quality (PSQI), <i>M</i> (<i>SD</i>)	9.45 (2.52)	3.43 (1.36)	-13.96	81	<.001
Depressive symptoms (GDS), <i>M</i> (<i>SD</i>)	7.50 (7.06)	2.38 (3.66)	-4.32	81	<.001
Global perceived stress (PSS), <i>M</i> (<i>SD</i>)	16.38 (6.93)	9.95 (5.31)	-4.39	78	<.001
Loneliness (UCLA-LS), <i>M</i> (<i>SD</i>)	42.43 (10.83)	29.58 (9.25)	-5.26	80	<.001
Anti-hypertensive use, <i>n</i> (%)	13 (21.3)	2 (9.5)	1.45	1	.33
Statin use, <i>n</i> (%)	2 (9.5)	8 (13.1)	.19	1	1.00
Education (highest grade completed), <i>M</i> (<i>SD</i>)	14.41 (3.36)	14.41 (3.86)	.59	81	.56
Baseline negative affect score (PANAS), <i>M</i> (<i>SD</i>)	11.33 (2.69)	10.66 (1.03)	-1.63	78	.11
Baseline IL-6 (pg/ml), <i>M</i> (<i>SD</i>)	1.86 (0.85)	2.19 (1.51)	.37	81	.71

Notes: BMI = Body Mass Index; PSQI = Pittsburgh Sleep Quality Index; GDS = Geriatric Depression Scale; PSS = Perceived Stress Scale; UCLA-LS = UCLA Loneliness Scale; PANAS = Positive and Negative Affect Schedule. One poor sleeper had missing medication use data, and two poor sleepers reported anti-depressant use on their home-completed medication form (but not at screening). Results from main analyses include these participants as excluding them did not alter findings. Degrees of freedom vary for t-tests due to missing PANAS, PSS, or UCLA-LS data.

Table 2
Adjusted Associations between Interleukin-6 (IL-6) Responses and Sleep Category

	Model 1			Model 2			Model 3			Model 4		
	B (SE)	t	p	B (SE)	t	p	B (SE)	t	p	B (SE)	t	p
Sleep category (PSQI or > 5)	1.21 (.46)	2.63	.01	1.42 (.47)	3.01	.004	1.01 (.49)	2.05	.04	1.20 (.50)	2.39	.02
Baseline IL-6	-2.25 (.73)	-3.07	.003	-2.28 (.73)	-3.14	.002	-1.98 (.77)	-2.59	.01	-2.33 (.76)	-3.05	.003
Age	.01 (.02)	.49	.62	.01 (.02)	.27	.79	.02 (.02)	.69	.50	.01 (.02)	.51	.61
BMI	-.02 (.04)	-.40	.73	-.03 (.04)	-.64	.56	-.01 (.05)	-.21	.87	-.01 (.05)	-.31	.75
Depressive symptoms (GDS)	-.09 (.04)	-2.31	.02	-.07 (.05)	-1.54	.13	-.09 (.06)	-1.51	.14	-.09 (.04)	-2.17	.03
Negative affect response (PANAS)				-.10 (.08)	-1.39	.17						
Global perceived stress (PSS)							.02 (.05)	.52	.61			
Loneliness (UCLA-LS)										.00 (.02)	.20	.85
R ²	.19			.24			.14			.20		

Notes: BMI = Body Mass Index; PSQI = Pittsburgh Sleep Quality Index; GDS = Geriatric Depression Scale; PSS = Perceived Stress Scale; UCLA-LS = UCLA Loneliness Scale; PANAS = Positive and Negative Affect Schedule. Linear regression models: Model 1 ($F(5, 82) = 3.67, p = .01$), sleep category (coded: good sleeper (PSQI = 5) = 0 and poor sleeper (PSQI > 5) = 1) adjusted for baseline IL-6 (log10 transformed), age, BMI, and GDS score; Model 2 ($F(6, 79) = 3.77, p < .001$), sleep category adjusted for Model 1 covariates + negative affect response (negative affect (NA) subscale of the PANAS; post-testing NA minus baseline NA); Model 3 ($F(6, 79) = 1.97, p = .08$), sleep category adjusted for Model 1 covariates + PSS score; Model 4 ($F(6, 81) = 3.02, p = .01$), sleep category adjusted for Model 1 covariates + UCLA-LS score.