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Sleep Quality and Cognitive Function in Type 1 Diabetes: Findings from the Study of Longevity in Diabetes (SOLID)

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Abstract

Study Objectives: To examine the association between sleep quality and global and domain-specific cognitive function among older individuals with type 1 diabetes (T1D).

Methods: We evaluated 695 individuals with T1D ages ≥60 that participated in the baseline assessment of the Study of Longevity in Diabetes (SOLID), which captured subjective sleep quality (Pittsburg Sleep Quality Index) and global and domain-specific (language, executive function, episodic memory, and simple attention) cognitive function. Multivariable linear regressions estimated the associations between sleep quality quartiles and overall and domain-specific cognitive function adjusting for age, sex, race/ethnicity, education, depressive symptoms, and severe hypoglycemic episodes. Sensitivity analyses examined the associations between aspects of sleep quality and global cognitive function.

Results: The worst sleep quality quartile was associated with lower global cognition (β=−0.08; 95% CI: −0.17, −0.01) and lower executive function (β=−0.17, 95% CI: −0.30, −0.03) compared to the best quartile of sleep quality adjusting for demographics and comorbidities. Sleep quality was not associated with language, episodic memory, or simple attention. Sleep medications and daytime dysfunction were most strongly associated with global cognition.

Conclusions: Our results suggest that sleep quality may be a modifiable risk factor for global cognitive function and executive function among elderly individuals with T1D.

Keywords

type 1 diabetes; sleep quality; cognitive function

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An estimated 50 to 70 million Americans are afflicted by sleep-related problems[1] and approximately 35.2% of US adults report short sleep duration (i.e. <7 hours in past 24 hours)[2]. The far-reaching negative impacts of sleep disorders and short sleep duration are exemplified by their associations with elevated risk of several health outcomes, including obesity[3], hypertension[3], stroke[3,4], and all-cause mortality[3,4]. Sleep disorders, short sleep duration, and sleep quality have also been associated with lower levels of cognitive function in general populations.[5–10] However, it remains unclear whether specific cognitive domains are impacted differentially by sleep quality[9–11].

Poor quality sleep burdens 31–41% of adults with type 1 diabetes (T1D)[12–14], as compared to 39–60% of adults with type 2 diabetes (T2D)[14–16], and 6.5–38% of adults without diabetes[12,17,18]. Poor sleep quality is more severe among adults with T1D compared to the general population.[19] Furthermore, T1D has been consistently associated with cognitive impairment.[20,21] However, the majority of this work has focused on individuals with T1D who are middle aged or younger.[20] As the life expectancy of individuals with T1D increases, a better understanding of cognitive function among older adults with T1D is needed. Identifying which risk factors for cognitive decline among individuals with T1D are modifiable is especially important for this population given the considerable burden and complexity of self-care management. It is unknown if sleep quality is associated with cognitive impairment among older adults with T1D.

In this study we examine the association between sleep quality and global and domain-specific cognitive function in a sample of individuals with T1D ages 60 and older. Cognitive data were collected by a thorough neuropsychological battery selected to assess global cognitive function as well as a range of cognitive domains including language, executive function, episodic memory, and simple attention. In sensitivity analyses we examine the association between various aspects of sleep quality and overall and domain specific cognitive function.

Methods

Study population.

These analyses included members of Kaiser Permanente Northern California (KPNC) with T1D who participated in the Study of Longevity in Diabetes (SOLID). SOLID is a prospective cohort study of diabetes and aging that recruited KPNC members ages ≥60. Potential participants were identified in electronic medical records using International Classification of Diseases (ICD)-9 and ICD-10 codes for T1D (250.x1, 250.x3, or E10.x) and T2D (250.x0, 250.x2, E11.x). Members were classified as having T1D if at least 75% of diagnostic codes related to diabetes were for T1D and they were prescribed insulin. Medical providers of potential participants were contacted and could provide information regarding whether a member met inclusion criteria or refuse their patient's participation for any reason. Potential participants for whom a medical provider did not report a refusal or ineligibility were sent an introductory letter. Potential participants that did not refuse by mail were contacted for a phone screening during which they were asked questions regarding type of diabetes diagnosis (T1D or T2D), age of diagnosis, and timing of insulin use initiation. Individuals who reported a diagnosis of T1D at ages ≤30 were classified as having T1D.

Manual medical record review was coducted for participants reporting the onset of T1D at ages ≥31 years to confirm T1D status. 805 individuals with T1D were enrolled in SOLID and completed baseline interviews.

This study was approved by the KPNC Internal Review Board and informed consent was provided by all enrolled participants.

Self-reported sleep quality.

Self-reported sleep quality in the past month was captured at the baseline interview by a modified version of the Pittsburgh Sleep Quality Index (PSQI)[22] that excluded an item assessing snoring frequency. The PSQI covers 7 components of sleep quality each of which has scores ranging from 0 (no difficulty) to 3 (severe difficulty): a one-item measure of subjective sleep quality, sleep disturbances, sleep medication use, daytime dysfunction, sleep latency, sleep duration, and sleep efficiency. The subjective sleep quality component was assessed through the following question: “During the past month, how would you rate your sleep quality overall?” and included the following response options: very good, fairly good, fairly bad, and very bad. Items assessing the frequency of sleep disturbances (e.g. too hot or cold, nightmares, pain), sleep medication use, and daytime dysfunction included the following response options: not during the past month, less than once a week, once or twice a week, three or more times a week. Sleep latency was captured through items assessing the average length of time spent transitioning from wakefulness to sleep and how often participants couldn’t fall asleep within 30 minutes (response options: not during the past month, less than once a week, once or twice a week, three or more times a week). Average sleep duration during the past month was captured continuously in hours and operationalized as a continuous variable and as binary variables using the following thresholds: ≤5 hours, ≤6 hours, ≤7 hours, and ≥9 hours of sleep. Sleep efficiency was defined as the percent of time in bed an individual was asleep. Global PSQI scores range from 0 to 21 with higher scores indicating worse sleep quality. Compared to polysomnographic results, a score of greater than 5 denotes poor sleep with a sensitivity and specificity of 90% and 87%.[22] Approximately 68% of the sample had poor sleep quality using a threshold of 5. Global PSQI was divided into quartiles, with higher quartiles reflecting worst sleep quality, to allow for a possible non-linear relationship between sleep quality and cognitive function.

Cognitive Function.

A comprehensive cognitive battery was administrated to all participants and, similar to a previous study among individuals with T2D, a factor analysis revealed four cognitive domains.[23] The language factor encompassed phonemic fluency (F and L), category fluency (animals and vegetables), list sorting (two alternative lists), and Multilingual Naming Test (MINT). The executive function domain encompassed the Trail Making Test (A and B), Digit Symbol Substitution, and the Stroop Color and Word Tests. The episodic memory domain encompassed the Word List Learning Test (immediate and delayed) and the Benson Complex Figure Copy (immediate and delayed). The simple attention domain encompassed the Diamond and TMX cancellation tests.

Overall and domain-specific scores were estimated using standardized (mean=0; standard deviations (SD)=1) cognitive function test scores. Domain-specific scores were estimated for individuals who completed at least 50% of the relevant tests. Global cognitive function scores were estimated as the average of the four domain specific scores for individuals who completed at least 50% of all cognitive function tests. Impaired global or domain-specific scores were defined as scores less than 1.5 standard deviation below the mean.

Covariates.

Date of birth and interview date were used to estimate age at interview. Self-reported race/ethnicity was obtained during baseline interviews and re-categorized into the following group: White, Black, Hispanic, Asian, other racial/ethnic group, and refuse/don't know. Sex was obtained from KPNC records. The frequency of severe hypoglycemic episodes during the past year was captured at baseline using the following item: "In the past year, how often have you had severe hypoglycemic episodes? (Episodes where you were unconscious or had a seizure and needed glucagon or intravenous glucose)". The frequency of severe hypoglycemic episodes was recoded into 0, 1 or 2, and ≥3. The Beck Depression Inventory was implemented to capture depressive symptoms. The scale is comprised of 21 items, each of which elicits a rating of symptom severity on a scale of 0 to 3, that are summed to provide a total score ranging from 0 to 63.[24] Individuals with a total score of at least 13 were considered to have elevated depressive symptoms based on prior work demonstrating a moderate to high sensitivity (0.85) and specificity (0.88) of this threshold compared to a diagnosis of current major depression according to the Diagnostic and Statistical Manual of Mental Disorders (DSM)-III-R.[25] Missing indicators were used for people missing values on depressive symptoms (n=18) and individuals missing data on race/ethnicity, education, or severe hypoglycemic episodes were excluded (see below).

Analytic sample.

These analyses exclude 67 people missing information on sleep measure components, 35 people who completed less than 50% of all cognitive testing, 4 people with missing or unknown race/ethnicity, 2 people missing information regarding educational attainment, and 2 people missing information regarding severe hypoglycemic episodes. The final sample for analyses examining associations with global cognitive function encompassed 695 individuals. The following number of people completed at least 50% of domain-specific cognitive tests for the relevant domain and are included in analyses specific to those domains: language: 680 participants; executive function: 680 participants; episodic memory: 661 participants; simple attention: 679 participants.

Analyses.

The distribution of demographics, elevated depressive symptoms, and severe hypoglycemic episodes was examined overall and by sleep quality quartile. The distribution of sleep quality characteristics was examined overall and by sex. In preliminary analyses, Pearson correlations examined the unadjusted association between overall sleep quality and specific sleep quality aspects with overall cognitive function.

Multivariable linear regression estimated the association between sex and cognition (overall and domain specific). Multivariable linear regressions estimated the associations between PSQI score quartiles (reference=best sleep quality quartile) and performance on overall and domain-specific cognitive function. Confounders were sequentially added to models in two groups: 1) demographics (age, sex, race/ethnicity, and education); and 2) comorbidities (elevated depressive symptoms, severe hypoglycemic episodes). Sensitivity analyses estimated the odds of global and domain-specific impaired cognitive function (defined as 1.5 SD below mean) associated with sleep quality quartiles.

Linear and logistic multivariable regression examined the associations between each of the 7 aspects of sleep quality and performance on global cognitive function (continuous) and impaired global cognition (binary) adjusting for demographics and comorbidities. Sleep duration was operationalized continuously and with thresholds at ≤5 hours, ≤6 hours, ≤7 hours, ≥9 hours.

Results

The mean PSQI score was 8.16 (SD=2.8) and PSQI quartiles had the following range of scores: 1st quartile (best sleep quality quartile) included scores 0–6, 2nd quartile included a score of 7, 3rd quartile included scores of 8 or 9, and the 4th quartile (worst sleep quality quartile) included scores of ≥10. The mean age at baseline interview was 67.3 years (SD=6.4 years) and participants were predominantly White (86.3%) and had at least a college degree (62.6%) (Table 1). Elevated depressive symptoms were reported by 7.5% of the participants and most participants reported no severe hypoglycemic episodes during the prior year. A total of 7.2% of participant had impaired global cognition and the prevalence of impairment within specific domains ranged from 6.3% to 7.9% (6.3% impaired language, 7.1% impaired attention, 7.9% impaired executive function, 7.4% impaired episodic memory). Women had higher scores for PSQI (t-test p-value<0.0001), sleep latency (t-test p-value<0.0001), sleep efficiency (p-value=0.03), sleep disturbances (t-test p-value<0.0001), and sleep medication (t-test p-value<0.01) than men (Table 2). There was no difference across sexes in sleep hours operationalized continuously (t-test p-value=0.73) or as ≤5 hours, 6 hours, 7 hours, 8 hours, or ≥9 hours (chi-square p-value=0.56) or in daytime dysfunction (t-test p-value=0.14). Sleep quality and its components were weakly correlated with global cognitive function (*r* range: 0.06 to −0.09; Supplemental Table 1).

Compared to men, women had a higher global cognitive score (β=0.22, 95% CI: 0.15, 0.29), executive function (β=0.13, 95% CI: 0.02, 0.24), episodic memory (β=0.35, 95% CI: 0.25, 0.44), and simple attention (β=0.29, 95% CI: 0.17, 0.41) adjusting for demographics. There was no difference by sex in scores in the language domain (β=0.08, 95% CI: −0.02, 0.18).

Compared to individuals in the best sleep quality quartile, individuals in the worst quartile of sleep quality scored 0.08 units lower on the global cognition score (β= −0.08; 95% Confidence Interval (CI): −0.17, −0.01; Table 3) in models adjusting for demographics, elevated depressive symptoms, and severe hypoglycemic episodes. There was no association between other quartiles of sleep quality and global cognitive function. In domain-specific analyses, individuals in the worst sleep quality quartile had −0.17 units lower scores of

executive function (β= −0.17; 95% CI: −0.30, −0.03) compared to individuals in the best sleep quality quartile. Although the associations between sleep quality and the other cognitive domains were in the same direction as that of the sleep quality-executive function relationship, the differences between the worst and best quartile of sleep quality were not significant (language (β= −0.07; 95% CI: −0.20, 0.06), episodic memory (β= −0.11; 95% CI −0.23, 0.02), simple attention (β= −0.004; 95% CI −0.16, 0.17)).

While the odds of impaired global cognitive function (i.e. scoring below 1.5 standard deviations below the mean) was elevated for the worst sleep quality quartile compared to the best sleep quality quartile, this difference was not significant (odds ratio (OR)=1.79; 95% CI: 0.82, 3.91). The worst quartile of sleep quality had more than double the odds (OR=2.49; 95% CI: 1.04, 5.98; Table 4) of impaired language compared to the best sleep quality quartile adjusting for demographics, elevated depressive symptoms, and severe hypoglycemic episodes. The worst sleep quality quartile was associated with elevated odds of impairment in the other domains but these differences were not significant (impaired executive function (OR=1.83; 95% CI: 0.86, 3.91), impaired episodic memory (OR=1.42; 95% CI: 0.66, 3.03), impaired simple attention (OR=1.96; 95% CI: 0.85, 4.50)).

In models examining the association between specific aspects of sleep quality and global cognitive function (Table 5), adjusting for demographics, elevated depressive symptoms, and severe hypoglycemic episodes, sleep medication use (β= −0.03; 95% CI: −0.06, −0.002) and daytime dysfunction (β= −0.07; 95% CI: −0.12, −0.02) were associated with lower global cognition. There was no evidence of an association between subjective sleep quality as reported in one item (β= 0.02; 95% CI: −0.02, 0.07), sleep latency (β= −0.01; 95% CI: −0.05, 0.03), sleep efficiency (β= −0.01; 95% CI: −0.04, 0.03), or sleep disturbances (β= −0.03; 95% CI: −0.08, 0.02) and global cognition. There was no evidence that sleep duration, as a continuous measure (β= −0.01; 95% CI: −0.04, 0.01) or using thresholds of sleep of ≤5 hours (β=0.06; 95% CI: −0.04, 0.17), ≤6 hours (β=0.0002; 95% CI: −0.07, 0.07), ≤7 hours (β=0.06; 95% CI: −0.01, 0.13), or ≥9 hours (β=0.04; 95% CI: −0.07, 0.15), was associated with global cognition. None of the specific aspects of sleep quality were associated with impaired global cognition.

Conclusions

Similar to prior work demonstrating an association between sleep quality and cognitive function in the general population and among people with T2D, this first study of sleep quality and cognition in elderly individuals with T1D detected a threshold effect in which poor sleep quality was associated with lower global cognition. Individuals in the worst quartile of sleep quality had lower global cognition compared to their counterparts in the best quartile of sleep quality. This relationship seemed to be primarily driven by the association between poor sleep quality and executive function. Sleep quality was not associated with performance on cognitive tests related to language, episodic memory, or simple attention. Individuals in the worst quartile of sleep quality had over double the odds of impaired language adjusting for age, sex, race/ethnicity, education, elevated depressive symptoms, and severe hypoglycemic episodes. Sleep medication use and daytime dysfunction were the aspects of poor-quality sleep associated lower global cognitive

function. Our findings are consistent with a study among 162 adults with prediabetes or T2D that showed an association between higher sleep efficiency and higher global cognition.[26] Each one-point increase in sleep efficiency among people with prediabetes or T2D was associated with a 0.09 point increase in the Montreal Cognitive Assessment (MoCA) score. Consistent with our findings, the study did not provide evidence of an association between sleep duration, measured continuously, and global cognitive function. Our findings are also consistent with prior prospective studies[5,9] and cross-sectional studies[6,10] in the general population that have demonstrated an association between sleep quality, captured by the PSQI[5,9,10] or other composite variables[6], and global cognitive function. However, the largest prospective study examining a composite of sleep quality and cognitive function in the general population included 2,822 men 65 years old and older and did not see an association between PSQI and global cognitive function measured by the Modified Mini-Mental State Examination (3MS) after an average of 3.4 years of follow-up.[11] Another large prospective study of 1,664 men and women ages 65 and older found an association between PSQI and global cognition measured one year later in men but not women.[9] Among men, each additional point on the PSQI was associated with 17% greater odds of incident global cognitive impairment. Possible reasons for inconsistencies in findings across studies in the general population include differences in follow-up time and measures of cognitive function.

It is unclear how overall measures of sleep quality are associated with specific domains of cognitive function as few studies have examined these relationships.[9–11] Consistent with our results, a study of 157 elderly men and women and a study of 2,822 elderly men have both demonstrated a relationship between poor sleep quality and lower scores on the Trails Making Test-Part B[10,11], which is a component of the executive function domain in our study. In the sample of 157 elderly individuals, there were also associations between poor sleep quality and lower scores on tests related to working memory and abstract problem solving but no association with tests related to episodic memory, inhibitory function, or abstract problem solving.[10] Different choices of cognitive tests make it difficult to compare results across studies and may explain some of the inconsistencies in findings.

Much of the prior research to date has examined the association between specific aspects of sleep quality (as opposed to an overall measure of sleep quality such as the PSQI) and cognitive function. Sleep disturbances and long sleep duration have been associated with global cognitive impairment in women while short sleep duration and sleep efficiency were associated with global cognitive impairment in men.[9] In line with our findings, daytime sleepiness has been associated with worse cognitive function in some studies[7,27,28] although other studies have not shown an association[9,11]. Inconsistent with our findings, sleep efficiency has been repeatedly associated with global cognition[5,9,26,29]; though in one study this association was found only among men and not women[9]. Consistent with some prior studies[5,9,27,30], we found no association between sleep latency and global cognitive function. Our results are also consistent with prior studies demonstrating no association between a continuous measures of sleep duration and global cognitive function.[11,26,29] However, our study is inconsistent with prior work showing an association with short sleep duration (i.e. ≤5 hours[5,9], ≤6 hours[6], ≤6.5 hours[27], or ≤7 hours[8]) and cognitive function. Our study is consistent with prior work demonstrating no association between long sleep duration (i.e ≥9 hours[5,27]) and cognition, though other studies have shown an association in a sample of both

sex[6], women but not men[9], or with dementia[31]. Differences in study type, sample populations, sleep quality measures, and cognitive function assessments hinder direct comparisons across studies.

Strengths of this study include a large sample of elderly with T1D, the ability to examine specific aspects of poor-quality sleep as well as overall sleep quality, and the ability to examine domains of cognitive function. Limitations of the study include reliance on self-reported measures of sleep quality as opposed to objective measures captured by polysomnography or actigraphy. Additionally, there is no neuroimaging or pathology data to examine the neuropathological substrates linking subjective sleep quality with cognition. Furthermore, at this time, our analyses include only baseline data from the SOLID study, which is ongoing, and therefore the directionality of the association between sleep quality and cognition cannot be ensured. The prevalence of impaired global cognition was 7% in this sample and, although the direction of the association between sleep quality and cognitive impairment was similar to analyses examining cognition as a continuous variable, analyses examining cognitive impairment may be underpowered. Examining the longitudinal relationship between sleep quality and cognitive function will be the focus of future research as more data is collected. Finally, our study is collecting data on participants with T2D and participants without diabetes so direct comparisons of associations of sleep quality with cognition to participants without T1D will be available in the future.

Although the exact pathway through which sleep quality is associated with cognitive function remains unknown, several mechanisms have been hypothesized to be at play in the general population. Some studies suggest that sleep is involved in amyloid beta (Aβ) clearance[32,33] and excessive daytime sleepiness has been associated with increased longitudinal Aβ accumulation[34,35]. Poor sleep quality has also been associated with higher levels of pro-inflammatory cytokines[36] and cortisol[37], both of which have been associated with cognitive function or decline[38,39]. Studies have also linked sleep quality to white matter microstructure[40] and the presence and severity of white matter hyperintensities[41], which are also associated with cognitive function. Among individuals with T1D, poor quality sleep has been associated with higher hemoglobin A1c (HbA1c) levels[19], and HbA1c has been associated with cognition[42].

To our knowledge this is the first study to examine the association of sleep quality and cognitive function among older adults with T1D. Healthy aging for individuals with T1D requires vigilance and extreme attention to self-care. Further research should examine sleep quality as a modifiable risk factor for cognitive function that, if improved, may increase individuals' ability to manage T1D in late-life.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

3MS	Modified Mini-Mental State Examination
Aβ	Amyloid beta
CI	Confidence Interval
DSM	Diagnostic and Statistical Manual of mental Disorders
HbA1c	hemoglobin A1c
ICD	International Classification of Diseases
PSQI	Pittsburgh Sleep Quality Index
MINT	Multilingual Naming Test
MoCA	Montreal Cognitive Assessment
OR	Odds ratio
SD	Standard deviations
SOLID	Study of Longevity in Diabetes
T1D	Type 1 diabetes
T2D	Type 2 diabetes

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Table 1.

Baseline characteristics by sleep quality quartile

	Sleep Quality Quartile				Overall
	1st Quartile (Best) N (%) or Mean (SD)	2nd Quartile N (%) or Mean (SD)	3rd Quartile N (%) or Mean (SD)	4th Quartile (Worst) N (%) or Mean (SD)	N (%) or Mean (SD)
N	**226**	**105**	**165**	**199**	**695**
Female	100 (44.3)	47 (44.8)	83 (50.3)	119 (59.8)	349 (50.2)
Race/ethnicity					
White	204 (90.3)	92 (87.6)	141 (85.5)	163 (81.9)	600 (86.3)
Black	<16	<16	<16	<16	20 (2.9)
Hispanic	<16	<16	<16	<16	20 (2.9)
Asian	<16	<16	<16	<16	17 (2.5)
Other	<16	<16	<16	<16	38 (5.5)
Age (years)	67.5 (6.8)	67.0 (6.8)	67.2 (6.1)	67.2 (5.8)	67.3 (6.4)
Education					
Some college	70 (31.0)	30 (28.6)	62 (37.6)	98 (49.3)	260 (37.4)
College degree	71 (31.4)	40 (38.1)	51 (30.9)	60 (30.2)	222 (31.9)
Graduate school	85 (37.6)	35 (33.3)	52 (31.5)	41 (20.6)	213 (30.7)
Elevated depressive symptoms	<16	<16	<16	28 (14.1)	52 (7.5)
Severe hypoglycemic episode *					
0	182 (80.5)	89 (84.8)	143 (86.7)	160 (80.4)	574 (82.6)
1–2	29 (12.8)	<16	<16	27 (13.6)	85 (12.2)
3+	<16	<16	<16	<16	36 (5.2)

Notes: Column % displayed.

* Frequency of self-reported severe hypoglycemic episode in the past year.

Table 2.

Sleep quality characteristics overall and by sex

	Males N (%) or Mean (SD)	Females N (%) or Mean (SD)	Overall N (%) or Mean (SD)
N	**346**	**349**	**695**
PSQI score (Mean (SD))	7.7 (2.6)	8.6 (2.9)	8.2 (2.8)
Sleep Quality Quartile			
1st Quartile (Best)	126 (36.4)	100 (28.7)	226 (32.5)
2nd Quartile	58 (16.8)	47 (13.5)	105 (15.1)
3rd Quartile	82 (23.7)	83 (23.8)	165 (23.7)
4th Quartile (Worst)	80 (23.1)	119 (34.1)	199 (28.6)
Sleep duration			
Mean (hours; SD)	7.0 (1.3)	7.0 (1.3)	7.0 (1.3)
≤5 hours	29 (8.4)	38 (10.9)	67 (9.6)
6 hours	92 (26.6)	98 (28.1)	190 (27.3)
7 hours	110 (31.8)	98 (28.1)	208 (29.9)
8 hours	75 (21.7)	68 (19.5)	143 (20.6)
≥9 hours	40 (11.6)	47 (13.5)	87 (12.5)
Sleep latency subscore (Mean (SD))	0.7 (0.8)	1.1 (1.0)	0.9 (0.9)
Sleep efficiency subscore (Mean (SD))	0.6 (1.0)	0.8 (1.0)	0.7 (1.0)
Sleep disturbances subscore (Mean (SD))	1.1 (0.6)	1.3 (0.7)	1.2 (0.7)
Sleep medication subscore (Mean (SD))	0.6 (1.1)	0.9 (1.3)	0.7 (1.2)
Daytime dysfunction subscore (Mean (SD))	0.6 (0.7)	0.7 (0.7)	0.6 (0.7)

Notes: Column % displayed. PSQI: Pittsburgh Sleep Quality Index

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Table 3:

Association between quartiles of sleep quality and performance on global and domain-specific cognitive function (continuous)

		Global Cognition β (95% CI)	Language β (95% CI)	Executive Function β (95% CI)	Episodic Memory β (95% CI)	Simple Attention β (95% CI)
N		**695**	**680**	**680**	**661**	**679**
Model 1	1st quartile (Best)	Ref	Ref	Ref	Ref	Ref
	2nd quartile	0.07 (−0.04, 0.18)	0.05 (−0.11, 0.20)	0.04 (−0.12, 0.20)	0.02 (−0.13, 0.17)	−0.15 (−0.04, 0.34)
	3rd quartile	0.01 (−0.08, 0.11)	0.09 (−0.05, 0.22)	−0.02 (−0.12, 0.16)	−0.04 (−0.17, 0.09)	−0.02 (−0.19, 0.14)
	4th quartile (Worst)	−0.09 (−0.18, −0.005)	−0.09 (−0.21, 0.05)	−0.19 (−0.32, −0.05)	−0.11 (−0.24, 0.02)	−0.02 (−0.18, 0.14)
Model 2	1st quartile (Best)	Ref	Ref	Ref	Ref	Ref
	2nd quartile	0.06 (−0.04, 0.17)	0.04 (−0.12, 0.19)	0.04 (−0.12, 0.20)	0.01 (−0.14, 0.16)	0.15 (−0.04, 0.34)
	3rd quartile	0.01 (−0.08, 0.10)	0.08 (−0.06, 0.21)	0.02 (−0.12, 0.16)	−0.05 (−0.18, 0.08)	−0.03 (−0.19, 0.14)
	4th quartile (Worst)	−0.08 (−0.17, −0.01)	−0.07 (−0.20, 0.06)	−0.17 (−0.30, −0.03)	−0.11 (−0.23, 0.02)	−0.004 (−0.16, 0.17)

Notes: Sleep quality measured by Pittsburgh Sleep Quality Index (PSQI). Model 1 adjusts for sex, age, race/ethnicity, and education. Model 2 further adjusts for elevated depressive symptoms and severe hypoglycemic episodes.

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Table 4:

Association between quartiles of sleep quality and impaired performance on global and domain-specific cognitive function

		Impaired Global Cognition OR (95% CI)	Impaired Language OR (95% CI)	Impaired Executive Function OR (95% CI)	Impaired Episodic Memory OR (95% CI)	Impaired Simple Attention OR (95% CI)
# cases		**50**	**43**	**54**	**49**	**48**
Model 1	1st quartile (Best)	Ref	Ref	Ref	Ref	Ref
	2nd quartile	0.28 (0.06, 1.30)	1.06 (0.31, 3.67)	1.10 (0.41, 2.92)	0.63 (0.22, 1.81)	0.59 (0.16, 2.15)
	3rd quartile	0.55 (0.21, 1.47)	0.83 (0.29, 2.40)	0.72 (0.28, 1.83)	0.54 (0.21, 1.38)	1.87 (0.83, 4.20)
	4th quartile (Worst)	2.12 (1.00, 4.48)	2.56 (1.09, 6.04)	1.89 (0.90, 3.96)	1.41 (0.67, 2.95)	2.32 (1.04, 5.17)
Model 2	1st quartile (Best)	Ref	Ref	Ref	Ref	Ref
	2nd quartile	0.28 (0.06, 1.31)	1.05 (0.29, 3.79)	1.04 (0.38, 2.85)	0.67 (0.23, 1.96)	0.62 (0.17, 2.30)
	3rd quartile	0.51 (0.19, 1.40)	0.86 (0.30, 2.52)	0.71 (0.27, 1.82)	0.55 (0.21, 1.43)	1.95 (0.85, 4.46)
	4th quartile (Worst)	1.79 (0.82, 3.91)	2.49 (1.04, 5.98)	1.83 (0.86, 3.91)	1.42 (0.66, 3.03)	1.96 (0.85, 4.50)

Notes: Impaired cognitive function defined as less than 1.5 standard deviations below the mean. Sleep quality captured by Pittsburgh Sleep Quality Index (PSQI). Model 1 adjusts for sex, age, race/ethnicity, and education. Model 2 further adjusts for elevated depressive symptoms and severe hypoglycemic episodes.

Table 5:

Associations between aspects of sleep quality and performance on global cognitive function (continuous) and impaired global cognition (binary)

	Global Cognition β (95% CI)	Impaired Global Cognition OR (95% CI)
Subjective sleep quality	0.02 (−0.02, 0.07)	1.03 (0.64, 1.66)
Sleep latency	−0.01 (−0.05, 0.03)	1.49 (0.94, 1.85)
Sleep efficiency	−0.01 (−0.04, 0.03)	1.04 (0.76, 1.42)
Sleep duration		
Continuous (hrs)	−0.01 (−0.04, 0.01)	1.12 (0.88, 1.42)
≤5 hours	0.06 (−0.04, 0.17)	0.56 (0.20, 1.60)
≤6 hours	0.0002 (−0.7, 0.07)	0.83 (0.41, 1.67)
≤7 hours	0.06 (−0.01, 0.13)	0.65 (0.34, 1.27)
≥9 hours	0.04 (−0.07, 0.15)	0.84 (0.27, 2.62)
Sleep disturbances	−0.03 (−0.08, 0.02)	1.30 (0.82, 2.06)
Sleep medication use	−0.03 (−0.06, −0.002)	1.24 (0.97, 1.58)
Daytime dysfunction	−0.07 (−0.12, −0.02)	1.34 (0.88, 2.03)

Notes: Adjusted for sex, age, race/ethnicity, education, elevated depressive symptoms, and severe hypoglycemic episodes. Impaired global cognition defined as 1.5 standard deviations below the mean.