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RESEARCH ARTICLE

Cross-sectional and prospective associations between self-reported sleep characteristics and cognitive function in men and women: The Midlife in the United States study

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Summary

Sleep behaviour is an important contributing factor in healthy human ageing and cognitive function. Previous studies have linked sleep deficiency with cognitive decline in older adults. However, there is need for more prospective investigations that focus on specific domains of cognitive function. The present study analysed cross-sectional and prospective associations between self-reported sleep and cognitive function in the Midlife in the United States (MIDUS) study. Weekday and weekend sleep duration and habitual sleep quality were obtained via questionnaire data. Brief Test of Adult Cognition by Telephone was conducted to assess overall cognitive function, as well as episodic memory and executive function. We found significant trend for both long weekday and weekend sleep (>8 hr) and lower episodic memory scores in the overall sample. Sex-specific cross-sectional analysis demonstrated men with longer weekend sleep duration have lower overall cognitive function scores, and a negative association between weekend sleep and episodic memory scores. Women demonstrated a positive association between weekend sleep duration and executive function scores. There was no prospective significance for overall or sex-specific analysis. Our present results suggest that sleep duration may contribute to cognitive function, and future studies should include objective sleep measurements and focus on the potential cognitive benefits of improving sleep to further elucidate this association.

KEYWORDS
cognitive scores, Midlife in the United States, self-report, sex differences, weekday sleep duration, weekend sleep duration

1 | INTRODUCTION

Cognitive impairment is a hallmark symptom of Alzheimer's disease (AD) and related dementia (Wennberg, Wu, Rosenberg, & Spira, 2017). Cognitive impairments, including deterioration in memory, processing speed, and executive function can contribute to difficulties in performing everyday activities. It has been estimated that the annual cost of treating AD and related dementias is expected to exceed $600 billion American dollars by 2050 (Lane, Hardy, & Schott, 2018). Thus, it is of utmost importance to identify modifiable risk factors for cognitive impairment to help develop strategies aimed at lowering the risk of AD and related dementia.

A large body of literature has suggested sleep deficiency as a risk factor for cognitive decline and dementia (Wennberg et al., 2017). For example, a meta-analysis synthesised findings from 11 cross-sectional and seven prospective cohort studies demonstrated a U-shaped association between sleep duration and cognitive impairment with short and long sleep associated with 40% and 58% increase in the odds of poor cognitive function, respectively (Lo, Groeger, Cheng, Dijk, & Chee, 2016). Another meta-analysis showed that multiple sleep problems, including insomnia and daytime dysfunction, were associated with higher risk of cognitive disorders (Xu, Tan, Zou, Cao, & Tan, 2020). Although there is a well-recognised bi-directional relationship between sleep deficiency and cognitive problems (Wennberg et al., 2017), previous studies suggested that sleep deficiency often precedes the onset of cognitive decline and midlife sleep problems are predictors of cognitive outcomes in later adulthood (Virta et al., 2013). However, many of the previous studies were cross-sectional, and there is a need for additional prospective studies focussing on middle-to-older aged adults, as such studies help to establish the temporal relationship between sleep deficiency and cognitive outcomes.

Despite convincing evidence suggesting a role of sleep deficiency in cognitive health, less attention has been paid to how this relationship may vary between men and women and differ according to different cognitive domains. Several studies suggested sex differences in cognitive changes in response to sleep deficiency, and a role of reproductive hormones on sleep regulation and cognitive performances (Hajali, Andersen, Negah, & Sheibani, 2019; Santhi et al., 2016). Although previous research suggested that women are more susceptible to cognitive impairment induced by sleep loss (Rangtell et al., 2019), large epidemiological investigation on sex differences in the association between sleep and cognitive decline remain limited (Lo et al., 2016; Xu et al., 2020). There is broad consensus that sleep duration and quality impact global cognition, it is unclear which aspects of cognitive function are more affected by sleep deficiency. Earlier studies suggested that sleep deprivation may have differential effects on different domains of cognition (Durmer & Dinges, 2005; Garcia, Angel, Borrani, Ramirez, & Valdez, 2021; Killgore, 2010). In addition, several population studies examined sleep deficiency in relation to high-level cognitive functions such as executive function and produced mixed results (Blackwell et al., 2011; Gildner, Salinas-Rodriguez, Manrique-Espinoza, Moreno-Tamayo, & Kowal, 2019; Saint Martin, Sforza, Barthelemy, Thomas-Anterion, & Roche, 2012; Titova et al., 2020), warranting further investigation.

To address aforementioned gaps in the literature, we studied the cross-sectional and prospective relationship between sleep patterns and cognitive performance, in a well-established cohort of middle-to-older aged adults in the United States. We focussed on overall cognitive function as well as function in episodic memory (EM) and executive function (EF), because EM and EF are core cognitive abilities that are critically impaired in dementia (Cacciaglia et al., 2018). We also assessed potential sex differences in the relationship between sleep and cognition.

2 | METHODS

2.1 | Study design

In 1995–1996, the MacArthur Midlife Research Network established the Midlife in the United States (MIDUS) study, a national survey of 7,108 Americans aged 25–74 years. The purpose of the study was to investigate the role of behavioural, psychological, and social factors in understanding age-related differences in physical and mental health. Data from the MIDUS study are publicly available (Ryff et al., 2017). With support from the National Institute on Aging, several longitudinal follow-ups of the original MIDUS samples were conducted, including the MIDUS II (2004–2006, n = 3,487) and MIDUS III (2013–2014, n = 3,294). Self-reported information on sleep characteristics was collected at MIDUS II and cognitive assessments were performed in both MIDUS II and III. For cross-sectional analysis, we included 3,212 participants with sleep and cognitive outcome data in MIDUS II. For prospective analysis, we additionally excluded those with no cognitive outcome data in MIDUS III, leading to a sample size of 2,375 subjects.

2.2 | Sleep characteristics

Participants were asked to report how many hours of sleep they usually got at night (or in their main sleep period) on weekdays or workdays and on weekend or non-workdays separately. Because previous studies reported a U-shaped relationship between sleep duration and cognitive health, we categorised sleep duration into short (<7 hr, n = 1,044 and 551 for weekday and weekend sleep, respectively), normal (7–8 hr, n = 1,884 and 1,934), and long (>8 hr, n = 284 and 727) groups. Because sleep patterns are often influenced by work and social schedules that differ between weekdays and weekends, we examined weekday and weekend sleep duration separately. Participants were also asked to report how long it usually took for them to fall asleep and how often (i.e. “never”, “rarely”, “sometimes”, “often”, “almost always”) they experienced the following in the past 30 days: (1) trouble getting to sleep or staying asleep; (2) waking up during the night and having difficulty going back to sleep; (3) waking up too early in the morning and unable to get back to sleep; (4) feeling unrested during the day; and (5) having trouble falling asleep. Using previously reported criteria (Bansil, Kuklina, Merritt, & Yoon, 2011; Xiao, Gu, Caporaso, & Matthews, 2016), we defined having a sleep problem for each aforementioned aspect of sleep quality as taking ≥1 hr to fall asleep or answering “often” or “almost always” to any of the other questions. Then we derived a sleep quality score by counting the total number of sleep problems and divided this score into three groups, 0 (n = 1,992), 1 (n = 531), and ≥2 (n = 689) sleep problems (Bansil et al., 2011; Xiao et al., 2016).

2.3 | Cognitive measures

Cognitive function in MIDUS II and III was assessed using the Brief Test of Adult Cognition by Telephone (BTACT; Lachman, Agrigoroaei, Tun, & Weaver, 2014) that consists of the following tests, administered in the following order: word list recall immediate, backward digit span, category fluency, Stop and Go Switch Task (SGST), number series, 30-s and counting (SACT), and word list recall delayed. The details of these tests are described in Lachman et. al (2014). These tests have been validated through previous studies of cognition identifying relevant dimensions of cognitive ageing (Fillenbaum et al., 2008; Gershon et al., 2010). For each BTACT component, the raw scores were standardised to *z*-scores, which were subsequently used to create an overall composite cognitive functioning score as the average of *z*-scores of all test components. In addition, the EM score was calculated as the average score of the immediate and delayed word recall tasks, and the EF score as the average score of the SGST and the number series, category fluency, digit span backwards, and backward counting items from the BTACT. Higher scores indicate higher cognition for all cognitive measures (Lachman & Liu, 2019). Changes in cognitive function between MIDUS II and MIDUS III were calculated as the difference in composite, EM, and EF scores. The BTACT has demonstrated to be an efficient cognitive assessment tool with a good construct validity in the MIDUS sample.

2.4 | Covariates

The MIDUS II collected information on age (years), sex (men, women), height and weight was obtained and a body-mass index (BMI, continuous) calculated, marital status (married, separated, divorced, widowed and never married), race/ethnicity (Caucasian, African American, Asian, Pacific Islander, and other ethnicities), and self-rated physical health, which was reported on a 5-point scale ranging from 1 (“poor”) to 5 (“excellent”). Participants reported the frequency of engaging in cognitively challenging activities (i.e. reading, doing word games, attending educational courses, writing) on a 6-point scale (1 = never, 2 = once a month, 3 = several times a month, 4 = once a week, 5 = several times a week, and 6 = daily) (Lachman, Agrigoroaei, Murphy, & Tun, 2010). Physical activity was assessed using 12 questions asking about vigorous- (e.g. competitive sports such as running, vigorous swimming, or high intensity aerobics; digging in the garden or lifting heavy objects) and moderate-intensity (e.g. leisurely sports such as light tennis, slow or light swimming, low-impact aerobics, or golfing without a power cart; brisk walking or mowing the lawn with a walking lawnmower) physical activity. These questions referred to frequency of physical activities separately for the summer and winter months, in three different settings (i.e. home, work, and leisure), with frequency ratings from 1 = never, 2 = less than once a month, 3 = once a month, 4 = several times a month, 5 = once a week, and 6 = several times a week. Higher scores indicate more frequent physical activity. The mean score across summer and winter was computed in all three settings for both moderate and vigorous intensity.

2.5 | Statistical analysis

All statistical analyses were performed using the Statistical Analysis System (SAS) version 9.4 software (SAS Institute). We used multiple linear regression model to examine sleep duration and quality measured at MIDUS II in relation to cognitive function at MIDUS II and changes in cognitive function between MIDUS II and MIDUS III. Model I was adjusted for sex and age. Model II was additionally adjusted for variables that we considered as potential confounders of the association between sleep and cognition, as they may influence both exposure and outcome variables. These included BMI, education, marital status, race, self-rated health, moderate and vigorous physical activity, and engagement in cognitive activities. Model 2 was considered the main model of the analyses. The referent group for weekday and weekend sleep duration was 7–8 hr. For sleep quality, we used the “0” or no sleep problem group as the reference. We calculated *p* value for trend by assigning numeric values (i.e. 1, 2, 3) to each category of sleep variables, and *p* value for interaction by including a product term between sleep variables and sex. In sensitivity analysis, we examined the associations between sleep variables and cognitive outcomes according to age groups (<60 and ≥ 60 years) to assess whether age modified the results.

3 | RESULTS

Subject characteristics according to weekday sleep duration at MIDUS II are presented in Table 1. The mean (*SD*, range) age of participants included in this study was 54.71 (12.28, 28–84) years. The sample was predominantly White (90.62%) with relatively high levels of education (some college or undergraduate degree, 49.89%). Most reported being currently married (72.03%) and engaging in cognitive activity from once a week to once a month (59.75%). When compared to participants who reported 7–8 hr of sleep on weekdays, those in the short sleep group were younger, had lower education levels, and more likely to be men, non-White, and obese. On the other hand, long sleepers were older, had a lower BMI and education level, and were more likely to engage in physical activities several times a week.

Table 2 presents cross-sectional associations between sleep duration and quality and cognitive scores in MIDUS II. Although long sleep duration on weekdays and both short and long sleep duration on weekends were associated with lower composite cognitive scores in the minimally adjusted Model 1, these associations were attenuated and became null after adjusting for covariates (Model 2). However, there was a significant trend between longer weekday and weekend sleep duration and lower EM scores (*p* trend, 0.04 for both weekday and weekend sleep duration, Model 2). In contrast, there was no statistically significant trend between sleep duration and EF scores. Moreover, our main model of analysis revealed no statistically significant association between self-reported sleep quality and composite, EM, or EF scores. In sensitivity analysis, we did not observe a significant modifying effect of age groups and the

TABLE 1 Subject Characteristics according to weekday sleep duration at baseline in MIDUS II (2004–2006)

Characteristic	Sleep duration <7 hr	7–8 hr	>8 hr
Sex, *n* (%)			
Men	524 (50.19)	849 (45.06)	125 (44.01)
Women	520 (49.81)	1035 (54.94)	159 (55.99)
p	0.02		
Age (years), *n* (%)			
<55	565 (54.12)	895 (47.51)	101 (35.56)
55–65	267 (25.57)	496 (26.33)	63 (22.18)
>65	212 (20.31)	493 (26.17)	120 (42.25)
p	<0.0001		
Race, *n* (%)			
White	944 (90.42)	1760 (93.42)	267 (94.01)
Black and/or African American	46 (4.41)	46 (2.44)	4 (1.41)
Other	54 (5.17)	78 (2.44)	13 (4.58)
p	0.01		
BMI (kg/m^2), *n* (%)			
<18.5	55 (5.27)	109 (5.79)	28 (9.86)
18.5-<25	296 (28.35)	597 (31.69)	95 (33.45)
25-<30	368 (35.25)	727 (38.59)	103 (36.27)
≥30	325 (31.13)	451 (23.94)	58 (20.42)
p	<0.0001		
Education, *n* (%)			
No school or High School diploma	345 (33.05)	563 (29.88)	102 (35.92)
No college degree yet or graduated from college	514 (49.23)	920 (48.83)	131 (46.13)
Some graduate or obtained professional degree	185 (17.72)	401 (21.28)	51 (17.96)
p	0.05		
Marital status, *n* (%)			
Married	752 (72.03)	1381 (73.30)	206 (72.54)
Separated/divorced/widowed	212 (20.31)	375 (19.90)	52 (18.31)
Never married	80 (7.66)	128 (6.79)	26 (9.15)
p	0.59		
Engagement in vigorous physical activity, *n* (%)			
Several times a week	95 (9.10)	181 (9.61)	37 (13.03)
Once a week-once a month	655 (62.74)	1196 (63.48)	151 (53.17)
Less than once a month-never	294 (28.16)	507 (26.91)	96 (33.80)
p	0.02		
Engagement in moderate physical activity, *n* (%)			
Several times a week	157 (17.58)	271 (16.53)	42 (18.18)
Once a week–once a month	591 (66.18)	1092 (66.63)	145 (62.77)
Less than once a month–never	145 (16.24)	276 (16.84)	44 (19.05)
p	0.76		
Engagement in cognitive activity, *n* (%)			
Several times/week or daily	37 (3.54)	62 (3.29)	14 (4.93)
Once a week–once a month	864 (82.76)	1602 (85.03)	227 (79.93)
Less than once a month–never	143 (13.70)	220 (11.68)	43 (15.14)
p	0.16		

p values were derived from chi-square test for categorical variables.

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TABLE 2 Cross-sectional associations between sleep characteristics and cognitive function at baseline in the MIDUS II (2004–2006)

	Composite score			Episodic memory			Executive function		
	Mean (*SD*)	Model 1, β (95% CI)	Model 2, β (95% CI)	Mean (*SD*)	Model 1, β (95% CI)	Model 2, β (95% CI)	Mean (*SD*)	Model 1, β (95% CI)	Model 2, β (95% CI)
Weekday sleep duration, hr									
<7	0.11 (1.00)	−0.03 (−0.10, 0.04)	0.04 (−0.03, 0.11)	0.10 (1.00)	0.04 (−0.04, 0.11)	0.08 (−0.004, 0.15)	0.11 (1.00)	−0.04 (−0.11, 0.03)	0.02 (−0.04, 0.09)
7–8	0.07 (0.96)	Ref	Ref	0.04 (0.97)	Ref	Ref	0.07 (0.96)	Ref	Ref
>8	−0.20 (1.00)	−0.16 (−0.30, −0.04)	−0.05 (−0.16, 0.06)	−0.16 (1.07)	−0.10 (−0.22, 0.01)	−0.02 (−0.14, 0.10)	−0.20 (1.00)	−0.20 (−0.31, −0.08)	−0.07 (−0.17, 0.04)
p trend		0.19	0.10		0.04	0.04		0.21	0.15
Weekend sleep duration, hr									
<7	−0.11 (0.99)	−0.16 (−0.25, −0.07)	−0.04 (−0.13, 0.04)	−0.003 (1.05)	−0.01 (−0.10, 0.09)	0.07 (−0.02, 0.17)	−0.11 (0.99)	−0.17 (−0.26, −0.09)	−0.06 (−0.14, 0.02)
7–8	0.10 (0.97)	Ref	Ref	0.04 (0.97)	Ref	Ref	0.10 (0.97)	Ref	Ref
>8	0.08 (0.99)	−0.12 (−0.20, −0.04)	−0.03 (−0.11, 0.04)	0.06 (1.01)	−0.08 (−0.16, −0.002)	−0.04 (−0.13, 0.04)	0.08 (0.99)	−0.10 (−0.17, −0.02)*	−0.01 (−0.08, 0.06)
p trend		0.82	0.97		0.11	0.04		0.32	0.42
Sleep quality score									
0 (no sleep problem)	0.07 (0.99)	Ref	Ref	0.03 (0.99)	Ref	Ref	0.07 (0.99)	Ref	Ref
1	0.07 (0.99)	−0.04 (−0.13, 0.05)	0.05 (−0.04, 0.13)	0.06 (1.04)	−0.02 (−0.11, 0.07)	0.04 (−0.05, 0.13)	0.07 (0.99)	−0.05 (−0.13, 0.04)	0.04 (−0.04, 0.12)
≥2	0.01 (0.96)	−0.07 (−0.15, 0.02)	0.04 (−0.03, 0.12)	0.03 (0.98)	−0.05 (−0.13, 0.03)	0.01 (−0.08, 0.10)	0.01 (0.96)	−0.07 (−0.16, 0.01)	0.04 (−0.04, 0.11)
p-trend		0.10	0.21		0.22	0.66		0.06	0.25

CI, confidence interval.

Model 1: Adjusted for sex, age. Model 2, adjusted for covariates in Model 1 and body mass index, education, marital status, race, self-rated health, vigorous physical activity, moderate physical activity, and engagement in cognitive activity.

*$p < 0.05$.

results were similar among subgroups who were aged < or ≥60 years (Table S1).

Sex-specific associations between sleep variables and cognitive scores in MIDUS II are shown in Table 3. We detected a statistically significant interaction between sex and weekend sleep duration in relation to the composite score (p interaction = 0.02). Among men, both short and long weekend sleep was associated with a lower composite score (β [95% confidence interval, CI] −0.24 [−0.37, −0.12] for short sleep and −0.13 [−0.25, −0.02] for long sleep). Among women, neither short nor long sleep duration was significantly associated with the composite score, although there appeared to be a positive association between sleep duration and cognitive function with a p trend of borderline statistical significance (0.05). For domain-specific cognitive outcomes, we found that the inverse association between weekend sleep duration and EM score observed in the overall analysis appeared to be more evident among men than women, and there was a suggestive trend between longer weekend sleep duration and higher EF score in women, but not men, although neither of the p values for interaction were statistically significant. Finally, we did not observe a significant trend for sleep quality and cognitive outcomes in either men or women.

Prospective associations between sleep variables and cognitive scores are presented in Table 4 (overall results) and Table 5 (sex-specific results). Overall, we found no association between weekday sleep duration, weekend sleep duration, or sleep quality, and changes in cognitive scores between MIDUS II and MIDUS III either in the overall sample, or in men and women specifically. The results were null for both the composite score, and for the EM and EF scores. Moreover, the results were similar among participants in different age groups (aged <60 versus ≥60 years, Table S2).

4 | DISCUSSION

In a large cohort of middle-to-older aged men and women in the United States, we found a cross-sectional association between longer weekday and weekend sleep duration and lower EM score. Further analysis suggested potential sex-differences in the relationship between weekend sleep duration and cognitive function. However, we did not observe an association between self-reported sleep quality and cognitive scores, and none of the sleep variables were prospectively associated with changes in cognitive scores over follow-up.

Previous studies on the cross-sectional relationship between sleep duration and cognitive function produced mixed results. For example, Ramos et al., 2013 demonstrated that in older men and women from the Northern Manhattan Study cohort, long sleep (≥9 hr) was significantly associated with lower scores in Mini-Mental State Examination (MMSE) (adjusted $\beta = -0.06$; $SE = 0.03$, $p = 0.012$), a measure of global cognitive function (Ramos et al., 2013). However, that study found no association between short sleep (<6 hr) and MMSE scores. In another study in a large cohort of older men, both short (≤5 hr) and long (>8 hr) sleep duration were associated with lower scores in the MMSE (Blackwell et al., 2014). Similar findings was also reported in another study of older Mexican adults, among whom both short (0–6 hr) and long (>9 hr) sleep duration were associated with lower scores in multiple cognitive tests (Gildner, Liebert, Kowal, Chatterji, & Snodgrass, 2014). Finally, several other studies reported no association between self-reported sleep duration with cognitive function (McSorley, Bin, & Lauderdale, 2019; Saint Martin et al., 2012). Conflicting results from these studies may be explained by the differences in characteristics of study participants and cognitive tests. Futures studies are needed to further clarify the relationship between sleep duration and cognitive function in older adults.

In our present study, we examined sleep duration and specific domains of cognitive function and found that the relationship between longer sleep, and cognition was more pronounced for EM than for EF. The stronger results for EM are consistent with several previous studies that examined various aspects of sleep in relation to EM. A systematic review found that poorer sleep quality was associated with worse memory function in both young and older adults (Hokett, Arunmozhi, Campbell, Verhaeghen, & Duarte, 2021). Moreover, in a cohort of older adults, long sleep duration was associated with poorer memory function over 14 years of follow-up, while difficulties staying asleep were associated with better function (Klaming, Annese, Veltman, & Comijs, 2017). There have also been a growing number of investigations that linked sleep duration with EF. For example, in a meta-analysis by Lo et al., the authors reported a significant relationship between both short and long self-reported sleep duration and poor EF (Lo et al., 2016). However, such a relationship was primarily driven by results from cross-sectional studies and there have been only two prospective investigations on this topic. Since the publication of the meta-analysis, several more recent studies examined sleep characteristics in relation to EF in cohort studies, but their results were mixed. For example, a longitudinal study of Mexican adults (aged >50 years) demonstrated that long sleep duration is a risk factor for impaired attention/working memory and EF (Gildner et al., 2019). Moreover, in a large sample of Swedish adults, short sleep duration (<7 hr) was linked to better EF (Titova et al., 2020). However, a recent analysis in the Whitehall II study did not report an association between self-reported sleep duration and EF (Zitser et al., 2020). Other studies examined sleep quality and various sleep problems in relation to EF: Parsey & Schmitter-Edgecombe, 2015 demonstrated that subjective sleep quality predicted performance on EF measures in healthy older adults (aged 59–94 years; Parsey & Schmitter-Edgecombe, 2015). In another study, the authors found an association between insomnia-related sleep problems and impaired EF in the Louisiana Aging Brain Study (Bernstein, Calamia, & Keller, 2018). The inconsistency among previous studies and our present study may be due to several factors, including differences in sleep measurement, cognitive tests, and population characteristics such as age distribution, gender, and country of residence (Aly & Moscovitch, 2010). Future studies are needed to clarify the relationship between sleep duration and domains of cognitive function, and pinpoint factors that may influence such relationships.

TABLE 3 Cross-sectional associations between sleep characteristics and baseline cognition at MIDUS II in men and women (2004–2006)

	Composite score		Episodic memory		Executive function	
	Mean (*SD*)	Model 2, β (95% CI)	Mean (*SD*)	Model 2, β (95% CI)	Mean (*SD*)	Model 2, β (95% CI)
Weekday sleep duration category, hr						
Men						
<7	0.19 (1.05)	0.05 (−0.05, 0.15)	−1.00 (0.93)	−0.05 (−0.21, 0.12)	0.27 (1.00)	0.03 (−0.06, 0.13)
7–8	0.05 (0.98)	Ref	−0.24 (0.88)	Ref	0.16 (0.95)	Ref
>8	−0.33 (1.06)	−0.11 (−0.28, 0.06)	−0.47 (1.00)	−0.004 (−0.17, 0.16)	−0.26 (1.03)	−0.15 (−0.31, 0.01)
p trend		0.10		0.14		0.08
Women						
<7	0.03 (0.95)	0.02 (−0.07, 0.11)	0.28 (1.03)	−0.15 (−0.32, 0.01)	−0.05 (0.96)	0.002 (−0.09, 0.09)
7–8	0.09 (0.95)	Ref	0.27 (0.98)	Ref	0.02 (0.94)	Ref
>8	−0.09 (0.94)	0.01 (−0.13, 0.16)	0.08 (1.07)	−0.03 (−0.21, 0.14)	−0.22 (1.02)	0.004 (−0.14, 0.14)
p trend		0.80		0.18		0.99
p interaction		0.43		0.64		0.65
Weekend sleep duration category, hr						
Men						
<7	0.02 (1.02)	−0.24 (−0.37, −0.12)	−0.17 (1.01)	0.07 (−0.06, 0.19)	0.09 (0.96)	−0.04 (−0.16, 0.08)
7–8	0.13 (0.99)	Ref	−0.19 (0.88)	Ref	0.23 (0.97)	Ref
>8	−0.09 (1.09)	−0.13 (−0.25, −0.02)	−0.31 (0.94)	−0.1 (−0.21, 0.02)	0.04 (1.03)	−0.09 (−0.20, 0.02)
p trend		0.14		0.03		0.40
Women						
<7	−0.23 (0.95)	−0.02 (−0.13, 0.09)	0.14 (1.06)	0.07 (−0.07, 0.21)	−0.32 (0.96)	−0.1 (−0.21, 0.02)
7–8	0.07 (0.96)	Ref	0.25 (1.00)	Ref	−0.01 (0.95)	Ref
>8	0.22 (0.89)	0.06 (−0.03, 0.16)	0.33 (0.98)	−0.002 (−0.12, 0.11)	0.13 (0.93)	0.06 (−0.04, 0.15)
p trend		0.05		0.46		0.02
p interaction		0.02		0.59		0.11
Sleep quality						
Men						
0	0.06 (1.01)	Ref	−0.22 (0.90)	Ref	0.18 (0.98)	Ref
1	0.10 (1.07)	0.15 (0.03, 0.28)	−0.16 (0.99)	0.13 (0.004, 0.25)	0.17 (1.02)	0.12 (−0.002, 0.24)
≥2	0.03 (1.01)	0.05 (−0.07, 0.17)	−0.24 (0.92)	0.02 (−0.10, 0.15)	0.11 (0.97)	0.04 (−0.08, 0.16)
p trend		0.17		0.36		0.27
Women						
0	0.08 (0.97)	Ref	0.28 (1.01)	Ref	−0.003 (0.97)	Ref
1	0.05 (0.93)	−0.04 (−0.15, 0.07)	0.23 (1.05)	−0.03 (−0.16, 0.10)	−0.04 (0.94)	−0.02 (−0.13, 0.08)
≥2	−0.004 (0.92)	0.02 (−0.08, 0.12)	0.21 (0.98)	−0.01 (−0.13, 0.11)	−0.08 (0.94)	0.02 (−0.07, 0.12)
p trend		0.88		0.81		0.73
p interaction		0.06		0.18		0.34

CI, confidence interval.

Cognitive scores mean (*SD*) are score from MIDUS II.

$^{*}p < 0.05$.

We found that short and long weekend sleep in men were associated with a lower overall cognition. Although we found the inverse association between weekend sleep duration and EM score observed in overall analysis. However, we found this association appeared to be more evident among men than women, and there was a suggestive trend between longer weekend sleep duration and higher EF score in women, but not men. Several previous studies also examined sex differences in the association of sleep characteristics with cognitive outcomes, but their results were mixed. An analysis in the National Social Life, Health, and Aging Project found that the association between sleep deficiency and cognitive decline was stronger in men than in women (McSorley et al., 2019). In

TABLE 4 Prospective associations between sleep characteristics and changes in cognition in the overall sample at MIDUS III (2013–2014)

	Composite score			Episodic memory			Executive function		
	Mean (*SD*)	Model 1, β (95% CI)	Model 2, β (95% CI)	Mean (*SD*)	Model 1, β (95% CI)	Model 2, β (95% CI)	Mean (*SD*)	Model 1, β (95% CI)	Model 2, β (95% CI)
Weekday sleep duration category, hr									
<7	−0.18 (0.62)	−0.02(−0.08, 0.04)	−0.02 (−0.08, 0.04)	−0.14 (0.94)	−0.01 (−0.10, 0.08)	0.01 (−0.87, 0.10)	−0.31 (0.77)	0.04 (−0.02, 0.10)	0.03 (−0.03, 0.10)
7–8	−0.19 (0.59)	Ref	Ref	−0.14 (0.92)	Ref	Ref	−0.34 (0.60)	Ref	Ref
>8	−0.18 (0.61)	−0.01 (−0.10, 0.09)	0.01 (−0.10, 0.11)	−0.17 (1.02)	−0.004 (−0.15, 0.14)	0.003 (−0.15, 0.16)	−0.29 (0.56)	0.06 (−0.05, 0.16)	0.04 (−0.07, 0.15)
p trend		0.6	0.54		0.85	0.92		0.66	0.63
Weekend sleep duration category, hr									
<7	−0.18 (0.62)	0.02 (−0.16, 0.09)	−0.01 (−0.09, 0.07)	−0.24 (0.92)	−0.09 (−0.21, 0.02)	−0.06 (−0.18, 0.06)	−0.32 (0.62)	0.02 (−0.06, 0.10)	−0.01 (−0.09, 0.08)
7–8	−0.19 (0.59)	Ref	Ref	−0.14 (0.94)	Ref	Ref	−0.34 (0.59)	Ref	Ref
>8	−0.17 (0.60)	0.02 (−0.05, 0.09)	0.002 (−0.06, 0.07)	−0.10 (0.93)	0.01 (−0.09, 0.11)	0.03 (−0.07, 0.13)	−0.30 (0.82)	0.03 (−0.03, 0.10)	0.02 (−0.05, 0.09)
p trend		0.85	0.76		0.17	0.22		0.63	0.6
Sleep quality									
0	−0.24 (0.66)	Ref	Ref	−0.13 (0.94)	Ref	Ref	−0.34 (0.61)	Ref	Ref
1	−0.19 (0.61)	−0.002(−0.08, 0.07)	0.02 (−0.06, 0.09)	−0.20 (0.93)	0.08 (−0.03, 0.19)	0.09 (−0.02, 0.20)	−0.30 (0.86)	−0.04 (−0.12, 0.04)	−0.03 (−0.11, 0.05)
≥2	−0.17 (0.58)	−0.01(−0.08, 0.06)	0.01 (−0.06, 0.08)	−0.15 (0.94)	0.03 (−0.07, 0.14)	0.02 (−0.09, 0.13)	−0.31 (0.61)	−0.02(−0.09, 0.06)	0.01(−0.07, 0.09)
p trend		0.74	0.7		0.34	0.47		0.52	0.97

CI, confidence interval.

Model 1: Adjusted for sex, age. Model 2: Adjusted for covariates in Model 1 and body mass index, education, marital status, race, self-rated health, vigorous physical activity, moderate physical activity, and engagement in cognitive activity. *$p < 0.05$.

TABLE 5 Cross-sectional associations between sleep characteristics and changes in cognition at MIDUS III in men and women (2013–2014)

	Composite score		Episodic memory		Executive function	
	Mean (*SD*)	Model 2, β (95% CI)	Mean (*SD*)	Model 2, β (95% CI)	Mean (*SD*)	Model 2, β (95% CI)
Weekday sleep duration category, hr						
Men						
<7	0.13 (0.68)	−0.004 (−0.09, 0.08)	−0.14 (0.83)	−0.01 (−0.13, 0.11)	0.05 (0.72)	−0.002 (−0.08, 0.08)
7–8	0.05 (0.66)	Ref	−0.26 (0.82)	Ref	−0.05 (0.72)	Ref
>8	−0.21 (0.73)	0.01 (−0.16, 0.17)	−0.56 (0.87)	−0.2 (−0.42, 0.02)	−0.31 (0.77)	0.05 (−0.10, 0.19)
p trend		0.89		0.33		0.67
Women						
<7	0.07 (0.67)	0.05 (−0.04, 0.13)	0.25 (1.06)	0.03 (−0.11, 0.17)	−0.12 (0.99)	0.08 (−0.02, 0.18)
7–8	0.03 (0.68)	Ref	0.19 (1.02)	Ref	−0.19 (0.73)	Ref
>8	0.01 (0.63)	−0.03 (−0.16, 0.10)	0.26 (1.03)	0.15 (−0.70, 0.37)	−0.20 (0.67)	0.02 (−0.14, 0.18)
p trend		0.22		0.61		0.22
p interaction		0.69		0.24		0.48
Weekend sleep duration category, hr						
Men						
<7	−0.07 (0.66)	−0.05 (−0.16, 0.07)	−0.31 (0.87)	−0.11 (−0.27, 0.06)	−0.13 (0.68)	−0.04 (−0.14, 0.07)
7–8	0.11 (0.67)	Ref	−0.21 (0.82)	Ref	0.03 (0.72)	Ref
>8	−0.01 (0.70)	0.04 (−0.07, 0.14)	−0.30 (0.87)	−0.04 (−0.18, 0.11)	−0.15 (0.77)	−0.03 (−0.12, 0.07)
p trend		0.22		0.56		0.97
Women						
<7	−0.17 (0.72)	0.04 (−0.08, 0.15)	0.14 (1.06)	−0.02 (−0.20, 0.17)	−0.40 (0.71)	0.03 (−0.11, 0.16)
7–8	0.03 (0.68)	Ref	0.25 (1.00)	Ref	−0.20 (0.74)	Ref
>8	0.19 (0.60)	−0.03 (−0.11, 0.06)	0.33 (0.98)	0.07 (−0.07, 0.22)	0.03 (0.96)	0.04 (−0.06, 0.15)
p trend		0.34		0.33		0.71
p interaction		0.35		0.38		0.57
Sleep quality						
Men						
0	0.03	Ref	−0.25 (0.86)	Ref	−0.03 (0.73)	Ref
1	Ref	−0.04 (−0.15, 0.07)	−0.26 (0.83)	−0.11 (−0.26, 0.05)	0.01 (0.78)	−0.01 (−0.11, 0.09)
≥2	0.04	−0.02 (−0.13, 0.10)	−0.22 (0.77)	0.02 (−0.14, 0.18)	−0.09 (0.65)	0.02 (−0.08, 0.13)
p trend		0.64		0.90		0.74
Women						
0	0.06 (0.68)	Ref	0.28 (1.01)	Ref	−0.003 (0.97)	Ref
1	0.02 (0.69)	0.004 (−0.10, 0.11)	0.23 (1.05)	−0.08 (−0.23, 0.09)	−0.04 (0.94)	0.06 (−0.06, 0.18)
≥2	0.03 (0.64)	0.01 (−0.09, 0.10)	0.21 (0.98)	−0.05 (−0.20, 0.10)	−0.08 (0.94)	−0.02 (−0.13, 0.09)
p trend		0.89		0.45		0.92
p interaction		0.83		0.39		0.83

CI, confidence interval; Ref, reference group.

Model 2: Adjusted for covariates in Model 1 and body mass index, education, marital status, race, self-rated health, vigorous physical activity, moderate physical activity, and engagement in cognitive activity. Cognitive scores mean (*SD*) are score from MIDUS II. *$p < 0.05$.

contrast, in another study conducted in Canada, long sleep duration (>9 hr) was associated with incident cognitive impairment in women, but not in men (Potvin et al., 2012). Finally, in a Taiwanese sample, both men and women reporting long sleep (>8.5 hr) demonstrated greater cognitive impairment (Chiu, Lai, Chen, & Tsai, 2016). In our present study, we further showed that the sex differences may vary for different domains of cognitive function. Previous studies have shown considerable differences in sleep behaviours between men and women, which may be driven by both biological and social factors (Mallampalli & Carter, 2014). More studies are needed to elucidate the relationship between sleep patterns and cognitive health and investigate how sex differences in sleep patterns may contribute to disparities in cognitive health between sexes.

We did not find an association between sleep quality and cognition either in cross-sectional or prospective analyses. Previous cross-sectional research from a sample of middle-aged adults from the Netherlands (aged 41–75 years) have shown that the associations of sleep quality, based on the single question of feeling rested, was not significantly associated with cognitive function (van Oostrom, Nooyens, van Boxtel, & Verschuren, 2018). Similarly, Blackwell et al., 2011 reported that there was no association between Pittsburgh Sleep Quality Index (PSQI) measured sleep quality and cognitive outcomes for cognitive function measured via the modified MMSE or EF via the Trails B test. Additionally, in the Nathan Kline Institute-Rockland Sample, a study found no association between lower PSQI scores and poorer cognition scores among older adults (Bernstein, DeVito, & Calamia, 2019). However, some studies have reported that poor sleep quality and lower cognitive scores are significantly related. For example, in women aged 70–81 years from the Nurses' Health Study, individuals self-reporting poor sleep quality had increased risk of cognitive impairment (odds ratio 1.85, 95% CI 11.04–3.30) (Tworoger, Lee, Schernhammer, & Grodstein, 2006). The mixed findings from these studies may reflect the challenges to study self-reported sleep quality in relation to cognition in the older population. For example, individuals may have different responses to sleep deficiency, and some studies have shown that older adults may be more resilient to the cognitive effects of poor sleep quality (Adam, Retey, Khatami, & Landolt, 2006). Moreover, older adults may also have difficulties reporting sleep patterns accurately, which may lead to exposure misclassification and introduce noise to the results (Scullin & Bliwise, 2015).

We did not find a prospective association between sleep duration and changes in cognition over ~8 years of follow-up. Other prospective studies, such as a Spanish study in older adults demonstrated that longer sleep duration (≥9 hr) was associated with increased risk of dementia. Additionally, from the Nurses' Health Study cohort, both short (<5 hr) and long (>9 hr) sleep duration was associated with poor cognition in older women (Devore et al., 2014). It is unclear what factors have contributed to lack of prospective association in our present study sample, while other studies found significant results. It has been postulated that there is a bi-directional association between sleep and cognitive decline. On one hand, unhealthy sleep behaviour may increase all-cause risk of cognitive decline and dementia (Wang & Holtzman, 2019), while on the other hand, individuals with cognitive decline have elevated risk of poor sleep behaviour (Ju et al., 2013). More studies are needed to elucidate the temporal relationship between sleep and cognition.

The present study has many strengths. The MIDUS included a large sample of cognitively intact middle-to-older aged adults at baseline and conducted repeated measures of cognitive performance over an extended period (~8 years). The MIDUS also collected information on a wide range of demographic and lifestyle factors, which allowed us to adjust for multiple potential confounders. However, there are a number of limitations. First, the findings may not be generalisable to the United States population as it was not a representative sample. In particular, the sample was predominantly White and thus the results may not be extended to racial/ethnic minority groups. Second, causality cannot be established due to the cross-sectional study design. As mentioned above, the association of cognition and sleep parameters may be bi-directional, so further research investigating directions of the associations with cognitive measures are needed. Third, although we adjusted for numerous covariates, we could not exclude the possibility of residual confounding. Fourth, we did not have information on sleep apnea and other sleep disorders and were not able to include these conditions in the analysis. Fifth, the association between sleep and cognitive outcomes may differ according to sociodemographic factors, and although we performed sensitivity analysis by age, the sample size did not allow us to fully evaluate potential effect modifiers with greater detail. Finally, sleep characteristics were assessed by self-report, and are thus prone to measurement error: validation studies have compared subjective and objective measures of sleep, and found that they were only moderately correlated (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008; O'Donnell et al., 2009). Furthermore, we only assessed sleep duration and overall quality, and there are other aspects of sleep, such as timing, regularity, and sleep disorders, that may influence cognitive function but were not measured in the present study.

In conclusion, the results of the present study suggested that people with long sleep duration may have lower cognitive performance and the relationship between sleep and cognition may differ between men and women. Our study contributes to a growing body of literature linking sleep with cognitive health. On the other hand, our study also highlights the importance of domain-specific cognitive assessment, objective sleep measurements, and prospective design. In addition, the field will benefit from intervention studies that examine the potential cognitive benefits in older adults of improving sleep via various strategies, such as enhanced sleep hygiene and exercise.

CONFLICT OF INTEREST

All authors have no conflict of interest to report for the submission of this manuscript.

AUTHOR CONTRIBUTIONS

AS wrote the main manuscript text and prepared tables and analytical procedures. CM edited the main manuscript, tables, and contributed to the analysis portion of this study. KW edited the main manuscript and tables. DZ edited main manuscript, tables, and contributed to the analytical portion of study. LC and WB edited main manuscript and tables. QX edited the main manuscript text and tables, as well as contributed to analytical portion of the study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

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