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SCIENTIFIC INVESTIGATIONS

Paradoxical relationship between subjective and objective cognition: the role of sleep

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Study Objectives: Subjective memory complaints and objective cognitive dysfunction are common in aging populations; however, research investigating the associations between them is inconclusive. Given the high prevalence of sleep complaints in middle-aged/older adults, this research tested whether objective cognition interacted with sleep parameters in its associations with subjective cognition.

Methods: Cognitively healthy adults aged 50+ years completed the Pittsburgh Sleep Quality Index, Cognitive Failures Questionnaire, and cognitive tasks: Stroop, Sternberg, and Posner cueing. Multiple regression and simple slope analyses examined whether objective cognition interacted with sleep parameters in its associations with subjective memory.

Results: Stroop performance and sleep (efficiency and disturbances) had interactive associations with Cognitive Failures Questionnaire–memory. Specifically, better Stroop performance (faster reaction time-control trials) was associated with more memory complaints at worst and average but not best sleep efficiency. Additionally, faster reaction time was associated with more memory complaints only for worst sleep disturbance. Similarly, Sternberg performance and sleep (efficiency and disturbances) had interactive associations with Cognitive Failures Questionnaire–memory. Specifically, higher proportion correct was associated with more memory complaints only at worst sleep efficiency and sleep disturbance. Finally, Posner performance and sleep disturbance had an interactive association with Cognitive Failures Questionnaire–memory. Faster exogenous orienting was associated with more memory complaints only for worst sleep disturbance.

Conclusions: Objective cognition interacts with sleep efficiency and sleep disturbances in its associations with subjective memory in mid-to-late life. Findings suggest sleep fragmentation plays a role in the discrepant relationship between objective and subjective cognition. Future studies should investigate this relationship in aging populations with sleep disorders and/or cognitive impairments.

Keywords: sleep disturbance, cognitive performance, subjective memory, middle-aged adults, older adults

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BRIEF SUMMARY

Current Knowledge/Study Rationale: Objective and subjective cognitive function are often discrepant in aging populations. Despite known associations between these abilities and sleep, research has not explored whether aspects of sleep contribute to the objective/subjective cognition relationship.

Study Impact: Findings suggest that, in middle-aged and older adults who are cognitively healthy, sleep efficiency and sleep disturbances interact with objective cognition in its associations with subjective memory, in that there is a greater discrepancy in their association (worse objective cognition associated with better subjective evaluation) at levels of worse sleep. These findings suggest that sleep fragmentation plays a role in the discrepant relationship between objective and subjective cognitive function.

INTRODUCTION

Sleep complaints, cognitive dysfunction, and subjective memory complaints are all common in aging populations.[1,2] The link between sleep complaints and cognitive dysfunction is established.[3] However, associations between objective cognition and subjective memory complaints are less clear,[4] and whether sleep plays a role in those associations is under researched. Considering that subjective memory complaints are used to diagnosis the prodromal phase of Alzheimer's disease[4] (mild cognitive impairment [MCI]), it is important to understand the relationship between subjective memory complaints and objective cognitive dysfunction and modifiable factors that might contribute to that relationship, such as sleep. Such understanding might point to potential intervention targets (specific sleep parameters) that could be treated (through behavioral sleep interventions) with the aim of improving cognition or mitigating the effects of cognitive decline.

Approximately half of people older than 55 years report problems initiating sleep or maintaining sleep,[1] while 12–20% of these individuals meet criteria for clinical insomnia disorder,[5] characterized by persistent (present 3+ times per week for 3+ months) difficulty with sleep initiation or maintenance, coupled with significant impairment in important areas of functioning[6] (cognitive, social, behavioral, etc.). Compared to younger adults, aging adults typically show decreases in sleep duration and increases in sleep fragmentation,[7] which contribute to decreases in sleep efficiency (time spent sleeping while in bed).

The previously described literature is clear that sleep problems increase with age, which can lead to problems with everyday functioning (eg, cognition, mood).[5]

Sleep problems are linked to both subjective memory complaints and objective cognitive dysfunction. In older adults, sleep problems have been shown to be associated with more subjective memory complaints, independent of global objective cognition.[8] Additionally, in older adults, worse overall sleep quality, longer sleep onset latency, and short sleep duration have been associated with subjective reports of difficulty with self-reported memory currently compared to their past.[9] Studies have also shown older adults with insomnia to have worse episodic memory,[10] learning rate,[10] temporal order judgment,[10] attention,[11] and processing speed.[11] A recent meta-analysis showed that the magnitude of objective cognitive deficits (attention, working memory) in insomnia was small to moderate compared to good sleepers.[12] Additionally, insomnia, short sleep duration, sleep fragmentation, and sleep-disordered breathing are risk factors for cognitive impairment disorders.[3,13,14] Moreover, compared to typically aging older adults, those with MCI have lower sleep duration and quality as well as greater sleep disturbances, onset latency, and efficiency, and these were unrelated to anxiety and depressive symptoms.[15]

Although subjective memory complaints are common in aging adults,[16] findings of associations between subjective memory complaints and objective cognition are inconclusive.[4] Some studies show in healthy older adults that subjective memory complaints are not associated with objective cognition,[17,18] while other studies show they are associated.[2,11] Interestingly, studies have shown that a majority of older adults with objective cognitive impairments do not have complaints about their memory.[19–21] Given that subjective memory complaints are often the first indicator of subsequent cognitive decline[22] and are part of the clinical diagnostic criteria for MCI,[23] it is important to better understand factors that may contribute to the relationship between subjective memory and objective cognition in aging populations. A lack of awareness of even subtle changes in one's objective cognitive performance could contribute to missed opportunities for early intervention and missed diagnoses of MCI.[24] It is possible that poor sleep may be a factor related to individuals not being able to recognize subtle changes in their objective performance. Understanding this may help clinicians determine under which circumstances (eg, in those with certain sleep symptoms), the relationship between objective cognition and subjective memory may diverge. Additionally, how subjective memory complaints are related to objective cognitive performance may depend on the cognitive abilities assessed.[25,26] For instance, although intuitively we would expect subjective memory to reflect objective memory, the supporting literature is mixed,[27] and thus, it is also possible that it is linked to other objective domains of functioning.[28] Therefore, in the present study, we examine how sleep may influence the relationship between subjective memory and objective performance across a range of cognitive tasks (processing speed, attention, inhibition, working memory).

A general theoretical framework to understand the relationship between objective cognition and subjective reports comes from research focusing on metacognition, the understanding of one's cognitive performance.[29] Like objective cognition, metacognitive awareness is thought to make use of limited, attention-demanding resources and central executive function. Disrupted sleep has been shown to reduce attentional resources via reduced slow-wave sleep.[30] Sleep disruption could reduce the availability of these resources, affecting both objective cognition and metacognitive awareness, and may exacerbate the disconnect between the two. For instance, less attentional resources available for those with more sleep disruption may be associated with worse objective cognition but also reduce the ability to accurately evaluate one's cognitive ability. Statistically, this may present as a negative association between objective cognition and metacognition in those with worse sleep disruption (worse cognition associated with paradoxical better ratings of metacognition or vice versa).

The goal of the present study was to examine the interactive associations of specific objective cognitive domains (processing speed, inhibition, attention, working memory) and sleep parameters (sleep quality, duration, efficiency, disturbances) in their associations with subjective memory in middle-aged and older adults. We hypothesized that objective cognition performance would interact with self-reported sleep in its associations with subjective memory. Such a possibility could indicate a potential moderating influence of sleep on the objective/subjective cognition relationship. Specifically, we predicted that in the presence of worst sleep (poor sleep quality, long or short duration, worst efficiency, more disturbances), the association between objective cognition and subjective memory would be strongest, and discrepant (worse objective cognition associated with better subjective memory evaluation).

METHODS

Participants

Middle-aged and older adults residing in the United States were recruited through Qualtrics panels, a national online data aggregator. Qualtrics panels provides users with access to market research panels and uses digital fingerprinting technology and IP address checks to ensure the data validity and reliability. Participants recruited via Qualtrics panels receive an email from Qualtrics inviting them to participate in the study by clicking on a questionnaire link. Participants who met inclusion criteria read and completed a documentation of consent prior to beginning the online survey and cognitive tasks. Participants were eligible for the study if they 1) were 50+ years of age, 2) were living in the United States, 3) reported no cognitive impairment or major neurological disorder (no diagnoses of MCI, dementia, Parkinson's Disease, etc.), and 4) had normal or corrected-to-normal vision and hearing (glasses, hearing aid). Participants were excluded if they were receiving any treatment for cognition, substance use, fatigue, mood, or were participating in nonpharmacological treatment for sleep. Participants were compensated $6.50 following completion of the survey and $10 following completion of the cognitive tasks. The University of Missouri Institutional Review Board approved all study procedures.

Measures

Sleep

The Pittsburgh Sleep Quality Index (PSQI[31]) was used to assess sleep. The PSQI measures 7 components of self-reported sleep, with a range of 0 to 3 for each item, with higher numbers representing worse sleep. Components are computed from individual items on the PSQI and include sleep quality, sleep onset latency, sleep duration, sleep efficiency, sleep disturbances, use of sleep medications, and daytime dysfunction. The PSQI global score is computed by summing the 7 component scores (with a possible range from 0 to 21 and higher scores indicating worse overall sleep quality). Our sleep parameters of interest included those shown in the literature to be most consistently associated with cognitive dysfunction[3] and included PSQI component scores of sleep quality, sleep duration, sleep efficiency, and sleep disturbances.

Objective cognition

Stroop Task (inhibition, attention, processing speed) Participants completed a color-word Stroop Task[32] via Inquisit web.[33] In this task, participants indicate the color of a word stimulus that appears in the center of a screen using a designated keyboard button. The words that appear are color words (red, green, blue, black). Participants complete trials measuring processing speed, processing speed and attention, and inhibition. These 3 types of trials are, respectively, identified as control trials (colored rectangles, **Figure S1a** in the supplemental material), congruent trials (color and name of word are matching, **Figure S1b**), and incongruent trials (color and name of word are not matching, **Figure S1c**).[32] Eighty-four trials were presented to the participants from these 3 types of trials, with each color word and colored rectangle being presented 7 times within each trial type. The different trial types were presented in a randomized order for each participant. A response by the participant was required for the stimuli to disappear. The intertrial interval time is 200 ms, with a red "X" presented upon incorrect responses for 400 ms. Mean reaction time (RT) was computed for each correct trial within the different trial types (control, congruent, incongruent), with lower RTs indicating better performance.

Posner Cueing task (attentional orienting) Participants completed the Posner Cueing task[34] via Inquisit Web.[33] This task measures orienting or shifting of attention.[34] For this task, participants are first presented with a fixation cross in the center of the screen for 1,000 ms and 2 empty boxes to the left and right of fixation. A target (star) then appears on the screen in the left or right box for a duration of 1000 ms and participants are instructed to press the spacebar key as quickly as possible upon target detection. For 80% of the trials, a valid cue is presented for a duration of 20 ms that predicts the location of the target. For the remaining 20% of trials, an invalid cue is presented, which predicts the opposite location of the target. Half of the cues are exogeneous (peripherally located) and consist of a highlight of the right or left box (see **Figure S2a** in the supplemental material). Valid exogenous cues consist of a highlighted right box and target appearing in the right box, whereas an invalid exogenous cue consists of a highlighted right box and target appearing in the left box. The other half of the cues are endogenous (centrally located) and consist of an arrow above the fixation cross, which points to the left or right box (see **Figure S2b**). A valid endogenous cue is an arrow pointing right and target appearing in the right box, whereas an invalid endogenous cue is an arrow point right and target appearing in the left box. Two test blocks of 100 trials are presented, with one block containing exogenous cues (80 valid, 20 invalid), and the other containing endogenous cues (80 valid, 20 invalid). The order of test blocks was randomly determined. Half of the trials (randomly determined) have a stimulus onset asynchrony between cue and target onset of 100 ms, and the other half have a stimulus onset asynchrony of 500 ms. Intertrial time is 1,500 ms. Each test block is preceded by a practice block of 10 trials (80% valid/20% invalid), which were excluded from analyses. Mean RTs for exogenous and endogenous valid and invalid test trials in which the location of targets was correctly identified were first computed. Invalid trials RT minus valid trials RT were then computed separately for each block of trials to compute an index of exogenous (peripheral/reflexive) orienting of attention and endogenous (central) orienting of attention.[35] Lower exogenous and endogenous orienting indices indicate better performance.

Sternberg (working memory) Participants completed the Sternberg memory task[36] via Inquisit Web.[33] This task measures working memory.[36] Individuals are shown a sequence of digits, presented one by one (for 1,000 ms; see **Figure S3** in the supplemental material). The sequence length is 2 to 7 numbers. A probe digit is then presented, and participants indicate (via designated keyboard response) if a specific digit was (in trial) or was not (out trial) part of the preceding sequence. One test block consists of 18 trials, with a randomized order of set sizes of digits (set sizes in include 2, 3, 4, 5, 6, and 7 digits). Nine trials consist of in trials and nine trials are out trials. A response must be made for the next trial to begin, with a green "O" presented if the participant was correct, and a red "X" presented if the participant was incorrect, for a duration of 500 ms. Given the known working memory capacity limits of middle-aged and older adults,[37] the proportion of correct answers for trials of sequence size 4, 5, 6, and 7 digits was calculated, with higher values representing better performance.

Subjective memory (Cognitive Failures Questionnaire)

Subjective memory was assessed via the Cognitive Failures Questionnaire[38] (CFQ). The CFQ measures everyday cognitive failures in perception, memory, and motor function. Participants rate items from 0 (never) to 4 (always), indicating the degree which they experience failures in 25 everyday cognitive tasks over the past month. The CFQ-total score ranges from a possible 0 to 100, with higher scores indicating greater everyday failures. Component scores can be calculated from the individual questions.[39] The memory component (CFQ-memory) measures general subjective memory failures and forgetfulness across eight questionnaire items (eg, "Do you find you forget appointments?", "Do you forget where you put something like a newspaper or book?"), ranging from a possible 0 to 32 and was the outcome of interest in the present study. Higher scores indicate more everyday memory failures.

Statistical analysis

Multiple linear regressions were conducting in SPSS (version 26) using the PROCESS macro[40] (model 1; version 3.5). The dependent variable was CFQ-memory. The independent variables included in the regression models consisted of objective cognitive task scores (Stroop RT on control trials [processing speed], Stroop RT on congruent trials [processing speed and attention], Stroop RT on incongruent trials [inhibition], Posner endogenous orienting RT index, Posner exogenous orienting RT index, and Sternberg proportion correct [4–7 number series, working memory]), sleep parameters (PSQI sleep quality, sleep duration, sleep efficiency, and sleep disturbances), and the objective cognitive outcome × sleep parameter interaction term. Separate models were conducted for each cognitive measure and sleep parameter. Given the smaller sample size of those who completed the online cognitive tasks (n = 62) and the general rule of thumb in regression analyses to examine 1 independent variable for every 10 cases,[41] we were limited in the number of covariates to be accounted for in regression models. We could examine 3 in our regression models to maintain adequate power.[41] Given the known associations between cognition and sex,[42] sleep medication,[43] and depressive/anxiety symptoms[44,45] (Hospital Anxiety and Depression scale[46]), we chose to control for them in analyses. Although we considered other standard covariates such as age and education, the ranges for these values in our sample of participants were relatively small (see **Table 1**; mostly middle-aged and younger older adults and highly educated), and as a result we did not consider these values to substantially impact our results. In addition, to further support our chosen covariates, we conducted a Pearson product moment correlation to investigate the relationship between age, sex, education, sleep medication usage, and depressive/anxiety symptoms with our dependent variable. Only use of sleep medication, depressive/anxiety symptoms, and sex were significantly correlated ($P < .05$) with the outcome variable. Therefore, our conduction of analyses without covarying for age and education was appropriate.

In the case of a significant interaction term (objective cognitive measure × sleep) in regression models, simple slopes were calculated to clarify the association between objective cognition and subjective cognition at sample-estimated values of the potential moderator, characterized as follows: best sleep (1 standard deviation below the mean of the sleep parameter), average sleep (mean value of the sleep parameter), and worst sleep (1 standard deviation above the mean of the sleep parameter). We accepted the false-positive risk in our analyses and no family-wise error corrections were applied, following statistical recommendations,[47] given the scarcity of research regarding subjective memory, specific sleep parameters, and specific objective cognitive domains in middle-aged and older adults. All regression results were evaluated at an alpha level of $P < .05$.

RESULTS

Participant characteristics

Participant demographics and descriptive values for objective cognition, sleep, and subjective memory variables are provided in **Table 1**. A total of 62 participants (M_{age} = 63.40, standard deviation = 1.70; 33 men/29 women) completed the online cognitive tasks and were included in the regression analyses.

Regression results

Stroop RT and sleep parameters: associations with CFQ-memory

Stroop RT-control trials (processing speed) All full regression models including sleep quality (full model $R^2 = .38$, $P = .002$), sleep duration (full model $R^2 = .43$, $P < .001$), sleep efficiency (full model $R^2 = .46$, $P < .001$), and sleep disturbances (full model $R^2 = .41$, $P < .0001$) were statistically significant, explaining 38 to 46% of the variance. As shown in **Table 2**, the interaction between processing speed and sleep efficiency was associated with CFQ-memory ($P = .009$, $R^2 = .07$). Specifically, as shown in **Figure 1A**, worse processing speed (slower Stroop RT-control trials) was associated with less memory complaints (lower CFQ-memory score) at worst ($\beta = -1.83$, $P = .001$) and average ($\beta = -.83$, $P = .03$) but not best ($P = .64$) sleep efficiency. Furthermore, as shown in **Table 2**, the interaction between processing speed and sleep disturbances was associated with CFQ-memory ($P = .03$, $R^2 = .05$). Specifically, as shown in **Figure 1B**, worse processing speed was associated with less memory complaints at worst ($\beta = -1.82$, $P = .005$) and average ($\beta = -.77$, $P = .05$) but not best ($P = .65$) sleep disturbances. Additionally, as shown in **Table 2**, there were no other significant associations between independent variables and CFQ-memory.

Stroop RT-congruent trials (attention and processing speed) All full regression models including sleep quality (full model $R^2 = .34$, $P = .007$), sleep duration (full model $R^2 = .38$, $P < .001$), sleep efficiency (full model $R^2 = .37$, $P < .001$), and sleep disturbances (full model $R^2 = .35$, $P < .001$) were statistically significant, explaining 34% to 38% of the variance. However, as shown in **Table 2**, there were no significant associations between independent variables and CFQ-memory.

Stroop RT-incongruent trials (inhibition) All full regression models including sleep quality (full model $R^2 = .43$, full model $P < .001$), sleep duration (full model $R^2 = .47$, $P < .001$), sleep efficiency (full model $R^2 = .48$, $P < .001$), and sleep disturbances (full model $R^2 = .41$, $P < .001$) were statistically significant, explaining 41%–48% of the variance. However, as shown in **Table 2**, there were no significant associations between independent variables and CFQ-memory.

Posner RT and sleep parameters: associations with CFQ-memory

Posner RT–Exogenous Orienting Index (exogenous orienting attention) All full regression models including sleep quality (full model $R^2 = .33$, $P < .001$), sleep duration (full model $R^2 = .37$, $P < .001$), sleep efficiency (full model $R^2 = .40$, $P < .001$), and sleep disturbances (full model $R^2 = .41$, $P < .001$) were statistically significant, explaining 33%–41% of the variance. As shown in **Table 3**, the interaction between exogenous orienting attention and sleep disturbances was associated with CFQ-memory ($P = .006$, $R^2 = .09$). Specifically, as shown in **Figure 2**, slower exogenous orienting was associated with

Table 1—Participant characteristics (n = 62).

Variable	Mean (SD)	Range
Age, y	63.4 (7.6)	50–78
Race, n (%)		
White/European American	56 (90.3)	—
Black/African American	2 (3.2)	—
Asian/Asian American	2 (3.2)	—
American Indian/Alaskan Native	0	—
Other	2 (3.2)	—
Education, n (%)		
Graduate of high school	10 (16.1)	—
Some college	19 (30.6)	—
Graduated college	22 (35.5)	—
Graduate or professional school	11 (17.7)	—
No. of medical conditions, n (%)	1.65 (1.87)	0–8
Heart disease	3 (4.9)	—
Cancer	2 (3.3)	—
High blood pressure	23 (37.7)	—
Neurological Disorder	0 (0)	—
Breathing Disorder	4 (6.6)	—
Diabetes	5 (8.2)	—
Chronic pain	18 (29.5)	—
Difficulty walking	6 (9.8)	—
Gastrointestinal Disorder	8 (13.1)	—
Urinary tract disorder	1 (1.6)	—
Vision disorder	13 (21.3)	—
Depression	7 (11.5)	—
Bipolar Disorder	0 (0)	—
Anxiety Disorder	3 (4.9)	—
Schizophrenia	0 (0)	—
Other mental illness	0 (0)	—
Use of sleep medications, n (%)		
Yes	14	—
No	48	—
Use of pain medication, n (%)		
Yes	34	—
No	28	—
HADS-Total	10.31 (7.95)	0–32
HADS-Depression	4.81 (4.17)	0–17
HADS-Anxiety	5.5 (4.22)	0–18
PSQI-Total	6.56 (4.34)	1–18
PSQI-Sleep quality	1.23 (.82)	0–3
PSQI-Sleep duration	.98 (.87)	0–3
PSQI-Sleep efficiency	.56 (.89)	0–3
PSQI-Sleep disturbances	1.19 (.54)	0–2
CFQ-Total	27.6 (12.42)	5–55
CFQ-memory	5.76 (3.73)	0–15
Stroop Task-RT (ms)		
Control trials	1,438.55 (518.42)	746.41–3,768.75

(continued on following page)

Table 1—Participant characteristics (n = 62). (*Continued*)

Variable	Mean (SD)	Range
Congruent trials	1,530.8 (618.14)	790.21–4,330.93
Incongruent trials[a]	1,853.77 (572.42)	971.96–3688.52
Posner Task-RT (ms)		
Exogenous orienting index	39.15 (34.64)	−56.39–140.71
Endogenous orienting index	39.90 (35.70)	−40.61–130.87
Sternberg Task – proportion correct 4–7 number series[b]	.78 (.20)	.33–1

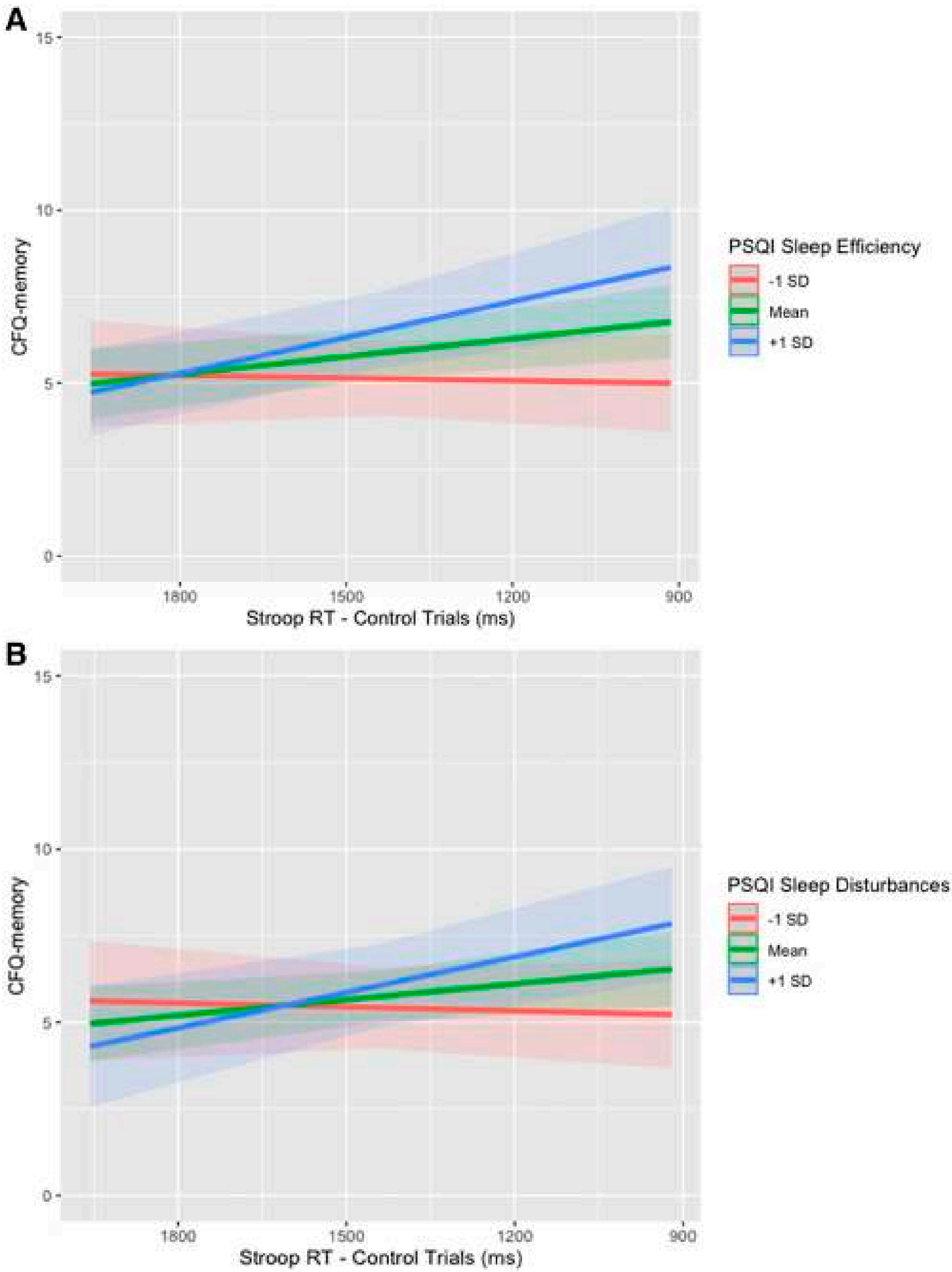
[a]Two participants obtained an accuracy of 0% on incongruent trials; therefore, no RT could be calculated (for correct trials). Therefore, this subsample is based on 60 participants. [b]One participant did not complete the Sternberg Task. Therefore, this subsample is based on 61 participants. CFQ = Cognitive Failures Questionnaire, HADS = Hospital Anxiety and Depression Scale, PSQI = Pittsburgh Sleep Quality Index, RT = reaction time, SD= standard deviation.

Table 2—Multiple regression results of Stroop performance interacting with self-reported sleep in its associations with subjective memory (CFQ-memory) in middle-aged and older adults.

	Control Trials (n = 62)				Congruent Trials (n = 62)				Incongruent Trials (n = 60)			
PSQI Subscale	β	SE	*t*	*P*	β	SE	*t*	*P*	β	SE	*t*	*P*
Sleep quality												
Stroop RT	−.68	0.40	−1.68	.10	−.33	0.43	−0.78	.44	.10	0.39	0.26	.80
Sleep quality	0.17	0.51	0.34	.74	.46	0.51	0.90	.37	.74	0.47	1.57	.12
Stroop RT × sleep quality	−.56	0.47	−1.19	.24	−.09	0.52	−0.17	.86	.45	0.39	1.16	.25
Sex	.33	0.87	0.38	.71	.07	0.88	0.08	.93	.71	0.83	0.85	.40
Sleep medicine usage	2.37	1.08	2320	.03	1.91	1.08	1.77	.08	2.78	1.03	2.70	.01
Total HADS	1.60	0.49	3.27	.00	1.42	0.49	2.87	.01	1.29	0.47	2.75	.01
Sleep duration												
Stroop RT	−.56	0.40	−1.42	.16	−.43	0.40	−1.07	.29	−.18	0.39	−0.47	.64
Sleep duration	.44	0.43	1.02	.31	.57	0.43	1.32	.19	.77	0.41	1.09	.06
Stroop RT × sleep duration	−.84	0.48	−1.74	.09	−.51	0.50	−1.02	.31	.22	0.32	0.69	.49
Sex	.41	0.81	0.50	.62	.27	0.84	0.32	.75	.92	0.79	1.17	.25
Sleep medicine usage	2.20	0.99	2.22	.03	1.88	1.04	1.81	.08	2.95	0.99	2.98	.00
Total HADS	1.54	0.41	3.72	.00	1.45	0.43	3.38	.00	1.14	0.39	3.60	.00
Sleep efficiency												
Stroop RT	−.85	0.38	−2.25	.03	−.61	0.45	−1.36	.18	−.13	0.38	−0.34	.74
Sleep efficiency	.78	0.46	1.69	.10	.47	0.49	0.95	.35	.74	0.47	1.57	.12
Stroop RT × sleep efficiency	−1.07	0.39	−2.72	.01	−.078	0.66	−1.19	.24	.38	0.36	1.05	.30
Sex	.89	0.80	1.12	.27	.64	0.88	0.73	.47	1.07	0.79	1.36	.18
Sleep medicine usage	2.64	0.98	2.68	.01	2.41	1.07	0.25	.03	2.86	0.99	2.90	.01
Total HADS	1.63	0.39	4.19	.00	1.61	0.43	3.77	.00	1.46	0.38	3.88	.00
Sleep disturbances												
Stroop RT	−.83	0.39	−2.13	.04	−.63	0.46	−1.37	.18	.06	0.40	0.14	.89
Sleep disturbances	.37	0.53	0.69	.49	.57	0.56	1.03	.31	.61	0.53	1.15	.25
Stroop RT × sleep disturbances	−1.10	0.51	−2.17	.03	−.62	0.51	−1.23	.23	.07	0.44	0.16	.88
Sex	.30	0.83	0.36	.72	.04	0.86	0.05	.96	.69	0.84	0.82	.42
Sleep medicine usage	2.37	1.07	2.22	.03	1.86	1.11	1.69	.10	2.77	1.08	2.56	.01
Total HADS	1.45	0.46	3.12	.00	1.33	0.50	2.66	.01	1.46	0.46	3.17	.00

Regression models were also conducted with age and education as covariates, but these covariates were nonsignificant and results remained similar across all outcomes. Therefore, regression models are presented without age and education. CFQ = Cognitive Failures Questionnaire, HADS = Hospital Anxiety and Depression Scale, PSQI = Pittsburgh Sleep Quality Index, RT = reaction time, SE = standard error.

Figure 1—Associations between CFQ-memory and sleep efficiency, disturbances in the Stroop RT-control trials.



Associations between CFQ-memory and the interaction of **(A)** sleep efficiency and Stroop RT-control trials and **(B)** sleep disturbances and Stroop RT-control trials, in middle-aged and older adults. Higher CFQ-memory scores reflect more reported memory failures. CFQ = Cognitive Failures Questionnaire, PSQI = Pittsburgh Sleep Quality Index, RT = reaction time, SD = standard deviation.

fewer memory complaints at worst ($\beta = 1.12$, $P = .03$), but not average ($P = .91$) or best ($P = .10$) sleep disturbance levels. Additionally, as shown in **Table 3**, there were no other significant associations between independent variables and CFQ-memory.

Posner RT–Endogenous Orienting Index (endogenous orienting attention) All full regression models including sleep quality (full model $R^2 = .34$, $P < .001$), sleep duration (full model $R^2 = .35$, $P < .001$), sleep efficiency (full model $R^2 = .36$, $P < .001$), and sleep disturbances (full model $R^2 = .34$, $P < .001$) were statistically significant, explaining 34%–36% of the variance. However, as shown in **Table 3**, there were no significant associations between independent variables and CFQ-memory.

Sternberg task and sleep parameters: associations with CFQ-memory

Sternberg Proportion Correct (working memory) All full regression models including sleep quality (full model $R^2 = .35$,

Table 3—Multiple regression results of Posner performance interacting with self-reported sleep in its associations with subjective memory (CFQ-memory) in middle-aged and older adults.

PSQI Subscale	Exogenous Orienting Index (n = 62)				Endogenous Orienting Index (n = 62)			
	β	SE	*t*	*P*	β	SE	*t*	*P*
Sleep quality								
Posner RT	−.12	0.47	−0.26	.80	.57	0.44	1.29	.20
Sleep quality	0.17	0.53	0.33	.74	.26	0.52	0.50	.62
Posner RT × sleep quality	−.33	0.47	−0.70	.49	.03	0.41	0.08	.93
Sex	.21	0.88	0.23	.82	−.10	0.87	−0.11	.91
Sleep medicine usage	2.11	1.10	1.93	.06	2.10	1.08	1.92	.06
Total HADS	1.66	0.53	3.15	.00	1.48	0.53	2.81	.01
Sleep duration								
Posner RT	−.39	0.47	−0.82	.41	.39	0.44	0.89	.38
Sleep duration	.04	0.47	0.09	.92	.09	0.48	0.19	.85
Posner RT × sleep duration	−.39	0.34	−1.12	.27	.22	0.32	0.67	.51
Sex	.64	0.86	0.74	.46	.15	0.84	0.18	.86
Sleep medicine usage	2.31	1.06	2.18	.03	2.40	1.07	2.24	.03
Total HADS	1.61	0.45	3.58	.00	1.55	0.46	3.37	.00
Sleep efficiency								
Posner RT	−.35	0.49	−0.71	.48	.39	0.43	0.90	.37
Sleep efficiency	.52	0.49	1.06	.29	.28	0.48	0.59	.56
Posner RT × sleep efficiency	−.51	0.29	−1.76	.08	.30	0.35	0.85	.37
Sex	.80	0.83	0.96	.34	.22	0.83	0.26	.79
Sleep medicine usage	2.21	1.06	2.09	.04	2.37	1.05	2.26	.03
Total HADS	1.52	0.43	3.51	.00	1.55	0.45	3.46	.00
Sleep disturbances								
Posner RT	−.15	0.41	−0.36	.72	.60	0.42	1.14	.16
Sleep disturbances	.56	0.52	1.08	.29	.35	0.54	0.64	.52
Posner RT × sleep disturbances	−1.15	0.40	−2.86	.01	−.29	0.44	−0.66	.51
Sex	−.06	0.83	−0.07	.95	−.17	0.86	−0.20	.84
Sleep medicine usage	2.04	1.07	1.90	.06	2.07	1.11	1.87	.07
Total HADS	1.54	0.46	3.31	.00	1.49	0.50	3.00	.00

Regression models were also conducted with age and education as covariates, but these covariates were nonsignificant and results remained similar across all outcomes. Therefore, regression models are presented without age and education. CFQ = Cognitive Failures Questionnaire, HADS = Hospital Anxiety and Depression Scale, PSQI = Pittsburgh Sleep Quality Index, RT = reaction time, SE = standard error.

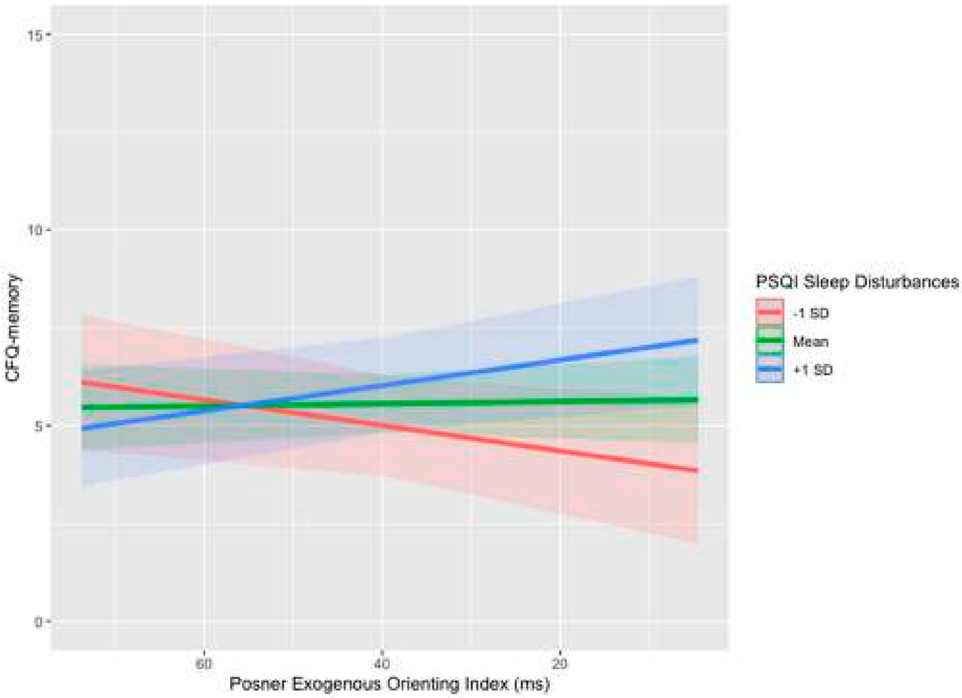
$P < .001$), sleep duration (full model $R^2 = .36$, $P < .001$), sleep efficiency (full model $R^2 = .40$, $P < .001$), and sleep disturbances (full model $R^2 = .39$, $P < .001$) were statistically significant, explaining 35%–40% of the variance. As shown in **Table 4**, the interaction between working memory and sleep efficiency was associated with CFQ-memory ($P = .02$, $R^2 = .06$). Specifically, as shown in **Figure 3A**, lower percentage correct (worse working memory) was associated with less memory complaints at worst ($\beta = 1.22$, $P = .03$), but not average ($P = .56$) or best ($P = .42$) sleep efficiency levels. Furthermore, as shown in **Table 4**, the interaction between working memory was associated with CFQ-memory ($P = .04$, $R^2 = .05$). Specifically, as shown in **Figure 3B**, lower percentage correct was associated with less memory complaints at worst ($\beta = 1.23$, $P = .048$), but not average ($P = .56$) or best ($P = .26$) sleep disturbance levels.

Additionally, as shown in **Table 4**, there were no other significant associations between independent variables and CFQ-memory.

Exploratory analyses

Analyses examining objective cognition interacting with PSQI global score in its associations with CFQ-memory in regression models can be found in **Table S1** in the supplemental material. Given our prior results showing sleep medication as a significant covariate in regression analyses (see **Table 2**, **Table 3**, and **Table 4**), additional analyses using objective cognition

Figure 2—Associations between CFQ-memory and the interaction of sleep disturbances and Posner RT-Exogenous Orienting Index in middle-aged and older adults.



Higher CFQ-memory scores reflect more reported memory failures. CFQ = Cognitive Failures Questionnaire, PSQI = Pittsburgh Sleep Quality Index, SD = standard deviation.

interacting with PSQI sleep medication score in its associations with CFQ-memory in regression models can be found in **Table S3** in the supplemental material. In short, findings indicated worst endogenous orienting index was associated with more memory complaints at worst PSQI global scores ($P = .048$). Findings also indicated worse exogenous orienting index was associated with more memory complaints at higher PSQI sleep medication usage scores ($P = .046$).

DISCUSSION

The present study examined whether objective cognitive performance interacts with specific sleep parameters in its associations with subjective memory in cognitively healthy middle-aged and older adults. Findings revealed processing speed and working memory interacted with self-reported sleep efficiency in their associations with subjective memory. Additionally, findings revealed processing speed, exogenous orienting attention, and working memory interacted with self-reported sleep disturbances in their associations with subjective memory. Specifically, and consistently, objectively worse cognitive performance was associated with the least subjective memory complaints only in those with worst levels of sleep efficiency and most sleep disturbances.

The hypothesis that objective cognitive performance would interact with sleep problems in its associations with subjective cognition was generally supported. Findings suggest at high levels of sleep fragmentation (worst sleep efficiency and disturbance), there is a stronger discrepancy in the association between objective cognition and subjective memory complaints. Specifically, despite worse objective cognitive performance, individuals are endorsing fewer memory complaints. Taken from another perspective, this relationship could also represent those with better objective cognitive performance are reporting more memory complaints. This finding is interesting, considering subjective memory complaints have been linked to future cognitive impairment, but not current cognitive dysfunction.[17]

Findings regarding the relationship between subjective memory complaints and current cognitive dysfunction have been inconsistent across studies.[25] However, subjective memory complaints have consistently been shown to be associated with future cognitive impairment.[17] A longitudinal study found older people with subjective memory complaints at baseline were at greater risk for developing dementia during the 5 years of follow-up, but performed as well on objective cognitive tasks as those without subjective memory complaints.[48] It has been shown self-reported sleep problems are associated with subjective memory complaints,[8] and fragmented sleep is a marker in the development of MCI or dementia.[49] Thus, it is possible that examining subjective memory complaints and sleep problems together will be a better indicator of MCI. Coupling previous findings with our current results, we suggest sleep fragmentation (rather than overall sleep quality or sleep duration) may play a role in the discrepant

Table 4—Multiple regression results of Sternberg performance interacting with self-reported sleep in its association with subjective memory (CFQ-memory) in middle-aged and older adults (n = 61).

PSQI Subscale	β	SE	*t*	*P*
Sleep quality				
Sternberg % correct	.23	0.41	0.56	.58
Sleep quality	.35	0.48	0.72	.48
Sternberg × sleep quality	.51	0.46	1.11	.27
Sex	.49	0.85	0.57	.57
Sleep medicine usage	2.32	1.06	2.18	.03
Total HADS	1.66	0.51	3.26	.00
Sleep duration				
Sternberg % correct	.27	0.41	0.66	.52
Sleep duration	.57	0.45	1.28	.21
Sternberg × sleep duration	.38	0.56	0.67	.51
Sex	.32	0.86	0.37	.72
Sleep medicine usage	1.94	1.05	1.84	.07
Total HADS	1.54	0.45	3.42	.00
Sleep efficiency				
Sternberg % correct	.24	0.39	0.62	.54
Sleep efficiency	.46	0.47	0.97	.34
Sternberg × sleep efficiency	1.06	0.45	2.36	.02
Sex	.65	0.82	0.80	.43
Sleep medicine usage	2.70	1.04	2.59	.01
Total HADS	1.55	0.43	3.57	.00
Sleep disturbances				
Sternberg % correct	.28	0.39	0.71	.48
Sleep disturbances	.82	0.52	1.59	.12
Sternberg × sleep disturbances	1.04	0.49	2.10	.04
Sex	.48	0.84	0.57	.57
Sleep medicine usage	1.90	1.06	1.80	.08
Total HADS	1.41	0.47	3.02	.00

Regression models were also conducted with age and education as covariates, but these covariates were nonsignificant and results remained similar across all outcomes. Therefore, regression models are presented without age and education. CFQ = Cognitive Failures Questionnaire, HADS = Hospital Anxiety and Depression Scale, PSQI = Pittsburgh Sleep Quality Index, SE = standard error.

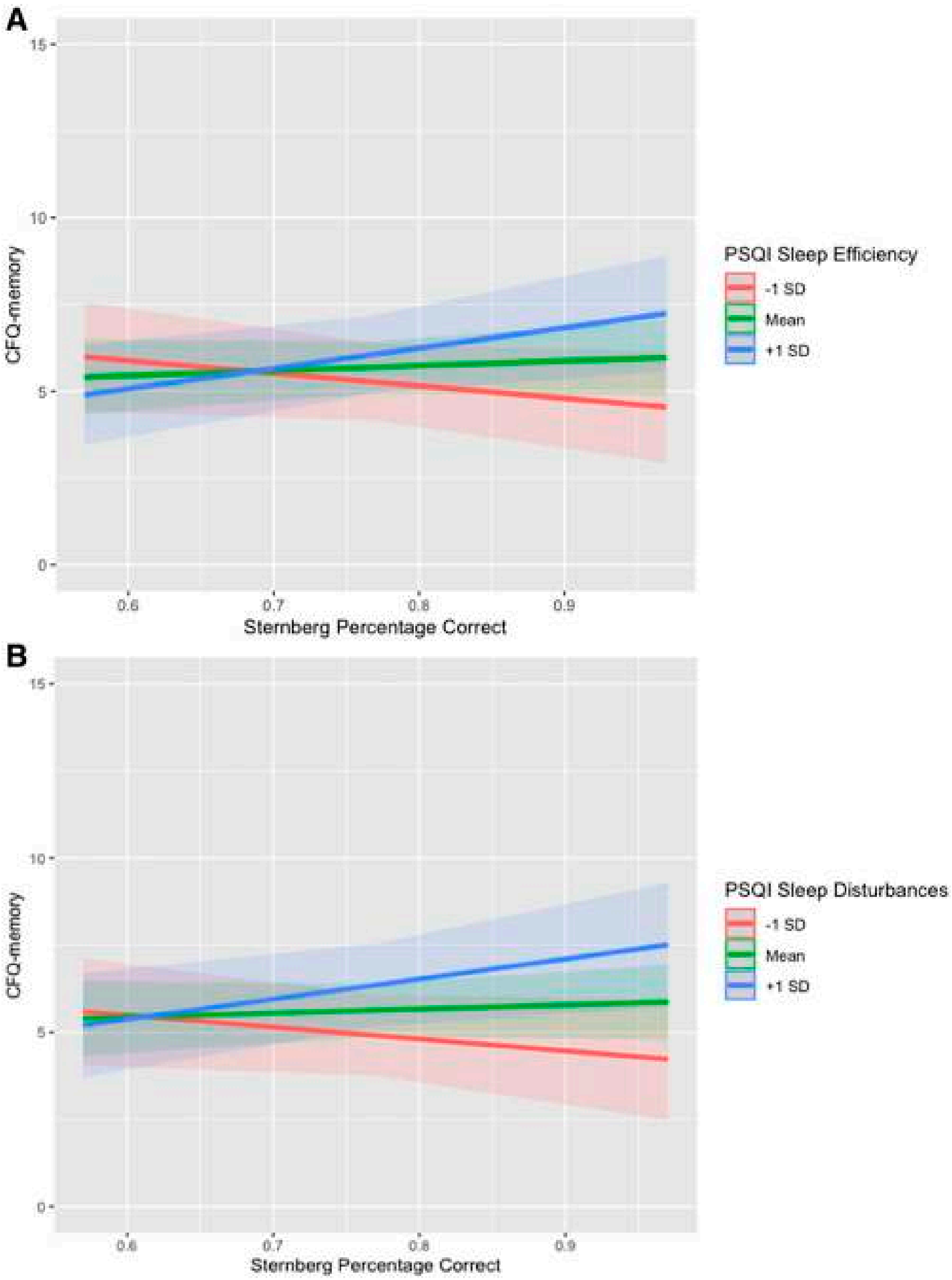
relationship between subjective memory and objective cognitive functioning. Specifically, we propose shared frontal attentional resources among cognitive function and sleep fragmentation may contribute to this pattern of results.

To explain these findings at a cognitive level, fragmented sleep might leave participants without the resources needed to accurately monitor their performance,[50] and thus in those that actually perform best, there are worse subjective ratings of performance (or vice versa). A similar finding related to these is known for effects of distraction on memory.[51] In particular, individuals with high memory spans who use executive attention the most to maximize performance, are the ones whose cognitive performance is affected by distraction the most, whereas low spans are relatively unaffected by distraction.[51] Fragmented sleep and distraction could function similarly. It is possible that individuals with fragmented sleep experience a cognitive burden, via reduced attentional resources, that makes it more difficult to perceive your own cognitive abilities.

At a neural level, sleep fragmentation has been linked with reduced slow-wave sleep.[52] Slow-wave sleep has a well-known connection with memory consolidation[53] and processing speed.[54] Moreover, in healthy older adults, a study showed a correlation between reduced frontal slow-wave spectral power and worse performance on tasks involving the prefrontal cortex.[55] Thus, it is possible that more sleep fragmentation (as indicated by worse scores for PSQI sleep efficiency and sleep disturbances) is linked to reduced time spent in deeper slow-wave sleep (and thus more time spent in lighter staged sleep that is easier to awaken from[56]) and reduced memory functioning.

Additionally, subjective memory has been linked to the frontal lobe.[57] It has been shown that subjective memory is closely related to executive function and the attentional networks

Figure 3—Associations between CFQ-memory and sleep efficiency, disturbances in the Sternberg Task-Proportion Correct.



Associations between CFQ-memory and the interaction of **(A)** sleep efficiency and Sternberg Task-Proportion Correct and **(B)** sleep disturbances and Sternberg Task-Proportion Correct, in middle-aged and older adults. Higher CFQ-memory scores reflect more reported memory failures. CFQ = Cognitive Failures Questionnaire, PSQI = Pittsburgh Sleep Quality Index, SD = standard deviation.

involved in control processes.[29] Moreover, it has been shown exogenous orienting attention is linked with working memory and is distinguishable from endogenous orienting attention in how the information is stored in working memory.[58] Furthermore, processing speed impacts working memory and attention skills.[59] Because of the relationships between processing speed, working memory, and exogenous orienting attention, it is likely that the objective cognitive functions that were found to be related to subjective memory (in the presence of worst sleep) share attentional resources in the frontal lobe. This could indicate middle-aged and older adults are compromised in the frontal lobe in part due to the age-related reduction in slow-wave sleep. Our consistent pattern of results showed only sleep parameters related to fragmentation (sleep efficiency, sleep disturbances) contribute to the objective cognition and subjective memory relationship, which suggests that sleep fragmentation (possibly through reduced slow wave sleep) exacerbates the disruption of cognitive and frontal neural resources and contributes to the objective/subjective discrepancy or misperception of cognitive abilities.

Clinical implications

The present findings have several clinical implications. First, they indicate sleep should be considered in the understanding of discrepancies in subjective reports vs neuropsychological/objective cognitive profiles in mid-to-late life. Second, given that memory complaints are common even without widespread or severe objective cognitive deficits in disorders such as MCI,[21] our findings further suggest improving sleep fragmentation may be an important treatment target. Current behavioral treatments for insomnia such as cognitive behavioral therapy for insomnia have been shown to improve sleep efficiency and wake time after sleep onset.[60] Thus, given the current results, it is important to examine whether cognitive behavioral therapy for insomnia also changes the relationship between objective/subjective cognition. Third, clinicians could use sleep problems as a potential indicator for MCI or early dementia in addition to subjective memory complaints. Subjective memory complaints are frequently used as a diagnostic criterion for MCI; however, a meta-analysis revealed that these complaints have a sensitivity of only 43.0%.[21] Being able to identify certain clinical profiles, such as those with specific insomnia symptoms (eg, primary complaints of trouble maintaining sleep), will help clinicians better understand how subjective memory complaints are related to patients' objective cognitive functioning. This may help identify those who may be at risk for missed early detection of cognitive impairment. For instance, objective cognition may not be appraised correctly in those with greater sleep fragmentation, and thus these individuals may need to be given early and more frequent comprehensive neuropsychological evaluations.

Limitations

The current study has several limitations. First, surveys and cognitive tasks were completed anonymously online and could be viewed as a source of concern as it relates to reliability and generalizability. The current study, however, implemented suggested steps to ensure that these concerns were minimalized and controlled for (ie, prescreening questions, ensuring only 1 response per same IP address[61]). Additionally, evidence shows online cognitive tasks such as the ones used in the present study (Inquisit) are valid and reliable when compared to in-person lab-based tasks,[62] so the concern of the online nature of the cognitive tasks is also mitigated. Second, in the PSQI, we were not able to distinguish between the specific type of nighttime sleep disturbance (waking due to insomnia, sleep-disordered breathing, nocturia, etc.). Thus, it will be important for future studies to assess for these specific symptoms to provide more comprehensive insight into the sleep mechanisms underlying the objective/subjective cognitive discrepancy. Third, our sample had a mean PSQI score of 6.56 (see **Table 1**), which meets the cutoff suggestive of disordered sleep.[63] Thus, our results may be biased toward those with poor sleep quality. Follow-up studies should be conducted in a sample with healthy sleepers to determine the role of sleep in the relationship between objective cognition and subjective memory in middle-aged and older healthy sleepers. Fourth, although the results describing the interaction effects could be indicative of a potential moderating effect of self-reported sleep parameters, this interpretation should be considered tentative. Previous work has indicated that the concept of a moderator should be introduced when there is either a weak or inconsistent relationship between an independent variable and an outcome.[64] It has been proposed that to establish a moderating effect, the moderator has to have temporal precedence[65,66] (moderator precedes the examined independent variable in time), and this is difficult to determine due to the cross-sectional design of the present study. Thus, future prospective studies will help provide further support for these interactive and potential moderating effects. Fifth, the sample size was relatively small. However, we followed the rule of thumb for regression models to examine 1 independent variable for every 10 cases.[41] Sixth, no multiple comparison adjustments were made due to the lack of studies regarding sleep as a moderator of subjective memory and objective cognition,[67] therefore, the results, while consistent, should be replicated in larger samples. Finally, the study sample lacked racial and ethnic diversity (90% white/Caucasian). Thus, future studies should seek to examine findings in a more racially and ethnically diverse sample. Similarly, the current study only examined middle-aged and older adults. Findings should be compared to younger adults to see if they are age specific.

CONCLUSIONS

Findings suggest in cognitively healthy middle-aged and older adults that sleep fragmentation (not duration or overall quality per se) might be a factor related to the discrepancies in the objective cognition and subjective memory relationship. These findings suggest that if we consider sleep fragmentation as a factor in this relationship, it might help researchers better understand disorders that experience discrepancies between subjective memory and objective cognition. Future studies should also investigate this relationship in aging populations with sleep disorders and/or cognitive impairments.

ABBREVIATIONS

CFQ, Cognitive Failures Questionnaire
MCI, mild cognitive impairment
PSQI, Pittsburgh Sleep Quality Index
RT, reaction time

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