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Original Research

The role of rurality on self-reported sleep and cognition in middle-aged and older adults: a preliminary study

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Abstract

Introduction: Despite independent associations of rurality and sleep with cognitive function in aging adults, studies examining their interactive association are limited. We aimed to determine whether rurality impacts the sleep–cognition relationship in aging adults.
Methods: Participants (N=61) aged ≥50 years completed measures of self-report sleep (Pittsburgh Sleep Quality Index (PSQI): total sleep time, sleep efficiency, and total subscores) and objective cognition (Sternberg working memory task, Wisconsin Card Sorting Test, Stroop color–word test (controlled trials and interference scores) and Posner cueing task (exogenous and endogenous scores)). Self-reported US ZIP codes dichotomized rural and non-rural areas. Moderated regressions examined associations between rurality and self-reported sleep with cognition, controlling for age, sex, and education.
Results: In rural residents, shorter PSQI total sleep time score (β=–

144.40, p=0.004) and worse PSQI total score (β=41.79, p=0.01) were associated with worse Stroop interference scores, while worse PSQI total scores was associated with better exogenous attention (β=–3.27, p=0.01). In non-rural residents, lower PSQI sleep efficiency scores were associated with worse working memory (β =0.01, p=0.02) and exogenous attention (β=–1.10, p=0.03). **Conclusion**: Findings suggest rurality-specific associations between self-reported sleep and objective cognition in mid-to-late life. Overall, patterns of results suggests that shorter sleep duration and poorer global sleep quality may be associated with worse higher order cognitive functioning (eg inhibitory control) in rural aging adults, whereas poorer sleep quality may be linked to better performance on lower order attention functioning (eg exogenous spatial attention). In non-rural aging adults, greater overall sleep fragmentation may broadly impact cognition. Future studies should examine urban-specific characteristics (eg traffic noise) and rural-specific characteristics (eg limited healthcare access and social support) that may play a role in the sleep–cognition relationship.

Keywords

objective cognition, older adults, rurality, self-report, sleep, US.

Introduction

Cognitive impairment is linked with poor sleep health (eg sleep duration, sleep efficiency, daytime sleepiness[1]) and is more prevalent in rural areas[2], where approximately 15% of Americans reside[3]. Rurality can be categorized by descriptive, sociocultural[4], population, or geographic criteria[5]. Despite urban–rural differences in cognitive impairment[6] and poor sleep health[7] in aging populations, their interactive association is unclear. Further understanding these interrelationships may inform precision medicine approaches by identifying potential treatment targets prior to cognitive impairment onset.

Age-related changes in cognition[8-10] and sleep[11] are well documented. Throughout the lifespan, processing speed[10,12], divided attention[13], memory (episodic[9,14,15] working[16], source and prospective memory[17]), and executive functioning[9,10] generally decline. However, spatial attention[18,19], sustained attention[20], and semantic memory[9], are relatively preserved. Sleep complaints are common in aging populations, with approximately 57% of older adults reporting at least one sleep complaint[21]. With age, sleep onset latency (time to sleep onset), wake after sleep onset[22,23], and sleep disturbances[24] increase, while total sleep time and sleep efficiency decline[11]. In older adults, poor sleep health is further associated with worse cognition[1,25].

Although associations between rurality and cognition are limited[26], existing findings indicate higher cognitive impairment prevalence in rural older adults[2,27,28], with twice the likelihood compared to non-rural counterparts[2,27,29]. Additionally, the rural oldest older adults (aged ≥75 years) were more likely to have dementia than non-rural counterparts[2,6]. In objective cognitive tests, some studies report worse global cognitive functioning[26], verbal learning, memory and fluency, orientation, and memory for rural versus non-rural older adults[30].

Findings regarding rurality and sleep associations are inconsistent. In rural areas, the prevalence of poor sleep quality is approximately 27% in middle-aged adults[31], approximately 58% in mid-to-late-life adults[32], and approximately 33–44% in older adults[33-35]. Rural older adults most frequently reported difficulty initiating sleep (40–85%[32-34]), sleep disturbances (44–82%[33,36]), and sleep complaints[33]. Despite rural older adults generally reporting worse sleep quality[35,36] and sleep duration than non-rural aging adults[37], other work has showed that non-rural adults across the lifespan have worse sleep health[38]. Some work also reports no rurality differences in sleep efficiency among older adults[39]. Notably, several rurality–sleep investigations were conducted in rural regions of China, and their findings may reflect cultural, healthcare, and environmental conditions that may differ from Western and US rural contexts, limiting direct generalizability. Therefore, further investigations of rurality–sleep associations in geographically rural areas in the US are warranted.

Although rurality and sleep are independently linked to cognition, their interactive association is unclear. Existing findings suggests that rural older adults with poor total sleep time, sleep efficiency, and daytime fatigue experienced a higher risk of all-cause dementia and Alzheimer's disease, and those with mild cognitive impairment were 1.5 times more likely to have sleep disturbances[7]. Conversely, non-rural-residing older adults with poor sleep quality had a faster rate of cognitive decline than healthy sleeping counterparts[40]. Therefore, further delineating the interactive association between rurality and sleep with cognition is warranted.

The present preliminary study examined whether rurality (non-rural v rural) moderates the associations between self-reported sleep and cognitive domains: working memory, executive functioning, spatial attentional orienting, and processing speed. We hypothesized that rurality would moderate the relationship between self-reported sleep and cognition; however, we did not have specific directional hypotheses regarding whether non-rural or rural areas would show stronger associations, given previous inconsistent findings.

Methods

Participants

Qualtrics (Qualtrics (https://www.qualtrics.com [https://www.qualtrics.com/]) market research panels recruited middle-aged and older adults using digital fingerprinting technology and IP addresses to ensure data reliability and validity. Qualtrics maintains a large, nationally distributed US participant pool to identify eligible panel members based on demographic screening criteria (eg US residency status) and distributes study initiations through their secure system. Participants provided their email address and ZIP code for compensation and demographic purposes.

The present study used a subsample of participants from a larger survey cohort (n=281[41]), specifically those participants who completed the objective cognition measures. Informed consent was obtained before survey administration. Inclusion criteria included age ≥50; US residency; no cognitive impairment or major neurological disorders (eg dementia, Parkinson's disease, epilepsy); and normal/corrected vision and hearing. Participants receiving treatment for cognition, mood, fatigue, or substance use, or non-pharmacological sleep treatment, were excluded. Participants were compensated US$6.50 (A$9.29). The University of Missouri's Institutional Review Board reviewed and approved all study procedures for both the larger survey cohort and the present study subsample (IRB# 2075002).

Measures

Rurality

Participants reported ZIP codes using an online demographic questionnaire, determining county and state residential location via the *zipcodeR* package in *R* software v4.4.1 (R Project; https://www.r-project.org). The US Department of Health Resources and Services Administration (HRSA[42]) incorporates federal rural definitions – including those from the US Census Bureau and Office Management and Budget[43], and Rural-Urban Commuting Area (RUCA) codes[44] – to determine rurality by county and state[43]. RUCA codes were linked to participants' ZIP codes to determine rurality (coded as 0, non-rural; 1, rural[43,44]). RUCA code classifications were used as recommended given the methodological robustness and precision for identifying rural and non-rural areas compared to other federal classifications[5,45]. Consistent with HRSA's criteria, rural areas were defined as RUCA codes 4–10, while all other RUCA codes were defined as non-rural areas[42].

Self-reported sleep

The Pittsburgh Sleep Quality Index (PSQI[46]) assessed self-reported sleep with seven components (scored 0–3), and higher scores indicating worse perceived sleep. Components scores are summed to calculate the PSQI global score (PSQI total, score range 0–21), with higher scores indicating worse overall sleep quality. In addition to PSQI total, the PSQI also measures specific sleep parameters, with sleep parameters of interest including total sleep time (hours) and sleep efficiency (calculated as the percentage total sleep time relative to total time in bed and ranging from 0% to 100%).

Objective cognition

Objective cognition measures were administered online using Inquisit Web (Millisecond; https://www.millisecond.com [https://www.millisecond.com]), which has demonstrated performance comparability to the lab-based Stroop color–word test[47], Wisconsin Card Sorting Test[48], Posner cueing task[49], and Sternberg working memory task[50]. After completing self-reported measures in Qualtrics, participants were sent an email with direct links to the Inquisit Web platform to complete the computerized tasks. All tasks were administered remotely, and responses – including key presses – were recorded automatically by the Inquisit system.

Working memory

The Sternberg working memory task[51] presented a sequence of two to seven digits (100 ms each), followed by a probe digit. Participants indicated (by key press) whether the digit probe was previously presented ('in-trial') or not ('out-trial'). Each test block included 18 trials (nine in-trials and nine out-trials), with digit set sizes randomized. A response initiated the next trial, and feedback (green 'O', correct; red 'X', incorrect) was presented (500 ms). The proportion of correct trials was computed, with higher scores demonstrating better working memory.

Executive function

The Wisconsin Card Sorting Test[52,53] measures set-shifting ability, an executive function. Participants sorted 128 response cards against four key cards, varying on three dimensions (card/sorting rules): colors (red, blue, yellow, or green), shapes (crosses, circles, triangles, or stars), and number of shapes (one to four shapes). Each trial consisted of four key cards, and feedback (green 'O', correct; red 'X', incorrect) was presented. Sorting rules changed without warning after four consecutive card sort responses, and the task terminated after the participant completed six categories (twice for each dimension) or after 128 trials[53]. Set-shifting performance was computed as the number of completed categories, scores ranging 1–6, with higher scores demonstrating better set-shifting.

Processing speed and inhibition

The Stroop color–word test[54] measured processing speed and inhibition. Participants indicated one of four color words (red, green, blue, black) presented at center screen by a key press. Stimuli consisted of 84 randomized trials – each trial type presented seven times – classified as control (colored rectangles as stimuli; assessing processing speed), congruent (color of the word and name of the color are the same; assessing processing speed and attention), and incongruent (color of the word and name of the color are different; assessing inhibition). A red 'X' (400 ms) was presented for incorrect responses. The intertrial interval time is 200 ms. Time from color–word rectangle stimuli onset until response for correct trials for each trial type were used to compute mean reaction times, with higher mean reaction times demonstrating worse processing speed (slower reaction times). The Stroop interference score was calculated as the difference between incongruent and congruent reaction time trials, with higher reaction times indicating worse inhibition (ie executive function).

Spatial attentional orienting

The Posner cueing task measures spatial attentional orienting[55]. Participants view a screen image of two boxes flanking a central fixation cross (1000 ms), and they press the keyboard space bar when they detect the target star shape (1000 ms) in one of the boxes. A valid cue was presented (20 ms) for 80% of trials, predicting target location. An invalid cue was presented (20 ms) for 20% of trials, predicting opposite target location. Two test blocks (100 trials each) were presented: 50% exogenous (peripheral) cues (highlighting the flanked box) and 50% endogenous (central) cues (with an arrow above the fixation cross). Cue–target stimulus onset asynchrony was either 100 ms (50% of trials) or 1500 ms (50% of trials). Invalid minus valid trial mean reaction times were calculated for each block of trials (with exogenous or endogenous cues), computing exogenous and endogenous attentional orienting scores. Lower reaction times indicate better spatial attention orienting.

Statistical analysis

Standardized moderated regression analyses were conducted in *R* software, testing five objective cognition criterion variables – Sternberg working memory task, Wisconsin Card Sorting Test, Stroop controlled trials and Stroop interference, Posner endogenous orienting, and Posner exogenous orienting scores – in separate models. Independent variables included self-reported sleep (PSQI: total sleep time, sleep efficiency, total) and rurality (0, non-rural; 1, rural), and their interaction (sleep × rurality). Given known associations with sleep and/or cognition, analyses controlled for age[11,56], sex (0, male; 1, female[11,57]) and years of education[58].

Simple slopes (via *reghelper* package in *R*) further evaluated the strength of associations between self-reported sleep and cognitive performance at the different levels of the moderator (rural/non-rural areas) for significant interactions. Regression coefficients and η^2 for the interaction terms (via *anova_stats* package in *R*) were used as effect sizes (small, 0.01; medium, 0.06; large, 0.16[59]). Given the preliminary nature of the present study and limited findings of sleep–rurality associations with cognition, family-wise error corrections were not conducted and we accepted the false-positive risk in our analyses[60]. Alpha levels of 0.05 were used for all analyses.

The present study consists of a secondary analysis and subsample of participants from a larger survey cohort (N=281[41]); therefore, the sample was constrained by the number of participants who completed all of the required measures. Given the preliminary nature of the present study, an a priori power analysis was not conducted; rather, a posthoc evaluation indicated that the final sample size met commonly recommended observation-to-predictor ratios[61] for preliminary moderated regression analyses.

Ethics approval

The Institutional Review Board (IRB) Ethics Review Committee at the University of Missouri approved all procedures for both the larger survey cohort and the present subsample analysis under a single IRB protocol (IRB#: 2075002) on 1 December 2021. Participants provided their written consent for review and signature before the start of the study. The current data analysis was conducted using de-identified data in accordance with the IRB guidelines.

Results

Participant characteristics

Participant demographics and descriptive values for sleep, rurality, and cognition variables are provided in Table 1. A total of 544 participants completed the study screening questions and initiated the survey[62] for the main study[41]. Of these, 325 participants met inclusion for the full study, with 13% (n=43) of participants providing incomplete data for the Coronavirus Anxiety Scale, and 15% (n=50) of participants having incomplete data for the COVID-19 status measure – both measures were critical for the main study outcomes[62]. A final subsample of 61 participants (mean age 63.74 years, standard deviation 7.75; 32 rural and 29 non-rural residents) completed the online cognitive measures that were relevant to the present study and were included in analyses. Of these, some participants had incomplete data and were excluded for the following objective cognitive measures: 5% (n=3) for Sternberg working memory task, 12% (n=7) for Wisconsin Card Sorting Test, 7% (n=4) for Stroop controlled trials, and 8% (n=5) for Stroop interference trials.

Rurality differences for each variable were evaluated by independent t-tests for continuous variables and χ^2 tests for categorical variables. Overall, there were no differences based on rurality for a majority of variables (p>0.05), except rural residents reported higher household income compared to non-rural residents (Table 1).

Table 1: Study participant demographics†

Characteristic	Variables	Total (N=61)						Rural area (N=32)						Non-rural area (N=29)						Group comparison
		M	SD	n	%	Min.	Max.	M	SD	n	%	Min.	Max.	M	SD	n	%	Min.	Max.	p
Age (years)		63.74	7.75			50.00	79.00	65.47	7.77			50.00	79.00	61.83	7.40			50.00	76.00	0.14
Sex	Male	–	–	32	52	–	–	–	–	15	47	–	–	–	–	17	59	–	–	–
	Female	–	–	29	48	–	–	–	–	17	53	–	–	–	–	12	41	–	–	–
Ethnicity	White/European American	–	–	55	90	–	–	–	–	31	37	–	–	–	–	24	85	–	–	–
	Black/African American	–	–	2	3	–	–	–	–	1	3	–	–	–	–	1	3	–	–	–
	Asian/Asian American	–	–	2	3	–	–	–	–	–	–	–	–	–	–	2	7	–	–	–
	American Indian/ Alaska Native	–	–	0	0	–	–	–	–	–	–	–	–	–	–	2	7	–	–	–
	Other	–	–	0	0	–	–	–	–	–	–	–	–	–	–	0	0	–	–	–
Education	Some high school	–	–	0	0	–	–	–	–	0	0	–	–	–	–	0	0	–	–	–
	Graduated high school	–	–	10	16	–	–	–	–	5	16	–	–	–	–	5	17	–	–	–
	Some college	–	–	19	31	–	–	–	–	7	22			–	–	12	41	–	–	–
	Graduated college	–	–	22	36	–	–	–	–	11	34	–	–	–	–	11	38	–	–	–
	Graduate or professional school	–	–	10	16	–	–	–	–	9	28	–	–	–	–	1	3	–	–	–
	Other	–	–	0	0	–	–	–	–	0	0	–	–	–	–	0	0	–	–	–
Income (US$)¶	≤$19,999	–	–	4	7	–	–	–	–		13	–	–	–	–	3	10	–	–	–
	$20,000–39,999	–	–	11	18	–	–	–	–	4	13	–	–	–	–	7	24	–	–	–
	$40,000–59,999	–	–	18	30	–	–	–	–	7	28	–	–	–	–	11	38	–	–	–
	$60,000–79,999	–	–	13	21	–	–	–	–	11	34			–	–	2	7	–	–	–
	$80,000–99,999	–	–	8	13	–	–	–	–	5	16	–	–	–	–	3	10	–	–	–
	$100,000	–	–	7	11	–	–	–	–	4	13	–	–	–	–	3	10	–	–	–
No. of medical conditions		1.57	1.79	–	–	0.00	8.00	1.62	1.76	–	–	0.00	6.00	1.52	1.86	–	–	0.00	8.00	0.20
No. of medications		3.30	3.22	–	–	0.00	16.00	3.50	3.60	–	–	0.00	16.00	3.07	2.78	–	–	0.00	9.00	0.24

PSQI subscore	Total	6.33	4.33	–	–	1.00	18.00	6.72	4.71	–	–	1.00	18.00	5.90	3.89	–	–	1.00	15.00	0.32
	Total sleep time (hours)	6.79	1.46	–	–	3.00	12.00	6.61	1.79	–	–	3.00	12.00	6.98	0.98	–	–	5.00	9.00	0.34
	Sleep efficiency (%)	88.06	14.21	–	–	42.86	100.00	88.31	15.40	–	–	42.86	100.00	87.79	13.03	–	–	55.56	100.00	0.66
Objective cognition	Sternberg working memory task[a]	0.79	0.26	–	–	0.33	1.00	0.80	0.26	–	–	0.33	1.00	0.77	0.27	–	–	0.33	1.00	0.26
	Wisconsin Card Sorting Test[b]	13.27	9.42	–	–	1.56	48.31	11.43	7.45	–	–	1.56	40.62	14.98	10.79	–	–	2.34	48.31	0.45
	Stroop color–word test, controlled trials[c]	1447.96	531.98	–	–	746.71	3768.74	1474.44	608.76	–	–	746.71	3768.74	1420.54	448.48	–	–	839.78	2802.96	0.67
	Stroop color–word test, interference score[d]	321.00	376.58	–	–	–642.41	1842.55	372.93	460.10	–	–	–642.41	1842.55	267.14	262.26	–	–	–607.42	654.31	0.37
	Posner endogenous orienting score	40.27	35.61	–	–	–40.61	130.87	37.51	38.61	–	–	–40.61	114.25	43.32	32.39	–	–	–9.38	130.87	0.66
	Posner exogenous orienting score	38.00	34.09	–	–	–56.39	140.71	32.85	35.07	–	–	–56.39	95.75	43.69	32.64	–	–	–12.77	140.71	0.45

*p<0.05, **p<0.01, ***p<0.001

† Differences between rurality were evaluated by independent t-test for continuous variables and χ^2 test for categorical variables at significance level 0.05.

¶ Income categories were collected in USD and converted using the average December 2021 exchange rate (1USD ˜ 1.40AUD).

[a] $N_{\text{Sternberg working memory task}}=58$

[b] $N_{\text{Wisconsin Card Sorting Test}}=54$

[c] $N_{\text{Stroop color–word test, controlled trials}}=57$

[d] $N_{\text{Stroop color–word test, interference scores}}=55$

–, not applicable descriptive statistics for specified variable. M, mean. PSQI, Pittsburgh Sleep Quality Index. SD, standard deviation.

Regression results

Violations of general linear model assumptions were assessed for all regression models. No influential outliers were detected in any regression models. However, some models exhibited slight skewness (on histogram and Q–Q plot) and heteroscedasticity (on bivariate and scale-location plots, and the Breusch–Pagan test in *bptest* package in *R*). Despite some regression models exhibiting minor violations in normality and homoscedasticity, general linear models are robust to such violations, and no data transformation or non-parametric methods were applied[63].

Rurality moderating self-reported sleep and objective cognition

Table 2 shows full models for each PSQI subscore and objective cognition domain. To facilitate regression results interpretation, moderation regression results are organized by each PSQI subscore to highlight rurality-specific patterns in the associations between self-reported sleep and objective cognition performance.

Table 2: Moderated regression results of association between self-reported sleep and rurality on objective cognitive functioning for working memory, executive functioning, processing speed, and attentional orientating

	PSQI subscore	Sternberg working memory task (n=58)				Wisconsin Card Sorting Test (n=54)				Stroop controlled trials (n=57)				Stroop interference score (n=55)				Posner endogenous orienting score (n=61)				Posner exogenous orienting score (n=61)			
		β	SE	t	p	β	SE	t	p	β	SE	t	p	β	SE	t	p	β	SE	t	p	β	SE	t	p
Total sleep time[a]		Full model: R^2=0.16, p=0.16				Full model: R^2=0.20, p=0.09				Full model: R^2=0.24, p=0.02				Full model: R^2=0.21, p=0.07				Full model: R^2=0.12, p=0.29				Full model: R^2=0.32, p=0.001			
	Rurality	0.46	0.34	0.71	0.48	–0.63	12.42	–0.95	0.35	–0.26	649.43	–0.42	0.68	1.54	489.50	2.36	0.02*	–0.61	44.76	–0.97	0.34	–0.85	37.70	–1.53	0.13
	Total sleep time	0.36	0.03	1.93	0.06	0.20	1.22	1.04	0.30	–0.12	64.45	–0.67	0.51	0.06	49.72	0.31	0.76	–0.20	4.39	–1.10	0.28	–0.03	3.70	–0.21	0.83
	Rurality x Total sleep time	–0.26	0.05	–0.41	0.69	0.80	1.81	1.19	0.24	0.14	94.91	0.22	0.83	–1.46	71.20	–2.24	0.03*	0.55	6.46	0.88	0.38	0.90	5.44	1.63	0.11
	Age	–0.18	0.01	–1.35	0.18	–0.08	0.16	–0.60	0.55	0.48	8.85	3.77	0.01*	–0.16	6.53	–1.17	0.25	–0.20	0.62	–1.46	0.15	0.16	0.52	1.35	0.18
	Sex	0.04	0.07	0.33	0.74	–0.10	2.53	–0.77	0.44	–0.12	135.14	–0.94	0.35	0.01	99.13	0.04	0.97	0.25	9.24	1.91	0.06	0.35	7.79	3.02	0.01*
	Education	0.16	0.04	1.14	0.26	0.16	1.40	1.11	0.27	–0.07	71.78	–0.51	0.61	0.19	54.31	1.40	0.17	–0.02	5.00	–0.14	0.89	–0.33	4.21	–2.77	0.01*

Sleep efficiency[a]		Full model: R^2=0.16, p=0.18				Full model: R^2=0.13, p=0.36				Full model: R^2=0.26, p=0.02				Full model: R^2=0.13, p=0.31				Full model: R^2=0.13, p=0.28				Full model: R^2=0.35, p<0.01			
	Rurality	1.95	0.46	2.21	0.03*	–0.69	17.68	–0.73	0.47	–1.06	877.91	–1.28	0.21	0.21	771.83	0.21	0.84	–0.93	62.33	–1.06	0.29	–1.86	51.52	–2.45	0.02*
	Sleep efficiency	0.56	0.01	2.31	0.02*	0.07	0.17	0.27	0.79	–0.27	8.41	–1.20	0.24	–0.26	7.67	–0.91	0.37	–0.22	0.59	–0.95	0.35	–0.46	0.49	–2.26	0.03*
	Rurality x Sleep efficiency	–1.90	0.01	–2.06	0.04*	0.83	0.20	0.84	0.41	1.01	10.00	1.16	0.25	–0.06	8.75	–0.06	0.95	0.92	0.70	1.01	0.32	1.97	0.58	2.50	0.02*
	Age	–0.14	0.01	–1.03	0.31	–0.03	0.17	–0.22	0.82	0.47	8.86	3.66	0.01*	–0.18	6.84	–1.31	0.20	–0.21	0.62	–1.54	0.13	0.17	0.51	1.42	0.16
	Sex	0.03	0.07	0.25	0.80	–0.11	2.62	–0.80	0.43	–0.12	133.40	–0.95	0.35	0.01	104.62	0.09	0.93	0.25	9.28	1.94	0.06	0.35	7.67	3.06	0.01*
	Education	0.11	0.04	0.87	0.39	0.12	1.41	0.81	0.42	–0.05	69.03	–0.43	0.67	0.16	54.36	1.13	0.27	0.01	4.90	0.07	0.95	–0.31	4.05	–2.76	0.01*
Total		Full model: R^2=0.10, p=0.50				Full model: R^2=0.11, p=0.46				Full model: R^2=0.24, p=0.02				Full model: R^2=0.19, p=0.11				Full model: R^2=0.11, p=0.34				Full model: R^2=0.38, p<0.001			
	Rurality	0.27	0.13	1.06	0.29	0.22	4.95	0.85	0.40	0.01	244.74	–0.02	0.99	–0.28	187.65	–1.13	0.26	0.05	16.90	0.23	0.82	0.51	13.49	2.58	0.01*
	Total	–0.08	0.01	–0.42	0.68	–0.13	0.46	–0.61	0.54	0.14	22.52	0.76	0.45	–0.11	18.84	–0.49	0.63	0.15	1.60	0.74	0.46	0.26	1.28	1.60	0.11
	Rurality total	–0.15	0.01	–0.53	0.60	–0.18	0.62	–0.65	0.52	–0.14	31.07	–0.55	0.59	0.60	24.50	2.08	0.04*	–0.14	2.19	–0.54	0.59	–0.67	1.75	–3.04	0.01*
	Age	–0.18	0.00	–1.29	0.20	–0.11	0.18	–0.78	0.44	0.50	9.01	3.79	0.01*	–0.13	6.85	–0.95	0.35	–0.19	0.63	–1.36	0.18	0.16	0.51	1.41	0.16
	Sex	0.00	0.07	0.03	0.97	–0.11	2.65	–0.79	0.43	–0.11	134.04	–0.88	0.38	0.00	100.93	0.01	0.99	0.26	9.29	2.01	0.05	0.34	7.42	3.10	0.01*
	Education	0.10	0.04	0.69	0.49	0.14	1.45	0.99	0.33	–0.07	71.06	–0.52	0.61	0.21	54.54	1.50	0.14	0.01	5.01	–0.02	0.98	–0.37	4.00	–3.30	0.01*

*p<0.05, **p<0.01, ***p<0.001

PSQI, Pittsburgh Sleep Quality Index. SE, standard error.

PSQI total sleep time

The PSQI total sleep time–rurality interaction was significantly associated with Stroop interference (p=0.03, 95%CI –302.80– –16.47, η^2=0.08). In rural residents, shorter total sleep time was associated with higher (worse) Stroop interference scores (β=–144.40, standard error (SE)=48.25, p=0.004, 95%CI –238.98– –49.82; Fig1), while in non-rural residents the association was not significant (β=15.24, SE=49.72, p=0.76, 95%CI –82.22–112.69). Independent and interactive associations for other cognitive outcomes were non-significant (Table 2).

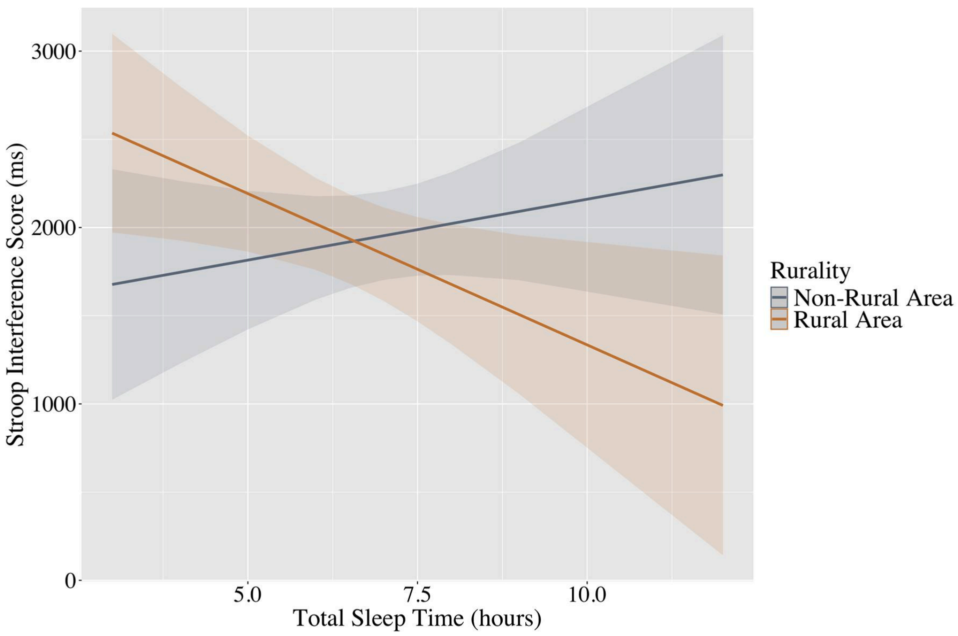

Figure 1: Rurality moderating the association between total sleep time and Stroop interference. (Note: Rurality moderated the association between self-reported total sleep time and Stroop interference scores in mid-to-late-life adults. In rural mid-to-late-life adults, shorter (worse) self-reported total sleep time was associated with worse inhibitory control (higher Stroop interference scores), while there was no association for non-rural mid-to-late-life adults.)

PSQI sleep efficiency

The PSQI sleep efficiency–rurality interaction was significantly associated with Sternberg working memory task scores (p=0.04, 95%CI –0.02– –0.001, η^2=0.07) and Posner exogenous scores

(p=0.02, 95%CI 0.30–2.62, η^2=0.08). In non-rural residents, lower (worse) PSQI sleep efficiency was associated with lower (worse) Sternberg working memory task scores (β=0.01, SE=0.004, p=0.02, 95%CI 0.001–0.02) and higher (worse) Posner exogenous scores (β=–1.10, SE=0.49, p=0.03, 95%CI –2.05– –0.14) (Fig2). In rural residents, PSQI sleep efficiency was not associated with Sternberg working memory task scores (β=–0.001, SE=0.003, p=0.84, 95%CI –0.01–0.01) or Posner exogenous scores (β=0.36, SE=0.32, p=0.27, 95%CI –0.27–0.99). Independent and interactive associations for other cognitive outcomes were non-significant (Table 2).

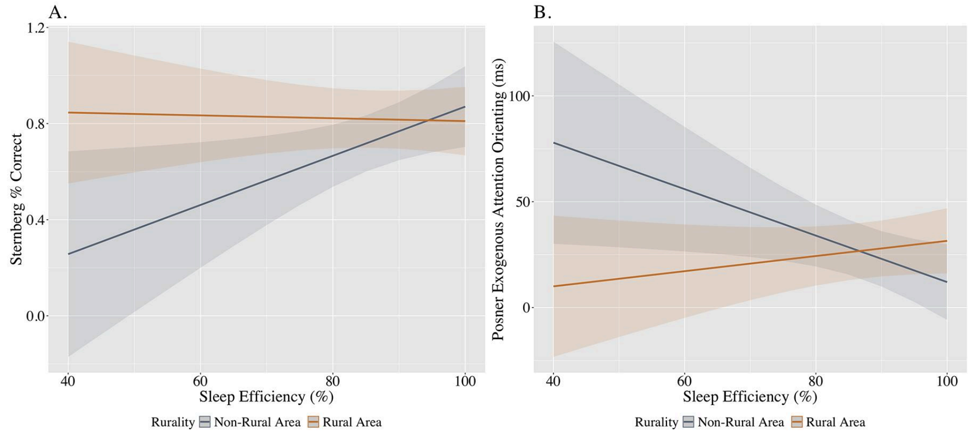

Figure 2: Rurality moderating the association between sleep efficiency, and Sternberg working memory (A) and Posner exogenous attentional orienting (B). (Note: Rurality moderated the association between self-reported sleep efficiency, and Sternberg working memory and Posner exogenous attention orientating scores in mid-to-late-life adults. In non-rural mid-to-late-life adults, lower (worse) self-reported sleep efficiency was associated with worse working memory (lower Sternberg working memory percentage correct scores) and worse exogenous spatial attentional orienting (higher Posner exogenous attention orienting scores), while no such associations were observed for rural mid-to-late-life adults.)

PSQI total

The PSQI total–rurality interaction was significantly associated with Stroop interference scores (p=0.04, 95%CI 1.68–100.20, η^2=0.07) and Posner exogenous scores (p=0.004, 95%CI –8.83– –1.81, η^2=0.11). In rural residents, higher PSQI total scores (worse global sleep quality) were associated with higher (worse) Stroop interference scores (β=41.79, SE=15.55, p=0.01, 95%CI 11.31–72.26) and lower (ie better) Posner exogenous scores (β=–3.27, SE=1.20, p=0.01, 95%CI –5.61– –0.92) (Fig3). In non-rural residents, PSQI total was not associated with Stroop interference scores (β=–9.15, SE=18.84, p=0.63, 95%CI –46.09–27.78) or Posner exogenous scores (β=–2.06, SE=1.28, p=0.11, 95%CI –0.46–4.57). Independent and interactive associations for other cognitive outcomes were non-significant (Table 2).

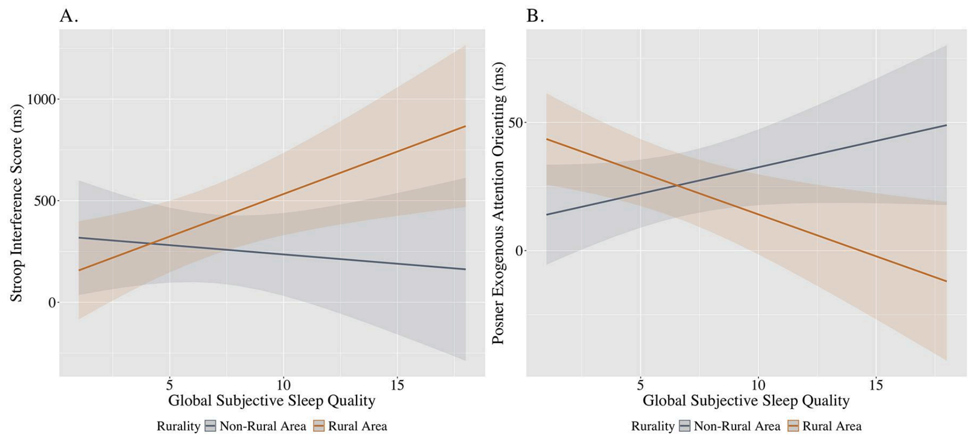

Figure 3: Rurality moderating the association between global subjective sleep quality, and Stroop interference score (A) and Posner exogenous attentional orienting (B). (Note: Rurality moderated the associations between global subjective sleep quality (via Pittsburgh Sleep Quality Index total scores), and Stroop interference and Posner exogenous attentional orienting scores in mid-to-late-life adults. In rural mid-to-late-life adults, worse (higher) global subjective sleep quality was associated with worse inhibitory control (higher Stroop interference scores) and better exogenous spatial attentional orienting (lower Posner exogenous spatial orienting scores). In non-rural mid-to-late-life adults, global subjective sleep quality was not associated with inhibitory control or exogenous spatial attentional orienting.)

Covariates associated with objective cognition outcome variables

Covariates generally showed no significant associations with cognitive domains across all regression models. However, older age was associated with higher (worse) Stroop controlled trials scores in our PSQI total sleep time regression model, and being an older adult women and lower years of education were significantly associated with higher (worse) Posner exogenous orienting scores in our PSQI total sleep time, PSQI sleep efficiency, and PSQI total regression models (Table 2).

Discussion

This preliminary study examined whether rurality moderated associations between self-reported sleep and objective cognition in mid-to-late-life adults. Among rural residents, shorter total sleep time and worse global sleep quality were associated with worse inhibitory control, while worse global sleep quality was associated with better exogenous spatial attentional orienting. Conversely, in non-rural residents, lower sleep efficiency was associated with worse working memory and exogenous spatial attentional orienting. Although the study is cross-sectional in nature, the observed patterns provide potential implications for clinical screening and early identification of sleep-related cognitive dysfunction in aging adults – particularly for rural residents. These patterns of results also offer insight into potential future clinical trajectories by identifying sleep-related risk profiles in specific geographical locations that may warrant closer monitoring or referral for early intervention in routine care.

Our hypothesis that rurality would moderate sleep–cognition associations was partially supported with domain-specific associations. Findings show that, in rural mid-to-late-life adults, self-reported shorter total sleep time and worse sleep quality may contribute to worse inhibitory control, aligning with findings in rural older adults[7]. We extend these insights by also showing that, in non-rural older adults, worse sleep efficiency may contribute to worse working memory and exogenous spatial attentional orienting. These findings may differ from prior findings in non-rural older adults, which linked worse global sleep quality, shorter total sleep time and worse sleep efficiency to worse global cognitive function over time[40]. However, methodological differences – including longitudinal study design, global versus specific cognitive domain examined, and older age range (65–80 years[40]) – likely contributed to these inconsistencies.

The overall pattern of findings suggests that, in rural mid-to-late-life adults, sleep duration and general perception of sleep quality may negatively impact higher order cognition (eg inhibitory control), whereas worse overall perceptions of sleep quality may be linked to better lower order attention functioning. In non-rural aging adults, worse overall sleep fragmentation may negatively impact cognition broadly. It is possible that psychosocial factors – such as greater social isolation[64] and limited cognitive engagement[65] – may exacerbate sleep-related inhibitory control in aging rural residents. Loneliness in older adults, linked with shorter sleep duration[66], is associated with reduced attentional resources[67] and impaired inhibitory control[68], a pattern supported by our findings. Loneliness in rural aging adults may contribute to associations between shorter sleep duration and functionality of specific brain regions for inhibitory control (ie prefrontal cortex hypoactivation[69] and greater frontotemporal cortical thinning[70,71]). Indirect effects between loneliness, sleep quality and pre-sleep arousal[72] may contribute to hyperarousal – associated with insomnia[73] and shorter sleep duration[74]. Hyperarousal may be a cognitive compensatory mechanism[75] for lower order cognitive domains (eg spatial attention) but not higher order cognitive domains (eg inhibition[76]) For instance, in middle-aged adults with insomnia and shorter sleep durations (<6 hours) there were associations with greater deficits in executive function, working memory and attention-switching tasks, but lower order cognitive domain tasks were not impacted[74], as reflected in our findings. In rural aging adults, geographical isolation may further perpetuate hyperarousal states, exacerbating associations between worse overall sleep perceptions and worse inhibitory control.

Additionally, rural residents may experience boredom[77], which has been linked with poor cognitive reserve[78] and sleep quality[79]. Consistent with our results, insufficient environmental stimulation and failure to attend to activities may lead to boredom in aging rural adults[80], potentially facilitating bedtime procrastination and poor sleep quality[79], as well as diminished activation of executive control networks[81], which are critical for inhibitory control. Alternatively, boredom-related poor sleep quality[79] may lead to increased arousal to engage in a stimulating task[82], improving spatial attention abilities, consistent with our findings.

Conversely, non-rural aging adults may experience greater urban-related environmental auditory noises, which is associated with poor sleep health, cognitive functioning, and somatic/mental health[83]. Additionally, lower sleep efficiency is associated with worse working memory and executive functioning (ie attentional control[84]), along with reduced superior frontal cortex volume and greater anterior atrophy – regions critical for attentional control[85]. Although rurality-related sleep differences were non-significant (Table 1), it is possible that urban-related environmental disruptions (eg traffic, sirens) may exacerbate the negative impact of worse sleep efficiency on cognition more broadly. Further, examining rurality-specific psychosocial and environmental factors with age-related neurophysiology and their interplay on sleep–cognition dynamics may inform the neurobiological of aging and sleep, and potentially tailored interventions for sleep complaints.

Considerations for future clinical work

Preliminary findings suggest that clinicians can monitor geographically specific sleep behaviors in aging adults – such as shorter total sleep time and global sleep quality in rural residents, and poor sleep efficiency in non-rural residents – to identify individuals who may benefit from additional screening and monitoring for potential cognitive decline and early intervention prior to onset. Additionally, given limited medical care access in rural areas[86], telehealth/digital sleep interventions – such as brief behavioral treatment for insomnia and cognitive behavioral therapy for insomnia, which improves sleep quality[87] and may extend benefits to total sleep time[88] – represent accessible options that clinicians can incorporate into their practice or send for referral to specialized behavioral sleep providers to support cognitive health in aging populations. Monitoring and targeting rurality-specific factors (eg psychosocial stress and environmental city noises) that potentially underly sleep fragmentation in mid-to-late-life adults may guide targeted strategies to reduce rurality-specific cognitive dysfunction.

In addition to clinical considerations, educational efforts for both rural residents and healthcare providers may enhance awareness of sleep's role in cognitive aging. Broader policy considerations, including improvements for rurality-specific factors – such as promoting quieter and safer neighborhood conditions – may also help support sleep health in rural communities.

Limitations and future directions

Although this preliminary study has several limitations to be considered, the nature of the study and the present pattern of results was intended to inform researchers and clinicians about early patterns of specific rurality-specific patterns in the association between sleep and cognitive functioning in aging adults. These findings provide foundational, hypothesis-generating insights that can guide future larger, longitudinal clinical investigations to clarify these rurality-moderated relationships. First, although the survey was completed anonymously online, recommended optimizing data quality and reliability procedures (ie one response per IP address, pre-screening questions[89]) were followed. Second, our cross-sectional design precludes temporal inference. Prospective studies are needed to elucidate the temporal precedence and potential underlying mechanism the rurality–sleep–cognition relationship. Third, sleep was self-reported using the PSQI[46], and is validated for clinically screening for poor sleep health[90]. However, rurality-related patterns may differ with objective sleep measures (eg actigraphy, polysomnography), warranting further investigation. Fourth, residential duration and engagement with agricultural/environmental factors were not assessed, potentially contributing to underlying mechanisms of the present results. Fifth, data was collected in the northern hemisphere summer of 2020, and COVID-19 related disruptions (eg non-typical sleep behavior, relocation) may have impacted the findings. Future investigations are encouraged to investigate this relationship post-pandemic. Sixth, rurality was operationalized dichotomously (via RUCA codes) with mutually exclusive geospatial categories. Rurality continuous or quasi-continuous measures assessing the degree of rurality impacting the interplay of sleep and cognition are encouraged in future investigations. Such approaches may better detect rural–urban differences and determine nuanced effects of geographical factors of cognitive functioning, sleep, and psychosocial factors in mid-to-late-life adults. Seventh, our modest sample size limits statistical power. Larger replication studies with recommended observation-to-predictor ratios[61] are needed. Finally, although having comparable rural (54%) and non-rural (46%) ratios, the sample lacked racial/ethnic diversity (90% White) and was limited to US residents. Additionally, rural communities within the US are culturally heterogenous, and variations in local norms, beliefs, and expectations surrounding sleep[91,92] may shape how sleep is perceived and managed. Broader cultural characteristics that are common in rural settings – such as lower engagement with formal healthcare services and greater reliance on informal community or neighbor networks – have been well documented[93], and these patterns may influence how rural adults perceive sleep difficulties and their likelihood of seeking guidance or treatment. These culture factors were not assessed in the present study and may further constrain generalizability of these findings across diverse rural contexts. Future studies should examine these associations in a more diverse sample and internationally representative samples to enhance generalizability across cultures and geographic contexts.

Conclusion

Thus far, this is the first known study to examine rurality-specific associations between self-reported sleep and objective cognition in mid-to-late-life adults. In rural residents, overall pattern of results suggests that worse total sleep time and global sleep quality may negatively impact inhibitory control, while worse sleep quality may positively impact attentional orienting. For non-rural residents, worse sleep efficiency may broadly impact cognition. Prospective studies exploring rural (eg limited health care and social support) and non-rural (eg traffic, noise) characteristics contributing to the patterns of sleep–cognition associations are warranted. Further research may inform geographically sleep-specific interventions that may mitigate the risk of cognitive decline in aging populations.

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Conflicts of interest

The authors report no potential conflict of interest.

AI disclosure statement

No generative AI or AI-assisted artificial tools were used in the conduct of this research or the preparation of this manuscript.

Data availability

Study data, analytical methods, and study materials can be made available upon request to the corresponding author. This study was not preregistered.

References

1 Yaffe K, Falvey CM, Hoang T. Connections between sleep and cognition in older adults. *The Lancet Neurology* 2014; **13(10):** 1017–1028.
https://doi.org/10.1016/S1474-4422(14)70172-3
https://www.ncbi.nlm.nih.gov/pubmed/25231524

2 Nunes B, Silva RD, Cruz VT, Roriz JM, Pais J, Silva MC. Prevalence and pattern of cognitive impairment in rural and urban populations from Northern Portugal. *BMC Neurology* 2010; **10:** 42.
https://doi.org/10.1186/1471-2377-10-42
https://www.ncbi.nlm.nih.gov/pubmed/20540726

3 Centers for Disease Prevention and Control (CDC). *About rural health.* CDC, 2017.
(Accessed 30 April 2023).

4 Nelson KS, Nguyen TD, Brownstein NA, Garcia D, Walker HC, Watson JT, et al. Definitions, measures, and uses of rurality: A systematic review of the empirical and quantitative literature. *Journal of Rural Studies* 2021; **82:** 351–365.
https://doi.org/10.1016/j.jrurstud.2021.01.035

5 Long JC, Delamater PL, Holmes GM. Which definition of rurality should I use?: The relative performance of 8 federal rural definitions in identifying rural-urban disparities. *Medical Care* 2021; **59(10 Suppl 5):** S413.
https://doi.org/10.1097/MLR.0000000000001612
https://www.ncbi.nlm.nih.gov/pubmed/34524237

6 Kaye J, Michael Y, Calvert J, Leahy M, Crawford D, Kramer P. Exceptional brain aging in a rural population-based cohort. *The Journal of Rural Health* 2009; **25(3):** 320–325.
https://doi.org/10.1111/j.1748-0361.2009.00237.x
https://www.ncbi.nlm.nih.gov/pubmed/19566620

7 Liu R, Tang S, Wang Y, Dong Y, Hou T, Ren Y, et al. Self-reported sleep characteristics associated with dementia among rural-dwelling Chinese older adults: a population-based study. *BMC Neurology* 2022; **22:** 42.
https://doi.org/10.1186/s12883-021-02521-0

8 Deary IJ, Corley J, Gow AJ, Harris SE, Houlihan LM, Marioni RE, et al. Age-associated cognitive decline. *British Medical Bulletin* 2009; **92(1):** 135–152.
https://doi.org/10.1093/bmb/ldp033
https://www.ncbi.nlm.nih.gov/pubmed/19776035

9 Harada CN, Natelson Love MC, Triebel KL. Normal cognitive aging. *Clinics in Geriatric Medicine* 2013; **29(4):** 737–752.
https://doi.org/10.1016/j.cger.2013.07.002
https://www.ncbi.nlm.nih.gov/pubmed/24094294

10 Salthouse TA. Selective review of cognitive aging. *Journal of the International Neuropsychological Society* 2010; **16(5):** 754–760.
https://doi.org/10.1017/S1355617710000706
https://www.ncbi.nlm.nih.gov/pubmed/20673381

11 Ohayon MM, Carskadon MA, Guilleminault C, Vitiello MV. Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. *Sleep* 2004; **27(7):** 1255–1273.
https://doi.org/10.1093/sleep/27.7.1255
https://www.ncbi.nlm.nih.gov/pubmed/15586779

12 Salthouse TA, Fristoe NM, Lineweaver TT, Coon VE. Aging of attention: does the ability to divide decline? *Memory & Cognition* 1995; **23(1):** 59–71.
https://doi.org/10.3758/BF03210557
https://www.ncbi.nlm.nih.gov/pubmed/7885266

13 Glisky EL. Changes in cognitive function in human aging. In: DR Riddle (Ed.). *Brain aging: Models, methods, and mechanisms.* CRC Press, 2007. 3–20.
https://doi.org/10.1201/9781420005523-1

14 Haaland KY, Price L, Larue A. What does the WMS-III tell us about memory changes with normal aging? *Journal of the International Neuropsychological Society* 2003; **9(1):** 89–96.
https://doi.org/10.1017/S1355617703910101
https://www.ncbi.nlm.nih.gov/pubmed/12570362

15 Rhodes S, Greene NR, Naveh-Benjamin M. Age-related differences in recall and recognition: a meta-analysis. *Psychonomic Bulletin and Review* 2019; **26(5):** 1529–1547.
https://doi.org/10.3758/s13423-019-01649-y
https://www.ncbi.nlm.nih.gov/pubmed/31396816

16 Naveh-Benjamin M, Cowan N. The roles of attention, executive function and knowledge in cognitive ageing of working memory. *Nature Reviews Psychology* 2023; **2(3):** 151–165.
https://doi.org/10.1038/s44159-023-00149-0

17 Luo L, Craik FI. Aging and memory: a cognitive approach. *The Canadian Journal of Psychiatry* 2008; **53(6):** 346–353.
https://doi.org/10.1177/070674370805300603
https://www.ncbi.nlm.nih.gov/pubmed/18616854

18 Ruthruff E, Lien M-C. Aging and attention. In: NA Pachana (Ed.). *Encyclopedia of Geropsychology.* Springer, 2016. 1–7.
https://doi.org/10.1007/978-981-287-080-3_227-1

19 Curtis AF, Turner GR, Park NW, Murtha SJ. Improving visual spatial working memory in younger and older adults: effects of cross-modal cues. *Aging, Neuropsychology, and Cognition* 2019; **26(1):** 24–43.
https://doi.org/10.1080/13825585.2017.1397096
https://www.ncbi.nlm.nih.gov/pubmed/29105548

20 Carriere JS, Cheyne JA, Solman GJ, Smilek D. Age trends for failures of sustained attention. *Psychology and Aging* 2010; **25(3):** 569.
https://doi.org/10.1037/a0019363
https://www.ncbi.nlm.nih.gov/pubmed/20677878

21 Foley D J, Monjan A A, Brown S L, Simonsick E M, Wallace R B, Blazer D G. Sleep complaints among elderly persons: an epidemiologic study of three communities. *Sleep* 1995; **18(6):** 425–432.
https://doi.org/10.1093/sleep/18.6.425
https://www.ncbi.nlm.nih.gov/pubmed/7481413

22 Landry G J, Best J R, Liu-Ambrose T. Measuring sleep quality in older adults: a comparison using subjective and objective methods. *Frontiers in Aging Neuroscience* 2015; **7:** 166.
https://doi.org/10.3389/fnagi.2015.00166

23 Nishikawa K, Kuriyama K, Yoshiike T, Yoshimura A, Okawa M, Kadotani H, et al. Effects of cognitive behavioral therapy for insomnia on subjective-objective sleep discrepancy in patients with primary insomnia: a small-scale cohort pilot study. *International Journal of Behavioral Medicine* 2021; **28:** 715–726.
https://doi.org/10.1007/s12529-021-09969-x
https://www.ncbi.nlm.nih.gov/pubmed/33629218

24 Li J, Vitiello MV, Gooneratne NS. Sleep in normal aging. *Sleep Medicine Clinics* 2018; **13:** 1–11.
https://doi.org/10.1016/j.jsmc.2017.09.001
https://www.ncbi.nlm.nih.gov/pubmed/29412976

25 Dzierzewski J M, Dautovich N, Ravyts S. Sleep and cognition in older adults. *Sleep Medicine Clinics* 2018; **13(1):** 93–106.
https://doi.org/10.1016/j.jsmc.2017.09.009
https://www.ncbi.nlm.nih.gov/pubmed/29412987

26 Glauber R. Rural depopulation and the rural–urban gap in cognitive functioning among older adults. *The Journal of Rural Health* 2022; **38(4):** 696–704.
https://doi.org/10.1111/jrh.12650
https://www.ncbi.nlm.nih.gov/pubmed/35257439

27 Chuang Y-F, Liu Y-C, Tseng H-Y, Lin P-X, Li C-Y, Shih M-H, et al. Urban–rural differences in the prevalence and correlates of mild cognitive impairment in community-dwelling older adults in Taiwan: the EMCIT study. *Journal of the Formosan Medical Association* 2021; **120(9):** 1749–1757.
https://doi.org/10.1016/j.jfma.2021.03.005
https://www.ncbi.nlm.nih.gov/pubmed/33810927

28 Rentería MA, Manly JJ, Vonk JM, Arango SM, Obregon AM, Samper-Ternent R, et al. Prevalence of mild cognitive impairment in Mexican older adults: data from the Mexican Health and Aging Study (MHAS). *medRxiv* 2020. 2020.01.03.20016345.
https://doi.org/10.1101/2020.01.03.20016345

29 Liu D, Li L, An L, Cheng G, Chen C, Zou M, et al. Urban–rural disparities in mild cognitive impairment and its functional subtypes among community-dwelling older residents in central China. *General Psychiatry* 2021; **34(5):** e100564.
https://doi.org/10.1136/gpsych-2021-100564
https://www.ncbi.nlm.nih.gov/pubmed/34790888

30 Saenz JL, Downer B, Garcia MA, Wong R. Cognition and context: rural–urban differences in cognitive aging among older Mexican adults. *Journal of Aging and Health* 2018; **30(6):** 965–986.
https://doi.org/10.1177/0898264317703560
https://www.ncbi.nlm.nih.gov/pubmed/28553815

31 Dong X, Wang Y, Chen Y, Wang X, Zhu J, Wang N, et al. Poor sleep quality and influencing factors among rural adults in Deqing, China. *Sleep and Breathing* 2018; **22(4):** 1213–1220.
https://doi.org/10.1007/s11325-018-1685-8
https://www.ncbi.nlm.nih.gov/pubmed/29936592

32 Wu W, Wang W, Dong Z, Xie Y, Gu Y, Zhang Y, et al. Sleep quality and its associated factors among low-income adults in a rural area of China: a population-based study. *International Journal of Environmental Research and Public Health* 2018; **15(9):** 2055.
https://doi.org/10.3390/ijerph15092055
https://www.ncbi.nlm.nih.gov/pubmed/30235864

33 Thichumpa W, Howteerakul N, Suwannapong N, Tantrakul V. Sleep quality and associated factors among the elderly living in rural Chiang Rai, northern Thailand. *Epidemiology and Health* 2018; **40:** e2018018.
https://doi.org/10.4178/epih.e2018018
https://www.ncbi.nlm.nih.gov/pubmed/29807410

34 Wang P, Song L, Wang K, Han X, Cong L, Wang Y, et al. Prevalence and associated factors of poor sleep quality among Chinese older adults living in a rural area: a population-based study. *Aging Clinical and Experimental Research* 2020; **32(1):** 125–131.
https://doi.org/10.1007/s40520-019-01171-0
https://www.ncbi.nlm.nih.gov/pubmed/30919262

35 Zhang Y-S, Jin Y, Rao W-W, Jiang Y-Y, Cui L-J, Li J-F, et al. Prevalence and socio-demographic correlates of poor sleep quality among older adults in Hebei province, China. *Scientific Reports* 2020; **10(1):** 12266.
https://doi.org/10.1038/s41598-020-68997-x
https://www.ncbi.nlm.nih.gov/pubmed/32703962

36 Lu L, Wang SB, Rao W, Zhang Q, Ungvari GS, Ng CH, et al. The prevalence of sleep disturbances and sleep quality in older Chinese adults: a comprehensive meta-analysis. *Behavioral Sleep Medicine* 2019; **17(6):** 683–697.
https://doi.org/10.1080/15402002.2018.1469492
https://www.ncbi.nlm.nih.gov/pubmed/29851516

37 Ursin R, Bjorvatn B, Holsten F. Sleep duration, subjective sleep need, and sleep habits of 40- to 45-year-olds in the Hordaland Health Study. *Sleep* 2005; **28(10):** 1260–1269.
https://doi.org/10.1093/sleep/28.10.1260
https://www.ncbi.nlm.nih.gov/pubmed/16295211

38 Asghari A, Farhadi M, Kamrava SK, Ghalehbaghi B, Nojomi M. Subjective sleep quality in urban population. *Archives of Iranian Medicine* 2012; **15(2):** 95–98.

39 Desjardins S, Lapierre S, Hudon C, Desgagne A. Factors involved in sleep efficiency: a population-based study of community-dwelling elderly persons. *Sleep* 2019; **42(5):** zsz038.
https://doi.org/10.1093/sleep/zsz038
https://www.ncbi.nlm.nih.gov/pubmed/30768200

40 Niu J, Han H, Wang Y, Wang L, Gao X, Liao S. Sleep quality and cognitive decline in a community of older adults in Daqing City, China. *Sleep Medicine* 2016; **17:** 69–74.
https://doi.org/10.1016/j.sleep.2015.07.033
https://www.ncbi.nlm.nih.gov/pubmed/26847977

41 Curtis AF, Rodgers M, Miller MB, McCrae CS. Impact of sex on COVID-19 media exposure, anxiety, perceived risk, and severity in middle-aged and older adults. *Journal of Aging and Health* 2022; **34(1):** 51–59.
https://doi.org/10.1177/08982643211025383
https://www.ncbi.nlm.nih.gov/pubmed/34114480

42 Health Resources and Services Administration (HRSA). *Rural health grants eligibility analyzer.* HRSA, 2023.
https://data.hrsa.gov/tools/rural-health
(Accessed 26 September 2023).

43 Health Resources and Services Administration (HRSA). *Defining rural population.* HRSA, 2022.
https://www.hrsa.gov/rural-health/about-us/what-is-rural
(Accessed 2 September 2025).

44 Cromartie J. *Rural-urban commuting area codes.* Economic Research Service, U.S. Department of Agriculture, 2023.
https://www.ers.usda.gov/data-products/rural-urban-commuting-area-codes/
(Accessed 26 September 2023).

45 Han PJ. Rural definitions matter. *Cityscape* 2022; **24(3):** 215–230.
https://doi.org/10.2307/48707853

46 Buysse DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh sleep quality index: a new instrument for psychiatric practice and research. *Psychiatry Research* 1989; **28(2):** 193–213.
https://doi.org/10.1016/0165-1781(89)90047-4
https://www.ncbi.nlm.nih.gov/pubmed/2748771

47 Barzykowski K, Wereszczyński M, Hajdas S, Radel R. Cognitive inhibition behavioral tasks in online and laboratory settings: data from Stroop, SART and Eriksen Flanker tasks. *Data in Brief* 2022; **43:** 108398.
https://doi.org/10.1016/j.dib.2022.108398
https://www.ncbi.nlm.nih.gov/pubmed/35789910

48 Steinke A, Kopp B, Lange F. The Wisconsin card sorting test: split-half reliability estimates for a self-administered computerized variant. *Brain Sciences* 2021; **11(5):** 529.
https://doi.org/10.3390/brainsci11050529
https://www.ncbi.nlm.nih.gov/pubmed/33919298

49 Anwyl-Irvine A, Dalmaijer ES, Hodges N, Evershed JK. Realistic precision and accuracy of online experiment platforms, web browsers, and devices. *Behavior Research Methods* 2021; **53:** 1407–1425.
https://doi.org/10.3758/s13428-020-01501-5
https://www.ncbi.nlm.nih.gov/pubmed/33140376

50 Leidheiser W, Branyon J, Baldwin N, Pak R, McLaughlin A. Lessons learned in adapting a lab-based measure of working memory capacity for the web. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting.* Los Angeles, US: Sage Publications, 2015.
https://doi.org/10.1177/1541931215591235

51 Sternberg S. High-speed scanning in human memory. *Science* 1966; **153(3736):** 652–654.
https://doi.org/10.1126/science.153.3736.652
https://www.ncbi.nlm.nih.gov/pubmed/5939936

52 Grant DA, Berg E. A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of Experimental Psychology* 1948; **38(4):** 404.
https://doi.org/10.1037/h0059831
https://www.ncbi.nlm.nih.gov/pubmed/18874598

53 Heaton RK. *A manual for the Wisconsin card sorting test.* Odessa, US: Psychological Assessment Resources, 1981.

54 Stroop JR. Studies of interference in serial verbal reactions. *Journal of Experimental Psychology* 1935; **18(6):** 643.
https://doi.org/10.1037/h0054651

55 Posner M I. Orienting of attention. *Quarterly Journal of Experimental Psychology* 1980; **32(1):** 3–25.
https://doi.org/10.1080/00335558008248231
https://www.ncbi.nlm.nih.gov/pubmed/7367577

56 Murman D L. The impact of age on cognition. *Seminars in Hearing* 2015; **36(03):** 111–121.
https://doi.org/10.1055/s-0035-1555115
https://www.ncbi.nlm.nih.gov/pubmed/27516712

57 Halpern DF. *Sex differences in cognitive abilities.* 3rd edn. New York, US: Psychology Press, 2000.
https://doi.org/10.4324/9781410605290

58 Lövdén M, Fratiglioni L, Glymour M M, Lindenberger U, Tucker-Drob E M. Education and cognitive functioning across the life span. *Psychological Science in the Public Interest* 2020; **21(1):** 6–41.
https://doi.org/10.1177/1529100620920576
https://www.ncbi.nlm.nih.gov/pubmed/32772803

59 Cohen J. *Statistical power analysis for the behavioral sciences* 2nd edn. Hillsdale, US: Lawrence Erlbaum, 1988.

60 Bender R, Lange S. Adjusting for multiple testing-when and how? *Journal of Clinical Epidemiology* 2001; **54(4):** 343–349. https://doi.org/10.1016/S0895-4356(00)00314-0 https://www.ncbi.nlm.nih.gov/pubmed/11297884

61 VanVoorhis CW, Morgan BL. Understanding power and rules of thumb for determining sample sizes. *Tutorials in Quantitative Methods for Psychology* 2007; **3(2):** 43–50. https://doi.org/10.20982/tqmp.03.2.p043

62 Curtis AF, Schmiedeler A, Musich M, Connell M, Miller MB, McCrae CS. COVID-19-related anxiety and cognition in middle-aged and older adults: examining sex as a moderator. *Psychological Reports* 2023; **126(3):** 1260–1283. https://doi.org/10.1177/00332941211064820 https://www.ncbi.nlm.nih.gov/pubmed/35099322

63 Judd CM, McClelland GH, Ryan CS. *Data analysis: a model comparison approach to regression, ANOVA, and beyond.* 3rd edn. New York, US: Routledge, 2017. https://doi.org/10.4324/9781315744131

64 DiNapoli E A, Wu B, Scogin F. Social isolation and cognitive function in Appalachian older adults. *Research on Aging* 2014; **36(2):** 161–179. https://doi.org/10.1177/0164027512470704 https://www.ncbi.nlm.nih.gov/pubmed/25650688

65 Salthouse T A. Mental exercise and mental aging: evaluating the validity of the 'use it or lose it' hypothesis. *Perspectives on Psychological Science* 2006; **1(1):** 68–87. https://doi.org/10.1111/j.1745-6916.2006.00005.x https://www.ncbi.nlm.nih.gov/pubmed/26151186

66 Shankar A. Loneliness and sleep in older adults. *Social Psychiatry and Psychiatric Epidemiology* 2020; **55:** 269–272. https://doi.org/10.1007/s00127-019-01805-8 https://www.ncbi.nlm.nih.gov/pubmed/31729538

67 Durmer J S, Dinges D F. Neurocognitive consequences of sleep deprivation. *Seminars in Neurology* 2005; **25(1):** 117–129. https://doi.org/10.1055/s-2005-867080 https://www.ncbi.nlm.nih.gov/pubmed/15798944

68 Zhang H, Lv Z, Chen H, Tang Z, Lei X. The benefit of inhibitory control training for insomnia with short sleep duration phenotype: a pilot randomized trial. *BMC Medicine* 2024; **22(1):** 591. https://doi.org/10.1186/s12916-024-03813-1 https://www.ncbi.nlm.nih.gov/pubmed/39696383

69 Altena E, Van Der Werf YD, Sanz-Arigita EJ, Voorn TA, Rombouts SA, Kuijer JP, et al. Prefrontal hypoactivation and recovery in insomnia. *Sleep* 2008; **31(9):** 1271–1276.

70 Spira AP, Gonzalez CE, Venkatraman VK, Wu MN, Pacheco J, Simonsick EM, et al. Sleep duration and subsequent cortical thinning in cognitively normal older adults. *Sleep* 2016; **39(5):** 1121–1128. https://doi.org/10.5665/sleep.5768 https://www.ncbi.nlm.nih.gov/pubmed/26951390

71 Tai XY, Chen C, Manohar S, Husain M. Impact of sleep duration on executive function and brain structure. *Communications Biology* 2022; **5(1):** 201. https://doi.org/10.1038/s42003-022-03123-3 https://www.ncbi.nlm.nih.gov/pubmed/35241774

72 O'Connor DB, Rogerson O. Loneliness, sleep and daily stress: evidence of direct and indirect effects. *Applied Psychology: Health and Well Being* 2024; **16(4):** 2302–2318. https://doi.org/10.1111/aphw.12586 https://www.ncbi.nlm.nih.gov/pubmed/39219181

73 Bonnet MH, Arand DL. Hyperarousal and insomnia. *Sleep Medicine Reviews* 1997; **1(2):** 97–108. https://doi.org/10.1016/S1087-0792(97)90012-5 https://www.ncbi.nlm.nih.gov/pubmed/15310517

74 Khassawneh BY, Bathgate CJ, Tsai SC, Edinger JD. Neurocognitive performance in insomnia disorder: the impact of hyperarousal and short sleep duration. *Journal of Sleep Research* 2018; **27(6):** e12747. https://doi.org/10.1111/jsr.12747 https://www.ncbi.nlm.nih.gov/pubmed/30069961

75 Drake C L, Roehrs T A, Burduvali E, Bonahoom A, Rosekind M, Roth T. Effects of rapid versus slow accumulation of eight hours of sleep loss. *Psychophysiology* 2001; **38(6):** 979–987. https://doi.org/10.1111/1469-8986.3860979 https://www.ncbi.nlm.nih.gov/pubmed/12240674

76 McCrae C S, Vatthauer K E, Dzierzewski J M, Marsiske M. Habitual sleep, reasoning, and processing speed in older adults with sleep complaints. *Cognitive Therapy and Research* 2012; **36:** 156–164. https://doi.org/10.1007/s10608-011-9425-4 https://www.ncbi.nlm.nih.gov/pubmed/23243328

77 An J, Payne LL, Lee M, Janke MC. Understanding boredom and leisure in later life: a systematic review. *Innovation in Aging* 2023; **7(8):** igad109. https://doi.org/10.1093/geroni/igad109 https://www.ncbi.nlm.nih.gov/pubmed/37941827

78 Conroy R M, Golden J, Jeffares I, O'Neill D, McGee H. Boredom-proneness, loneliness, social engagement and depression and their association with cognitive function in older people: a population study. *Psychology, Health & Medicine* 2010; **15(4):** 463–473. https://doi.org/10.1080/13548506.2010.487103 https://www.ncbi.nlm.nih.gov/pubmed/20677084

79 Teoh AN, Ooi EYE, Chan AY. Boredom affects sleep quality: the serial mediation effect of inattention and bedtime procrastination. *Personality and Individual Differences* 2021; **171:** 110460. https://doi.org/10.1016/j.paid.2020.110460

80 Westgate EC, Wilson TD. Boring thoughts and bored minds: the MAC model of boredom and cognitive engagement. *Psychological Review* 2018; **125(5):** 689–713. https://doi.org/10.1037/rev0000097 https://www.ncbi.nlm.nih.gov/pubmed/29963873

81 Danckert J, Merrifield C. Boredom, sustained attention and the default mode network. *Experimental Brain Research* 2018; **236(9):** 2507–2518. https://doi.org/10.1007/s00221-016-4617-5 https://www.ncbi.nlm.nih.gov/pubmed/26979438

82 Danckert J, Hammerschmidt T, Marty-Dugas J, Smilek D. Boredom: under-aroused and restless. *Consciousness and Cognition* 2018; **61:** 24–37. https://doi.org/10.1016/j.concog.2018.03.014 https://www.ncbi.nlm.nih.gov/pubmed/29631194

83 Stansfeld S, Haines M, Brown B. Noise and health in the urban environment. *Reviews on Environmental Health* 2000; **15(1-2):** 43–82. https://doi.org/10.1515/REVEH.2000.15.1-2.43 https://www.ncbi.nlm.nih.gov/pubmed/10939085

84 Curtis AF, Dzierzewski JM, Buman MP, Giacobbi PR, Roberts BL, Aiken-Morgan AT, et al. Preliminary investigation of interactive associations of sleep and pain with cognition in sedentary middle-aged and older adults. *Journal of Clinical Sleep Medicine* 2021; **17(2):** 233–242.

https://doi.org/10.5664/jcsm.8856
https://www.ncbi.nlm.nih.gov/pubmed/33006311

85 Sexton CE, Storsve AB, Walhovd KB, Johansen-Berg H, Fjell AM. Poor sleep quality is associated with increased cortical atrophy in community-dwelling adults. *Neurology* 2014; **83(11):** 967–973.
https://doi.org/10.1212/WNL.0000000000000774
https://www.ncbi.nlm.nih.gov/pubmed/25186857

86 Probst J, Eberth JM, Crouch E. Structural urbanism contributes to poorer health outcomes for rural America. *Health Affairs* 2019; **38(12):** 1976–1984.
https://doi.org/10.1377/hlthaff.2019.00914
https://www.ncbi.nlm.nih.gov/pubmed/31794301

87 McCrae CS, Curtis AF, Williams JM, Dautovich ND, McNamara JPH, Stripling A, et al. Efficacy of brief behavioral treatment for insomnia in older adults: examination of sleep, mood, and cognitive outcomes. *Sleep Medicine* 2018; **51:** 153–166.
https://doi.org/10.1016/j.sleep.2018.05.018
https://www.ncbi.nlm.nih.gov/pubmed/30195661

88 Montgomery P, Dennis J. Cognitive behavioural interventions for sleep problems in adults aged 60+. *Cochrane Database of Systematic Reviews* 2003. **(1).** CD003161.
https://doi.org/10.1002/14651858.CD003161

89 Chang T-Z, Vowles N. Strategies for improving data reliability for online surveys: a case study. *International Journal of Electronic Commerce Studies* 2013; **4(1):** 131–140.
https://doi.org/10.7903/ijecs.1121

90 Buysse DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Research* 1989; **28(2):** 193–213.
https://doi.org/10.1016/0165-1781(89)90047-4
https://www.ncbi.nlm.nih.gov/pubmed/2748771

91 Pronk NP, Arena R, Laddu D, Woodard C. Regional cultures and insufficient sleep in the United States. *Journal of Activity, Sedentary and Sleep Behaviors* 2024; **3(1):** 4.
https://doi.org/10.1186/s44167-023-00043-3
https://www.ncbi.nlm.nih.gov/pubmed/40217336

92 Sephton SE, Kay DB. How do psychosocial and cultural factors influence sleep and circadian health disparities? *Research Directions: Sleep Psychology* 2024; **1:** e1.
https://doi.org/10.1017/slp.2023.3

93 Meit M, Knudson A. Leveraging rural strengths to overcome population health challenges. *American Journal of Public Health* 2020; **110(9):** 1281–1282.
https://doi.org/10.2105/AJPH.2020.305641
https://www.ncbi.nlm.nih.gov/pubmed/32783740