Received: 16 June 2023 | Accepted: 17 October 2023

DOI: 10.1002/gps.6022

RESEARCH ARTICLE

International Journal of Geriatric Psychiatry WILEY

Self-reported sleep fragmentation and sleep duration and their association with cognitive function in PROTECT, a large digital community-based cohort of people over 50

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Abstract

Objective: Sleep is vital for normal cognitive function in daily life, but is commonly disrupted in older adults. Poor sleep can be detrimental to mental and physical health, including cognitive function. This study assessed the association between self-reported short (<6 h) and long (>9 h) sleep duration and sleep fragmentation (3≥ nightly awakenings) in cognitive function.

Methods: Cross-sectional data from 8508 individuals enroled in the PROTECT study aged 50 and above formed the basis of the univariate linear regression analysis conducted on four cognitive outcomes assessing visuospatial episodic memory (VSEM), spatial working memory, verbal working memory (VWM), and verbal reasoning (VR).

Results: Short (β = −0.153, 95% CI [−0.258, −0.048], p = 0.004) and long sleep duration (β = −0.459, 95% CI [−0.826, −0.091], p = 0.014) were significantly associated with poorer cognitive performance in VWM. Long sleep duration (β = −2.986, 95% CI [−5.453, −0.518], p = 0.018) was associated with impaired VR. Short sleep (β = −0.133, 95% CI [−0.196, −0.069], p = <0.001) and sleep fragmentation (β = −0.043, 95% CI [−0.085, −0.001], p = 0.043) were associated with reduced VSEM. These associations remained significant when including other established risk factors for dementia and cognitive decline (e.g., depression, hypertension).

Conclusions: Our findings suggest that short and long sleep durations and fragmented sleep, may be risk factors for a decline in cognitive processes such as working memory, VR and episodic memory thus might be potential targets for interventions to maintain cognitive health in ageing.

KEYWORDS
cognitive function, older adults, sleep duration, sleep fragmentation

Key points

- This study assessed the association between self-reported short (<6 h) and long (>9 h) sleep duration and sleep fragmentation (3 or more nightly awakenings) in cognitive function.
- Univariate linear regression analysis indicated that short and long sleep duration, and sleep fragmentation impaired cognitive processes such as working memory, verbal reasoning (VR) and episodic memory in individuals aged 50+, even when including other established risk factors for dementia and cognitive decline, such as low educational level, hearing loss, traumatic brain injury, hypertension, diabetes, alcohol consumption, obesity, smoking, depression, social isolation, and physical inactivity.
- Both sleep duration and sleep fragmentation are highlighted as potential risk factors for reduced cognitive function and might be a possible target for interventions to maintain cognitive health in ageing.

1 | INTRODUCTION

Sleeping well is essential for good health and wellbeing, yet almost 50% of older adults report difficulty initiating or maintaining sleep.[1] This is attributed to altered sleep architecture, potentially resulting in less restorative sleep, but is also linked to declining health, reduced physical function, and heightened mental health concerns, rendering older adults more susceptible to poor sleep and sleep disturbances.[2] Poor sleep has been associated with increased mortality rate and cardiovascular events,[3] hypertension, and diabetes,[4] and also found to have a bi-directional association with depression.[5] Poor sleep can also lead to a reduction in cognitive function, with research suggesting that sleep deprivation might impact specific brain regions, particularly the prefrontal cortex, which plays an integral role in functions such as working memory and executive functions.[6] There has been a recent increase in interest regarding the role of sleep in cognition, and sleep characteristics such as sleep duration and sleep fragmentation, in particular, have been explicitly highlighted.[7] In older adults, sleep duration has been associated with cognitive function[8] and risk of cognitive impairment, where 7–8 h of sleep has the lowest incident risk of cognitive decline.[9,10] The systematic review and meta-analysis conducted by Lo et al.[8] reported that both long and short sleep duration were associated with reduced performance in a global cognitive function assessment and in single-domain tasks assessing verbal memory, working memory capacity and executive functions. Similarly, fragmented sleep, is associated with poorer cognitive performance both in global cognitive function as well as cognitive domains such as processing speed, memory and executive function,[11–14] in addition to an increased cognitive decline rate and Alzheimer's disease incidence.[7,15] Reviews and meta-analyses consistently report associations between sleep disturbances such as insomnia and sleep-disordered breathing and cognitive decline and dementia respectively.[16–20] However, two recent long-term follow-up studies show disparate results in relation to sleep patterns and dementia risk. Recent findings from the Whitehall II study with its 25-year follow-up, suggest that sleeping six hours or less in mid-life may increase dementia risk by 30%.[21] In contrast, a Norwegian study with an 11 yearlong follow-up period[22] found no link between insomnia and dementia or Alzheimer's disease. Surprisingly, in the latter, fragmented sleep was associated with lower dementia risk and better cognition scores.

Livingston et al.[23] estimate that as many as 40% of dementia risk could be prevented by addressing risk factors throughout the human lifespan. These risk factors include less education and air pollution, along with lifestyle factors like excessive alcohol consumption, smoking and physical inactivity. Depression and social isolation, diabetes, hypertension, obesity, hearing loss and traumatic brain injury were also highlighted. For sleep the author argues that the evidence base remains insufficient. A complicating factor in establishing the role of sleep in cognition is the high variability in measuring both sleep and cognition and a significant amount of the literature on sleep and cognition is based on using the Mini-Mental State Examination (MMSE) as a cognitive outcome, which might be insensitive to measure cognitive variability in cognitively healthy individuals.[24]

What we do know is that risk factors for dementia tend to group together,[23] and that sleep may be associated with other risk factors for dementia such as depression, diabetes hypertension and other cardiovascular factors.[4,5] It is therefore important to determine whether sleep duration and fragmentation are truly independently associated with impaired cognitive function using sensitive and well-validated cognitive outcomes.

Utilizing data derived from the PROTECT study, a comprehensive automated and digital prospective cohort study that employs a cognitive test battery tailored for use among cognitively healthy individuals, we aim to assess the cross-sectional association between self-reported sleep duration and sleep fragmentation on cognitive function in a large population of more than 8500 individuals aged 50 years and older.

2 | MATERIALS & METHODS

2.1 | Study design

This is a cross-sectional analysis of data from the ongoing online PROTECT Study (http://www.protectstudy.org.uk/) in the UK,

launched in November 2015 (London Bridge NHS Research Ethics Committee (13/LO/1578)).

2.2 | Participants and eligibility criteria

The PROTECT Study is a prospective cohort study aiming at understanding how the brain ages and how to reduce the risk of dementia and mental health issues in later life. PROTECT participants were 50 years old and older at the time of data collection and living in the UK. They had access to a computer or tablet device with internet connection and were not diagnosed with dementia. Individuals joining the study completed a self-eligibility check before proceeding with registration and informed consent. This process is completed digitally via the study website, and consent is recorded electronically. Promotion of the study was achieved through national UK publicity and recruitment from partner cohorts and organisations via the University of Exeter and Kings College London.

2.3 | Data collection

PROTECT Study participants provide annual demographic, lifestyle, medical history and mental health data through a series of online questionnaires, in addition to completing a computerised cognitive test battery.

This analysis utilised participant responses to items in the online questionnaires that aligned to sleep duration, sleep fragmentation, age and gender and 11 of 12 potentially modifiable risk factors for dementia identified by Livingston et al.[23] including educational level, hearing, traumatic brain injury, hypertension, diabetes, alcohol consumption, obesity, smoking, depression, social isolation and physical inactivity. The questionnaires did not include an item pertaining to air pollution.

2.4 | Demographic data

Participant demographic information collected at baseline, included age, gender, marital status, ethnicity, employment status, and educational attainment. Based on marital status, a new *living arrangement* variable was derived by aggregating married, civil partnership and cohabitating to one category and widowed, separated, divorced and single to another category. The variable was applied as a proxy for social isolation based on literature showing that adults in single persons households are significantly more likely to experience loneliness and social isolation.[25,26]

2.5 | Lifestyle data collection

A lifestyle questionnaire incorporated a modified version of the St. Mary's Hospital Sleep Questionnaire, where previous test-retest correlations using Kendall's Tau nonparametric correlation coefficient, demonstrated the reliability of each item (tau values ranging from 0.70 to 0.96), including in a normative sample.[27] It measures sleep characteristics during the last month. Two items were selected. For sleep fragmentation, the following variable was chosen: "On average in the last month, how many times do you wake during a night?" (sleep fragmentation) rated on an 8-point scale: 1 = Not at all, 2 = Once, 3 = Twice, 4 = Three times, 5 = Four times, 6 = Five times, 7 = Six times and 8 = More than six times. We collapsed and defined the sleep fragmentation variable as having three or more nightly awakenings. For sleep duration, participants responded to the following question: "On average in the last month, how many hours of sleep have you had at night?" by entering the number of hours and minutes into text boxes. We categorized the continuous sleep duration variable into three distinct categories: "short" (<6 h), "normal" (6–9 h), and "long" (>9 h).

Further, analyses utilised self-reported data on alcohol consumption, current smoking and physical activity from the mentioned PROTECT lifestyle questionnaire. For physical activity, participants were asked: "In the last month, how many times have you done any physical activity lasting at least 20 min that has left you out of breath?" with response options on a five-point scale: 0 = Null, 1 = 1–3 times, 2 = 4–10 times, 3 = 11–20 times and 4 = More than 20 times. Current smoking was collected as a dichotomous response with categories of Yes/No. Alcohol consumption was captured by the response to the question: "How often do you normally have a drink of something with alcohol in?" through a Likert scale of 0 = Never, 1 = Less than once a month 2 = Less than once a week and 3 = At least weekly.

2.6 | Medical and mental health data collection

A medical history questionnaire captured participant height and weight, which was transformed into a Body Mass Index (BMI) variable (kg/m^2). Hearing loss and previous head trauma were captured as yes/no response variables. Diagnoses of diabetes and hypertension were indicated through a multi-select list containing common health conditions. As part of a composite mental health questionnaire, participants completed the validated nine-item patient health questionnaire that assesses symptoms of depression.[28] Scores of ≥10 were defined as suggesting moderate or higher depression severity[29] and were interpreted as clinically significant depression (yes) and <10 as no clinically significant current depression (no).

2.7 | Cognitive assessment

A validated online cognitive test battery was conducted to assess cognitive function.[30] The PROTECT Cognitive Test System includes four tasks completed in sequence without a break. These are: the Paired Associate Learning task (PAL) that assesses visuospatial episodic memory (VSEM), the Self-Ordered-Search task (SOS) that assesses spatial working memory (SWM), the Digit Span task (DS)

that assesses verbal working memory (VWM), and the Grammatical Reasoning task that assesses VR. These tasks are described in full in a previous publication.[31] The outcome measure of each task is the total score of correct responses, corrected for errors made. Participants were encouraged to complete the cognitive assessments up to three times over a period of 1 week, with at least 24 h between each session.

2.8 | Data analysis

Of the 10,175 participants in the dataset, 9178 had responded to the sleep questionnaire. Data was scrutinised for missingness and outliers were excluded.

2.8.1 | Linear regression analysis

To determine whether sleep fragmentation or sleep duration were related to performance on each of the four cognitive tasks, multiple linear regression analyses were conducted using IBM SPSS Statistics 26. Analyses were conducted with summary scores of first-session tests from each of the four cognitive measures as the dependent variable. Independent variables in our analysis were responses on sleep fragmentation and duration, physical activity, alcohol consumption, smoking, sex, living arrangement, age, BMI, education, depression, history of diabetes, history of high blood pressure, having experienced head trauma and hearing loss. Marital status included several similar sub-categories with relatively low frequencies. Thus, the inclusion of *living arrangement* instead of *marital status* facilitated the robustness of the model. Finally, 670 of 9178 records (7.3%) had missing values in at least one of the covariates *depression*, *BMI*, *physical activity*, *alcohol consumption*, *smoking*, *problem hearing* or *head trauma* and were excluded. In total, 8508 records were included in the regression analysis. For the linear regression analysis, age is centred at 64 years (the mean of 8508 records).

In order to study the association with the four cognitive tasks, analyses were conducted with all variables separately (unadjusted model), all at once included in the model (adjusted model), and finally removing the parameter with the highest *p*-value from the adjusted model (final model) except for the sleep variables, being the variables of interest in our study. Pairwise interactions between all included covariates in the final model of all four cognitive tasks were checked, but no significant interactions were identified based on the Bayesian Information Criteria.

3 | RESULTS

3.1 | Baseline characteristics

Baseline demographic characteristics of the study sample is presented in Table 1. Demographic, lifestyle and physical and mental health variables included as covariates in regression analysis—are described in Table 2. The mean age of the participants was 64 years [95% CI: 63.90, 64.20]. The participants were mainly female (74.8%), cohabitating (74.4%), and 86.2% had completed post-secondary education. Table 3 show descriptive statistics of cognitive measures in the study sample.

TABLE 1 Demographic information for participants included in the regression analysis.

Total *n* = 8508	*m*	*n*	%
Age	64		
Gender			
Female		6367	74.8
Male		2141	25.2
Marital status			
Married		5794	68.1
Widowed		579	6.8
Separated		133	1.6
Divorced		932	11.0
Civil partnership		43	0.5
Co-habiting		495	5.8
Ethnicity			
White		8388	98.6
Mixed		42	0.5
Asian		46	0.5
Black		10	0.1
Other		22	0.3
Employment			
Employed full		1382	16.2
Employed part		1362	16.0
Self-employed		864	10.2
Retired		4700	55.2
Unemployed		200	2.4
Education			
GCSE		964	11.3
A level		1714	20.1
Vocational		2888	33.9
Undergrad		1451	17.1
Post-grad		314	3.7
PhD		964	11.3

Note: This table presents the participant demographic information collected at baseline, including age, gender, marital status, ethnicity, employment status, and educational attainment. The table provides the total number of participants (*n*), the mean (*m*), and the percentage (%) for each variable category.

3.2 | Cohort sleep characteristics

In total, 88.8% of the participants in this study reported a sleep duration of 6–9 h a night during the last month, and we categorised them as normal sleepers (Table 2). 10.5% reported sleeping less than 6 hours and were categorised as short sleepers. Sixty-two individuals (0.7%) reported sleeping more than 9 hours and were defined as long sleepers. 31.0% of participants reported fragmented sleep, defined as having three or more nightly awakenings in the last month.

3.3 | Sleep duration and cognitive function

Parameter estimates for long sleep, short sleep and sleep fragmentation are summarized in Table 4. Short and long sleep durations were found to be negatively associated with all four cognitive tasks compared with normal sleep duration. However, only associations across three tasks were significant—including DS, PAL and VR. More specifically, Table 4 shows that short sleep duration was significantly associated with poorer performance on DS ($\beta = -0.153$, 95% CI [−0.258, −0.048], $p = 0.004$) and PAL ($\beta = -0.133$, 95% CI [−0.196,

TABLE 2 Demographic, lifestyle and physical and mental health variables included.

Total $n = 8508$	*m*	*n*	%		*m*	*n*	%
Age	64						
Gender				Depression			
Female		6367	74.8	No		8171	96.0
Male		2141	25.2	Yes		337	4.0
Education				Physical activity			
GCSE		1177	13.8	Null		2478	29.1
A level		964	11.3	1–3		1366	16.1
Vocational		1714	20.1	4–10		2375	27.9
Undergrad		2888	33.9	11–20		1437	16.9
Post-grad		1451	17.1	>20		852	10.0
PhD		314	3.7				
Living arrangement				Smoking			
Living alone		2176	25.6	No		8337	98.0
Cohabiting		6332	74.4	Yes		171	2.0
Sleep duration				Sleep fragmentation			
6–9 h		7555	88.8	≤2		5872	69.0
<6 h		891	10.5	≥3		2636	31.0
>9 h		62	0.7				
Alcohol use				BMI			
Never		565	6.6	Underweight		130	51.0
<1 month		1002	11.8	Normal weight		4336	1.5
<1 week		1281	15.1	Overweight		2778	32.7
>1 week		5660	66.5	Obese/very obese		1264	14.9
Problem hearing				Hypertension			
No		6318	74.3	No		6142	72.2
Yes		2190	25.7	Yes		2366	27.8
Diabetes				Traumatic brain injury			
No		8200	96.4	No		7421	87.2
Yes		308	3.6	Yes		1087	12.8

Note: This table presents the demographic, lifestyle, and physical and mental health variables included in the study. Variables include age, gender, depression status, education level, living arrangement, sleep duration, sleep fragmentation, alcohol use, BMI (Body Mass Index), problem hearing, hypertension, diabetes, and history of traumatic brain injury. The table provides the total number of participants (n), the mean (m), and the percentage (%) for each variable category.

−0.069], p = <0.001) and long sleep duration was significantly associated with decreased performance on DS (ß = −0.459, 95% CI [−0.826, −0.091], p = <0.014) and VR (ß = −2.986 95% CI [−5.453, −0.518], p = 0.018).

3.4 | Sleep fragmentation and cognitive function

As shown in Table 4, sleep fragmentation (three or more nightly awakenings) were associated with adverse effects on all tasks including DS (ß −0.067, 95% CI [−0.136, 0.002], p = 0.058), VR (ß = −0.291, 95% CI [−0.751, 0.170], p = 0.216), SOS (ß = −0.058, 95% CI [−0.141, 0.025], p = 0.170), but only on the PAL task the negative association was significant (ß = −0.043, 95% CI [−0.085, −0.001], p = 0.043).

3.5 | Regression analysis of independent variables

Table 5 shows all final models from the linear regression analyses and include all covariates with significant p-value on at least one out of four cognitive tasks in the PROTECT cognitive test battery. Covariates in our analysis were sleep fragmentation and duration, physical activity, alcohol consumption, smoking, sex, living arrangement, age, BMI, education, depression, history of diabetes, history of high blood pressure, having experienced head trauma and hearing loss. Marital status was included as a proxy for social isolation. Extant smoking, head trauma and diabetes were excluded from Table 5 due to non-significant p-values in either cognitive outcome. For full analyses, please see supplementary file.

TABLE 3 Descriptive statistics of cognitive measures.

Cognitive task	*n*	*m*	*SD*
Digit span task	8508	7.60	1.562
Paired associates learning task	8508	4.70	0.957
Verbal reasoning task	8508	36.97	10.443
Self-Ordered search task	7913	8.18	1.790

Abbreviations: m, mean; n, sample size; SD, standard deviation.

3.5.1 | Demographic variables

As expected, there is a correlation between age and education with the outcome variables (Table 5).

3.5.2 | Modifiable risk factors for dementia

Other established risk factors such as current depression, being overweight or obese, hypertension, hearing problems and physical activity also contributed to the models. The analyses are shown in Table 5.

4 | DISCUSSION

In our study of more than 8500 cognitively healthy adults aged 50 and above, we examined nocturnal sleep duration and sleep fragmentation and their associations with cognitive function. Overall, sleep characteristics such as short (<6 h) and long (>9 h) sleep duration and fragmented sleep (3+ nightly awakenings) were associated with a significant impairment of cognitive function in three of the four tasks; 1) Digit span task assessing VWM, 2) Paired Associate Learning task assessing VSEM and 3) Grammatical Reasoning task assessing VR. The associations reported were adjusted for demographic variables such as age, gender and education, and were significant as independent associations of impaired cognitive function even when including established modifiable risk factors for dementia.[23]

4.1 | Sleep duration and cognitive function

In line with a previously published systematic review and meta-analysis,[8] we found adverse associations between sleep duration and cognitive function. Lo et al.[8] found negative associations in single-domain tasks assessing verbal memory, working memory capacity and executive functions in both short and long sleepers. Similarly, we found both short and long sleep duration to be significantly associated with poorer cognitive function in VWM. This is also

TABLE 4 Final model parameter estimates for long sleep, short sleep and sleep fragmentation derived from the generalized linear models.

	Long sleep	Short sleep	Sleep fragmentation
DS	ß = −0.459, 95% CI [−0.826, −0.091], p = **0.014**	ß = −0.153, 95% CI [−0.258, −0.048], p = **0.004**	ß = −0.067, 95% CI [−0.136, 0.002], p = 0.058
PAL	ß = −0.098, 95% CI [−0.321, 0.126], p = 0.391	ß = −0.133, 95% CI [−0.196, −0.069], p = **<0.001**	ß = −0.043, 95% CI [−0.085, −0.001], p = **0.043**
VR	ß = −2.986, 95% CI [−5.453, −0.518], p = **0.018**	ß = −0.623, 95% CI [−1.326, 0.079], p = 0.082	ß = −0.291, 95% CI [−0.751, 0.170], p = 0.216
SOS	ß = −0.111, 95% CI [−0.569, 0.347], p = 0.634	ß = −0.078, 95% CI [−0.206, 0.050], p = 0.230	ß = −0.058, 95% CI [−0.141, 0.025], p = 0.170

Note: The parameter estimates are represented by ß (beta) values along with their corresponding 95% confidence intervals (CI) and p-values.

TABLE 5 Final models from generalized linear models for digit span task (DS), paired associates learning task (PAL), verbal reasoning task (VR) and self-ordered search task (SOS) including covariates that were significant on at least one of four cognitive outcomes.

		DS				PAL				VR				SOS			
			95% CI				95% CI				95% CI				95% CI		
		ß	Lower	Upper	*p*	ß	Lower	Upper	*p*	ß	Lower	Upper	*p*	ß	Lower	Upper	*p*
Age at testing		−0.021	−0.026	−0.017	**<0.001**	−0.023	−0.026	−0.020	**<0.001**	−0.348	−0.379	−0.317	**<0.001**	−0.060	−0.066	−0.055	**<0.001**
Gender Ref: 1 = female		0.135	0.060	0.210	**<0.001**	-	-	-	-	−1.266	−1.759	−0.773	**<0.001**	0.547	0.459	0.635	**<0.001**
Education Ref: 1 = secondary education	6 = PhD	0.563	0.379	0.747	**<0.001**	0.193	0.081	0.304	**0.001**	7.187	5.962	8.412	**<0.001**	0.368	0.149	0.588	**0.001**
	5 = postgrad	0.361	0.247	0.476	**<0.001**	0.103	0.034	0.172	**0.004**	5.255	4.493	6.016	**<0.001**	0.144	0.007	0.281	**0.040**
	4 = Undergrad	0.374	0.273	0.475	**<0.001**	0.145	0.084	0.206	**<0.001**	5.595	4.923	6.266	**<0.001**	0.349	0.228	0.471	**<0.001**
	3 = vocational	0.099	−0.010	0.209	0.075	0.053	−0.014	0.119	0.119	2.362	1.632	3.091	**<0.001**	0.084	−0.048	0.217	0.211
	2 = post secondary	0.177	0.051	0.302	**0.006**	0.052	−0.024	0.129	0.180	3.018	2.182	3.854	**<0.001**	0.098	−0.053	0.250	0.204
Sleep fragmentation Ref: 1 = two or less awakenings		−0.067	−0.136	0.002	0.058	−0.043	−0.085	−0.001	**0.043**	−0.291	−0.751	0.170	0.216	−0.058	−0.141	0.025	0.170
Sleep duration Ref: 6–9 h	3 = >9 h	−0.459	−0.826	−0.091	**0.014**	−0.098	−0.321	0.126	0.391	−2.986	−5.453	−0.518	**0.018**	−0.111	−0.569	0.347	0.634
	2 = <6 h	−0.153	−0.258	−0.048	**0.004**	−0.133	−0.196	−0.069	**<0.001**	−0.623	−1.326	0.079	0.082	−0.078	−0.206	0.050	0.230
Living arrangement Ref: 1 = Co-habiting		-	-	-	-	-	-	-	-	0.641	0.150	1.132	**0.011**	-	-	-	-
Current depression Ref: 0 = No current depression		-	-	-	-	-	-	-	-	−2.002	−3.090	−0.914	**<0.001**	−0.312	−0.509	−0.115	**0.002**
BMI Ref: 1 = normal BMI	4 = obese/morbidly obese	−0.171	−0.265	−0.078	**<0.001**	-	-	-	-	-	-	-	-	-	-	-	-
	3 = overweight	−0.130	−0.201	−0.059	**<0.001**	-	-	-	-	-	-	-	-	-	-	-	-
	2 = underweight	0.146	−0.112	0.403	0.267	-	-	-	-	-	-	-	-	-	-	-	-
Alcohol Ref: 0 = never	3 = at least weekly	0.151	0.023	0.279	**0.021**	-	-	-	-	-	-	-	-	-	-	-	-
	2 = <once weekly	0.004	−0.142	0.150	0.956	-	-	-	-	-	-	-	-	-	-	-	-
	1 = <once monthly	0.032	−0.119	0.184	0.678	-	-	-	-	-	-	-	-	-	-	-	-
Number of physical activity Ref: 0 = null	4 = >20	0.036	−0.079	0.151	0.542	-	-	-	-	0.474	−0.291	1.240	0.225	−0.063	−0.202	0.075	0.369
	3 = 11–20	0.139	0.042	0.236	**0.005**	-	-	-	-	1.290	0.646	1.933	**<0.001**	0.087	−0.029	0.202	0.141
	2 = 4–10	0.098	0.014	0.182	**0.022**	-	-	-	-	1.526	0.968	2.083	**<0.001**	0.118	0.018	0.218	**0.021**
	1 = 1–3	0.050	−0.047	0.147	0.314	-	-	-	-	0.772	0.123	1.422	**0.020**	0.052	−0.065	0.169	0.383
Problem hearing Ref: 0 = No		−0.077	−0.151	−0.003	**0.040**	-	-	-	-	-	-	-	-	-	-	-	-
Hypertension Ref: 0 = No		-	-	-	-	−0.042	−0.085	0.002	0.060	-	-	-	-	−0.097	−0.183	−0.011	**0.027**

Note: Areas containing a hyphen in the table indicate the absence of significant associations in the adjusted analysis. Consequently, these variables were not included in the final models. Notably, the sleep variables, which were the focal point of this study, were retained in the final models regardless of their *p*-values exceeding the predetermined significance level (0.05). *The table provide ß (beta) values along with their corresponding 95% lower and upper confidence intervals (CI) and p-values.* A bold *p*-value indicate statistical significance. *The term 'Ref' signifies the reference variable for analysis of categorical factors.*

in alignment with the proposed u-shaped non-linear relationship of sleep duration and risk of cognitive decline, with the lowest risk of cognitive decline occurring at 7 h sleep.[9] Conversly, we do not find a simliar u-shaped non-linear relationship between sleep duration and cognitive domains such as VR and visouspatial episodic memory in our study, as only short sleepers showed significantly impaired visouspatial episodic memory and only long sleepers were found to have significantly poorer VR abilities. In addition, neither short or long sleep duration had significant impact on SWM.

4.2 | Sleep fragmentation and cognitive function

Fragmented sleep-wake rhythms have previously been reported to impair memory function, reduce processing speed and decrease executive functions in older adults.[13] However, prospective studies reporting on sleep fragmentation and its relationship with cognitive function have been heterogenous, with some longitudinal studies reporting an association with cognitive decline,[32] some reporting null findings[33] and others finding better general cognitive function.[22] In this cross-sectional study we found fragmented sleep to significantly associate with impaired memory function, such as episodic memory, but we found no significant association between fragmented sleep and verbal or SWM, nor did we find significant evidence for impaired VR abilities.

4.3 | Sleep duration and fragmentation as factors influencing cognitive function in ageing

Poor sleep can affect various brain regions, including the prefrontal cortex,[6] which may explain the observed associations with working memory and episodic visuospatial memory in our study. The self-ordered search task measures SWM and the paired associate learning task assesses learning and visual memory. These represent distinct forms of working memory, and it is conceivable that sleep-related factors may exert varying effects on these cognitive domains, hence the non-significant finding for self-ordered search task. Our findings show sleep duration and sleep fragmentation to be independent associations in cognitive function in the analysis with other established risk factors for dementia as per Livingston et al.[23] Together with current depression and physical activity, sleep characteristics such as sleep duration and sleep fragmentation may emerge as potent factors to target with regards to maintaining cognition in ageing, as they were significantly associated with performance in multiple cognitive domains—reasoning and memory—in individuals aged 50 and above. These three modifiable risk factors for dementia are highly intertwined, with a bi-directional relationship existing between sleep and depression,[5] whilst physical activity is often recommended for enhancing mental health and sleep.[34,35] In light of these findings, poor sleep in ageing individuals should perhaps be considered as a modifiable risk factor for targeted interventions and public health initiatives to maintain cognition in ageing. Such an approach aligns with the concept of brain maintenance. Brain maintenance involves the reduction of age-related brain changes and disease pathology influenced by genetics and lifestyle choices, thus prescribing to the core consept that the brain is adaptable through experience over time.[36] However, there is currently not enough evidence suggesting that treating sleep problems improves cognitive function,[37] emphasising the need for more research in this field.

A recent systematic review on the role of daytime napping on cognition suggests that a nap during the day might benefit cognitive health in older adults, including psychomotor function and working memory.[38] However, daytime napping in older adults sleeping poorly at night could potentially aggravate existing sleep problems, thus this group could potentially benefit more from other interventions as a means to maintain cognitive health in ageing. Identifying the cause of sleep complaints and assessing the severity of these should underlie and guide potential sleep promoting interventions. Sleep fragmentation, for example, as defined in our study as three or more awakenings during a night, could potentially be a symptom of both insomnia and sleep related breathing disorders, which are sleep disorders that warrant different kinds of treatment.

4.4 | Strengths and limitations

One major strength of our study was the use of a cognitive test battery assessing different cognitive domains, developed for use in a cognitively healthy population and well-validated and sensitive to changes in cognition. In contrast, a significant amount of the literature on sleep and cognition is based on using the MMSE as a cognitive outcome,[24] which might be insensitive to measure cognitive variability in cognitively healthy individuals. However, all other data were based on self-report measures, which may limit the interpretation of these data. The longitudinal associations are unknown, and causality cannot be determined due to the cross-sectional design of this study. Due to the design of the sleep fragmentation variable, it only gave information on the number of night-time awakenings and not the amount spent awake during each awakening. Another limitation was that the overall sample had an overrepresentation of relatively educated people, being predominantly white and female-which could be traced back to the self-selection recruitment design of the PROTECT study. This could limit the overall generalizability of the findings in this study, however, due to the very large study population, our findings still provide valuable information on the effects of sleep duration and fragmentation on cognitive function.

5 | CONCLUSION

Our results suggest that disrupted or abnormal sleep patterns, such as short and long sleep durations and fragmented sleep, may be risk factors for a decline in cognitive processes such as working memory, VR and episodic memory in individuals aged 50 and above. Thus, sleep duration and fragmented sleep are highlighted as potential

targets to maintain cognitive health in ageing through interventions. However, further research is needed to better understand the mechanisms underlying the associations between sleep fragmentation and short or long sleep duration, and the above-mentioned cognitive processes. Also, there is need for trials exploring the effect of maintaining good sleep in ageing on cognitive function.

ACKNOWLEDGEMENTS

This paper represents independent research coordinated by the University of Exeter and King's College London and is funded in part by the National Institute for Health Research (NIHR) Biomedical Research Centre at South London and Maudsley NHS Foundation Trust and King's College London. This research was also supported by the National Institute for Health Research (NIHR) Collaboration for Leadership in Applied Health Research and Care South West Peninsula and the National Institute for Health Research (NIHR) Exeter Clinical Research Facility. This study was supported by the National Institute for Health and Care Research Exeter Biomedical Research Centre. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

This study is based on data collected in the PROTECT study: https://www.protectstudy.org.uk/. PROTECT data can be shared with investigators outside the PROTECT team after request and approval by the PROTECT Steering Committee.

ETHICAL STATEMENT

This study use data from the PROTECT Study (http://www.protectstudy.org.uk/), launched in November 2015, which have received REC approval by London Bridge NHS Research Ethics Committee (13/LO/1578).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Aakre JA, Schulz J, Ballard C, et al. Self-reported sleep fragmentation and sleep duration and their association with cognitive function in PROTECT, a large digital community-based cohort of people over 50. *Int J Geriatr Psychiatry*. 2023;e6022. https://doi.org/10.1002/gps.6022