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Research article

The association between sleep duration, bedtime, and cognitive ability in Chinese adults: Evidence from the China family panel studies

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A R T I C L E I N F O

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A B S T R A C T

Introduction: Dementia is marked by a steady decline or worsening in cognitive abilities, affecting memory, logic, and social competencies. While many studies suggest a potential link between the amount of sleep and dementia risk, the outcomes are not yet consistent. This research delved into the relationship between sleep length and bedtime on cognitive abilities using an extensive dataset from the China Family Panel Studies (CFPS) from 2014 to 2020.
Methods: Data from 175,702 observations were collected, including cognitive function test data from 22,848 participants. Various cognitive tests were used to assess cognitive function. Restricted cubic spline (RCS) models were used for data analysis.
Results: The optimal sleep duration for cognitive function was found to be 6–7 h, and the optimal bedtime was generally between 22:00–23:00. Longitudinal analysis revealed that sleep duration four years prior had a significant impact on current cognitive function. After accounting for various factors, those who slept for 7–8 h and over 8 h displayed lower cognitive function scores. Conversely, individuals sleeping less than 6 h had higher scores on the Vocabulary Test. Bedtime before 22:00 was associated with lower scores on the Vocabulary Test and Mathematical Test. Subgroup analyses based on age, gender, and urban residence showed variations in optimal sleep duration for different populations. Propensity Score Matching (PSM) analysis supported the findings.
Conclusions: Maintaining a sleep duration of 6–7 h and a regular bedtime between 22:00–23:00 is important for optimizing cognitive performance.

1. Introduction

Some serious health issues people face globally include declining cognitive abilities and dementia symptoms associated with brain aging [1,2]. Dementia is characterized by a consistent or worsening deterioration in cognitive capabilities, impacting memory,

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reasoning, and social skills [3]. Cognitive impairments have a profound effect on the health and daily lives of the elderly, resulting in considerable strain on families and the broader community. The financial implications and health strain linked to dementia are significant, with individuals diagnosed with dementia incurring Medicare and Medicaid costs that are 2–22 times higher than those without the condition. As the worldwide population grows older, the annual increment in dementia cases is predicted to be around 10 million, further exacerbating these costs and burden.

Given the current lack of effective dementia treatments, researchers are zeroing in on potential risk elements affecting brain health to potentially slow down dementia's advancement [1,3]. There's a growing body of research suggesting a correlation between sleep duration and an increased dementia risk in seniors, though conclusions remain varied [4–6]. A comprehensive review and meta-analysis have shown that both prolonged and insufficient sleep periods correlate with reduced cognitive performance. Yet, a study spanning 25 years found that only a lack of adequate sleep, compared to a standard sleep length, led to a 30 % increased dementia risk in individuals over 50 [6]. On the other hand, another study indicated that extended sleep durations are correlated with worse mental status and memory evaluations in older Chinese individuals [4]. Experimental research has further established links between circadian rhythms, sleep, and neurodegenerative conditions, especially Alzheimer's disease (AD) [7,8].

Previous studies have not only failed to reach a consensus but also have certain limitations. Firstly, the existing studies are limited by small sample sizes or methodological constraints, making it challenging to draw definitive conclusions regarding the impact of increased or decreased sleep duration on cognitive function or the risk of dementia. Secondly, a majority of these studies were conducted in affluent nations, and it remains to be determined if similar patterns exist in low- middle-income nations (LMICs). Grasping the relationship between sleep length and cognitive health in China is vital, especially in light of the country's rapid economic and health transitions [9], coupled with its swiftly aging population, escalating disease-related challenges [9]. In conclusion, new and larger-scale studies, specifically tailored to developing countries like China, are needed.

To delve deeper into the association between sleep and cognitive ability, we posit the following hypothesis: adhering to the optimal sleep duration will be associated with improved cognitive functions, while deviations from this range could result in reduced cognitive performance. To validate this hypothesis, a longitudinal cohort study approach is essential. Our study utilizes the CFPS dataset, an in-depth longitudinal survey from China, to examine the connection between sleep duration, bedtime, and cognitive performance. The primary objectives of our investigation are: (1) to reassess the U-shaped correlation between sleep duration and cognitive function in a Chinese cohort; (2) to understand the continuous link between baseline sleep patterns and cognitive function evolution; (3) to determine the best sleep duration and ideal bedtime; and (4) to pinpoint additional factors influencing the sleep-cognition connection.

In summary, understanding the impact of sleep duration and bedtime on cognitive function is crucial for developing strategies to prevent or delay dementia and improve cognitive health in aging populations. This study endeavors to augment the existing literature by scrutinizing the interrelation between sleep duration, bedtime routines, and cognitive performance via an expansive longitudinal cohort involving Chinese subjects. The findings from this research may provide insights for public health strategies aimed at optimizing sleep patterns to promote cognitive health and reduce the burden of dementia.

2. Methods

2.1. Data source and study sample

We relied on data from the China Family Panel Studies (CFPS). Coordinated by Peking University's Institute of Social Science Survey in collaboration with the Survey Research Center at the University of Michigan, the CFPS stands as a nationwide longitudinal study. CFPS employs proportional probability sampling (PPS) with implicit stratification, multi-stage, multi-level, and population proportionality, considering the significant regional differences in Chinese society. Initiated in 2010, subsequent data rounds were gathered in 2012, 2014, 2016, 2018, and 2020. The CFPS had a target demographic comprising roughly 16,000 Chinese households, encompassing 95 % of China's populace. Using a stratified sampling method based on size, the CFPS selected 144 counties across 25 provinces and 32 townships in Shanghai as the primary sampling units. From within these counties, a selection of 640 communities was made at random, followed by the random selection of 25 households within each community. Every qualifying household and its members were enrolled for the survey. To conduct this survey, we obtained permission to use the public data from the CFPS portal (https://www.isss.pku.edu.cn/cfps/en/data/public/index.htm), ensuring that no personal details of participants were discernible. The need for ethical committee endorsement was deemed unnecessary for this research.

2.2. Study sample selection

To ensure the cognitive functions analyzed were representative of the adult population, individuals below 18 years were not considered in the study. To delve into the relationship between sleep and cognitive abilities, participants lacking data on sleep patterns, bedtime, and cognitive assessments were omitted.

2.3. Outcome measures

The CFPS utilized two distinct testing methodologies to gauge individual cognitive capabilities. Cognitive abilities were defined by combining aspects of "crystallized intelligence" and "fluid intelligence", each measured using distinct tools over varying years [10,11]. Specifically, during the years 2010, 2014, and 2018, tests in math and vocabulary were administered to gauge "crystallized intelligence", an attribute reflecting the capacity to employ previously acquired knowledge and educational experiences [10]. Conversely, during 2016 and 2020, evaluations encompassing immediate word recall, delayed word recall, and number sequence tests were executed to gauge “fluid intelligence"—an attribute signifying the capacity for logical thinking and tackling new challenges [10,11]. Both groups of tests are extensively recognized and have been validated in prior research for assessing cognitive skills within the Chinese demographic [12]. The scoring criteria were set as follows: 0–24 points for the math test, 0–34 for the vocabulary test, 0–10 for both immediate and delayed word recall assessments, and 0–15 for the number sequence test. Higher scores indicated better performance, with 0 as the lowest possible score.

2.4. Covariates

In the preliminary evaluation, guided by the conclusions of antecedent studies [1,2,6], we adjusted for fundamental demographics like age and gender. Additionally, educational background was factored in, considering its potential influence on cognitive performance scores [13,14]. To further investigate, we categorized age into <65 and ≥ 65 years, educational attainment into ≤6 years and >6 years, and BMI into ≤24 and > 24.

2.5. Statistical analysis

The relationship between the cognitive development of the descendants and the depressive state of their parents was probed utilizing a series of linear regression models. The initial model accounted solely for age, while the comprehensive model additionally adjusted for educational attainment and residential location. To confirm the consistency of our findings, we undertook six separate sensitivity analyses. For determining the ideal sleep duration and bedtime in relation to cognitive performance, we used the restricted cubic splines (RCS) approach with four knots, which is proficient in detecting complex patterns and capturing curvature between variables. To captures the variability of individuals effectively in the panel data, which consists of observations of individuals at different time points, subsequent analyses employed mixed-effects Poisson regression with random intercept and fixed slope to probe into the relation between sleep patterns, bedtime, and cognitive abilities using the optimization algorithm BOBYQA (Bound Optimization BY Quadratic Approximation). To neutralize the effects of external factors, we used propensity score matching (PSM) to pair specific demographics with 1:1 matching and the nearest-neighbor matching method, utilizing random forest to compute the propensity score, to ensure well-balanced characteristics between individuals with optimal sleep patterns and those without optimal sleep, and t-tests were carried out for analytical comparisons. All statistical evaluations were executed using the R programming platform using packages of stats, lme 4 and MatchIt. A bidirectional criterion was employed for all testing, setting $p < 0.05$ as the threshold for determining statistical relevance.

3. Results

3.1. Characteristics of study participants

A total of 175,702 observations were included in our study, with 22,848 observations having cognitive function test data. The cognitive test data included sleep duration and bedtime, with a total of 22,846 observations from four surveys conducted between 2014 and 2020. Each survey had 8,764, 6,608, 5,594, and 1882 observations, respectively. The average age of the participants was 54.87 ± 19.37. Among them, there were 8387 male participants with an average education duration of 6.83 years and an average sleep duration of 7.56 h. In 2016 and 2020, the cognitive function tests employed the Immediate Word Recall Test (IWR), Delayed Word Recall Test (WDR), and Number Series Test (NST), with a total of 8490 observations. In 2014 and 2018, the vocabulary test and mathematics test were used for cognitive function assessment, with a total of 14,358 observations (Table 1). Therefore, we analyzed

Table 1
Characteristics of study participants. Data were presented as means ± SD for normally distributed variables and numbers (percentages) for categorical variables.

Variables	Overall	2014	2016	2018	2020
Sample size	22,848	8764	6608	5594	1882
Age, years	54.87 (19.37)	52.33 (20.59)	53.68 (20.31)	60.09 (15.95)	55.39 (16.17)
Male, n (%)	8387 (36.7)	3117 (35.6)	2410 (36.5)	1969 (35.2)	891 (47.3)
Education level, years	6.83 (4.91)	7.09 (4.93)	7.22 (5.01)	6.42 (4.75)	5.43 (4.59)
Sleep duration, hours	7.56 (1.82)	7.73 (1.84)	7.55 (1.84)	7.33 (1.85)	7.53 (1.51)
Bedtime					
≤22:00	17,477 (76.5)	6674 (76.2)	4937 (74.7)	4344 (77.7)	1522 (80.9)
>22:00 to 23:00	3676 (16.1)	1451 (16.6)	1132 (17.1)	861 (15.4)	232 (12.3)
>23:00 to 1:00	1560 (6.8)	595 (6.8)	495 (7.5)	356 (6.4)	114 (6.1)
>1:00	135 (0.6)	44 (0.5)	44 (0.7)	33 (0.6)	14 (0.7)
Immediate word recall score	4.35 (2.04)		4.47 (2.05)		3.95 (1.94)
Delayed word recall score	3.53 (2.27)		3.57 (2.32)		3.35 (2.07)
Number series test score	5.17 (4.57)		5.42 (4.70)		4.27 (3.99)
Vocabulary test score	16.41 (11.34)	16.40 (11.62)		16.43 (10.89)	
Mathematic test score	8.83 (6.54)	9.88 (7.05)		7.18 (5.23)	

the data from 2016 to 2020 together and the data from 2014 to 2018 separately for further analysis (Table 2) (see Fig. 1).

3.2. Possible optimal patterns of sleep duration and bedtime on cognition

The impact of sleep duration on cognitive ability was examined through the Restricted Cubic Spline (RCS) model. The results showed that the optimal sleep durations for IWR, WDR, and NST were 6.53 h, 6.6 h, and 6.75 h, respectively. For the vocabulary test and mathematics test, the optimal sleep durations were 6.39 h and 8.06 h, respectively (Fig. 2). Generally, the best sleep duration for cognitive performance fell within the 6–7 h bracket. Hence, we categorized sleep duration into four segments for a more detailed analysis: less than 6 h, 6–7 h, 7–8 h, and more than 8 h.

We found that the optimal bedtimes for IWR, WDR, and NST were 22.55, 22.67, and 24:00, respectively. For the vocabulary test and mathematics test, the optimal bedtime was consistently 24:00 (Fig. 3). The optimal bedtime for cognitive function was generally in the range of 22:00–23:00. Therefore, we divided the bedtime into the following intervals for analysis: ≤22:00, 22:00–23:00, 23:00–1:00, and >1:00.

3.3. Longitudinal impact of sleep duration and bedtime on cognition

We focused on participants who underwent cognitive function tests in both 2016 and 2020 (n = 1310) and participants who underwent tests in both 2014 and 2020 (n = 4618) (Tables 2 and Tables 3). The results showed that sleep duration four years ago did not have a significant impact on IWR and WDR scores ($p > 0.05$). For the NST, those who slept for 7–8 h (IRR 0.795, 95 % CI: 0.691, 0.916, $p < 0.05$) and more than 8 h (IRR 0.710, 95 % CI: 0.601, 0.837, $p < 0.05$) exhibited notably lower NST scores than individuals who slept for 6–7 h. For the vocabulary test, individuals with sleep durations less than 6 h (IRR 0.927, 95 % CI: 0.908,0.948, $p < 0.05$), 7–8 h (IRR 0.969, 95 % CI: 0.945,0.994, $p < 0.05$), and >8 h (IRR 0.899, 95 % CI:0.873,0.926, $p < 0.05$) had significantly lower scores compared to those with sleep durations of 6–7 h. For the mathematics test, individuals with sleep durations less than 6 h (IRR 0.929, 95 % CI: 0.899,0.961, $p < 0.05$) and >8 h (IRR 0.940, 95 % CI: 0.899,0.983, $p < 0.05$) had significantly lower scores compared to those with sleep durations of 6–7 h.

The results showed that bedtime four years ago did not have a significant impact on IWR, WDR, and NST scores ($p > 0.05$). However, compared to individuals with a bedtime between 22:00 and 23:00, those with earlier bedtimes had significantly lower scores on the vocabulary test (IRR 0.978, 95 % CI: 0.958,0.998, $p < 0.05$) and mathematics test (IRR 0.847, 95 % CI: 0.716,0.995, $p < 0.05$).

These results indicate that sleep duration four years ago can affect current cognition, with a wider range of impacts on cognition observed for sleep duration.

3.4. Associations of sleep duration and bedtime with cognition

The influence of a variety of factors on sleep duration and cognitive function was also examined in this study. The characteristics of the study participants and other variables can be seen in Table 4. After adjusting for potential confounding variables (smoking, drinking, napping, marital status, urban residence, and BMI), the following associations were observed (Table 5) .

In terms of IWR, there was no notable difference between people who slept less than 6 h and those who slept 6–7 h. However, individuals who slept for 7–8 h (IRR 0.955, 95 % CI: 0.914,0.997, $p < 0.05$) and those who slept more than 8 h (IRR 0.915, 95 % CI: 0.871,0.961, $p < 0.05$) demonstrated significantly reduced scores in cognitive function tests. Similar results were observed for Delayed Word Recall, where individuals sleeping 7–8 h (IRR 0.926, 95 % CI: 0.884,0.969, $p < 0.05$) and more than 8 h (IRR 0.888, 95 % CI: 0.843,0.935, $p < 0.05$) showed significantly lower cognitive function scores compared to those with a sleep duration of 6–7 h. Only individuals sleeping more than 8 h had lower scores on the Number Series Test (IRR 0.899, 95 % CI: 0.841,0.962, $p < 0.05$). However,

Table 2
Characteristics of study participants for longitudinal impact. Data were presented as means ± SD for normally distributed variables and numbers (percentages) for categorical variables.

Variables	Overall	2014&2018	2016&2020
Sample size	5928	4618	1310
Age, years	60.64 (14.65)	61.38 (14.71)	58.02 (14.12)
Male, n (%)	2270 (38.3)	1648 (35.7)	622 (47.5)
Education level, years	6.23 (4.67)	6.52 (4.70)	5.21 (4.43)
Sleep duration, hours	7.33 (1.79)	7.28 (1.86)	7.48 (1.49)
Bedtime, n (%)			
≤22:00	4743 (80.0)	3646 (79.0)	1097 (83.7)
>22:00 to 23:00	834 (14.1)	681 (14.7)	153 (11.7)
>23:00 to 1:00	324 (5.5)	269 (5.8)	55 (4.2)
>1:00	27 (0.5)	22 (0.5)	5 (0.4)
Immediate word recall score	3.86 (1.86)		3.86 (1.86)
Delayed word recall score	3.23 (1.99)		3.23 (1.99)
Number series test score	4.10 (3.83)		4.10 (3.83)
Vocabulary test score	16.71 (10.67)	16.71 (10.67)	
Mathematic test score	7.16 (5.04)	7.16 (5.04)	

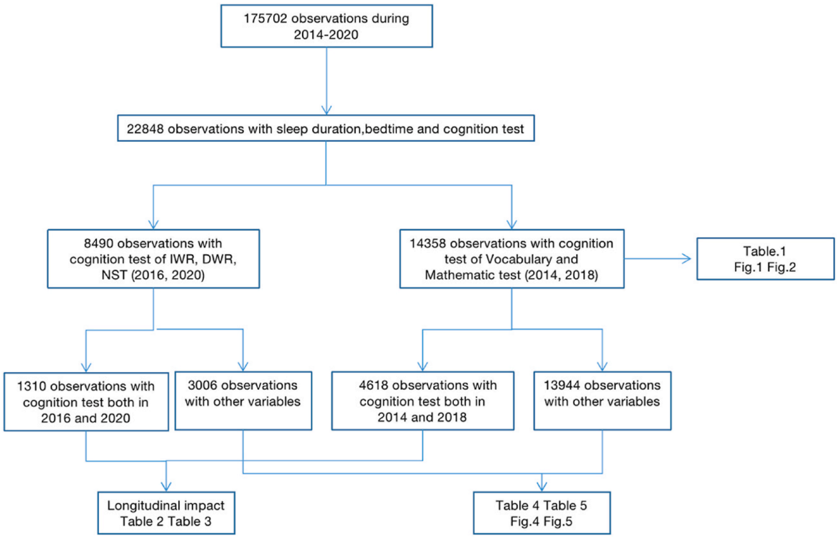

Fig. 1. Flow diagram of subject recruitment.

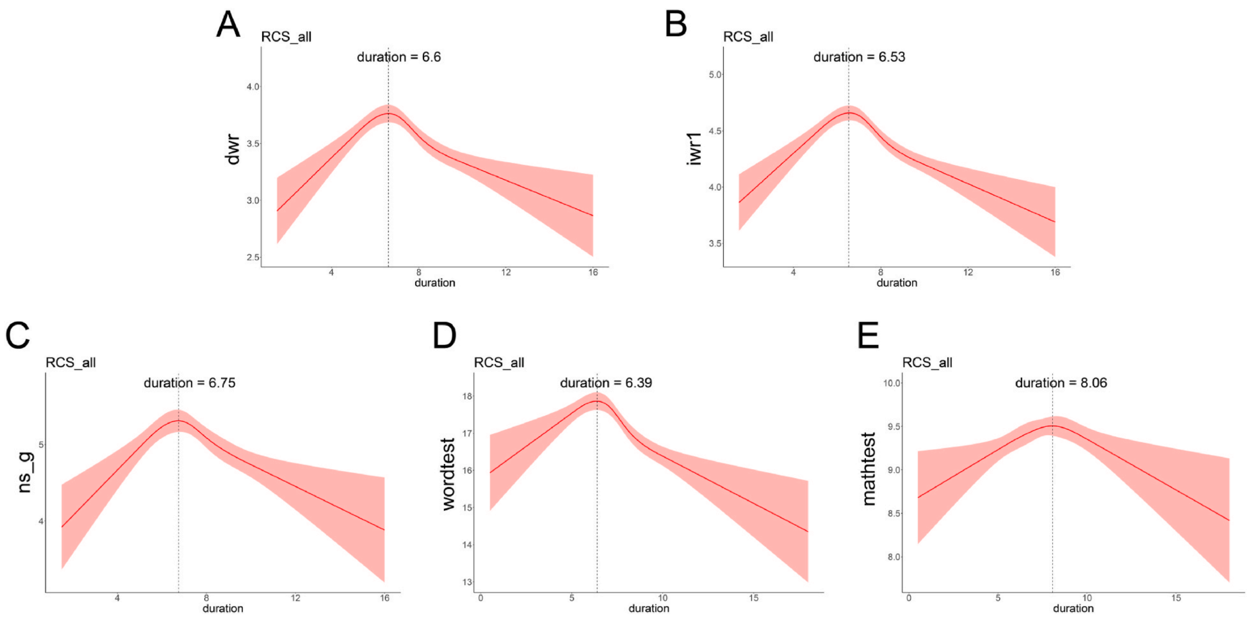

Fig. 2. Restricted cubic spline for associations of sleep duration with cognitive ability.
Model adjusted for age, gender, and education level. A. Immediate word recall; B. Delayed word recall; C. Number series test; D. Vocabulary test score; E. Mathematic test score.

no significant differences were found for Vocabulary Test scores and Mathematical Test scores.

After adjusting for other variables (smoking, drinking, napping, marital status, urban residence, and BMI), we examined the association between bedtime and cognitive function. No significant differences were found in Immediate Word Recall, Delayed Word Recall, or Number Series Test scores. However, when using Vocabulary Test scores as the outcome measure, individuals who went to bed before 22:00 had the lowest scores (IRR 0.940, 95 % CI: 0.916,0.964, $p < 0.05$). For Mathematical Test scores, going to bed before 22:00 (IRR 0.959, 95 % CI: 0.939,0.980, $p < 0.05$) and between 23:00–1:00 (IRR 0.960, 95 % CI: 0.928,0.993, $p < 0.05$) were associated with lower scores.

These results suggest that a sleep duration of 6–7 h and a bedtime between 22:00–23:00 are optimal for cognitive function.

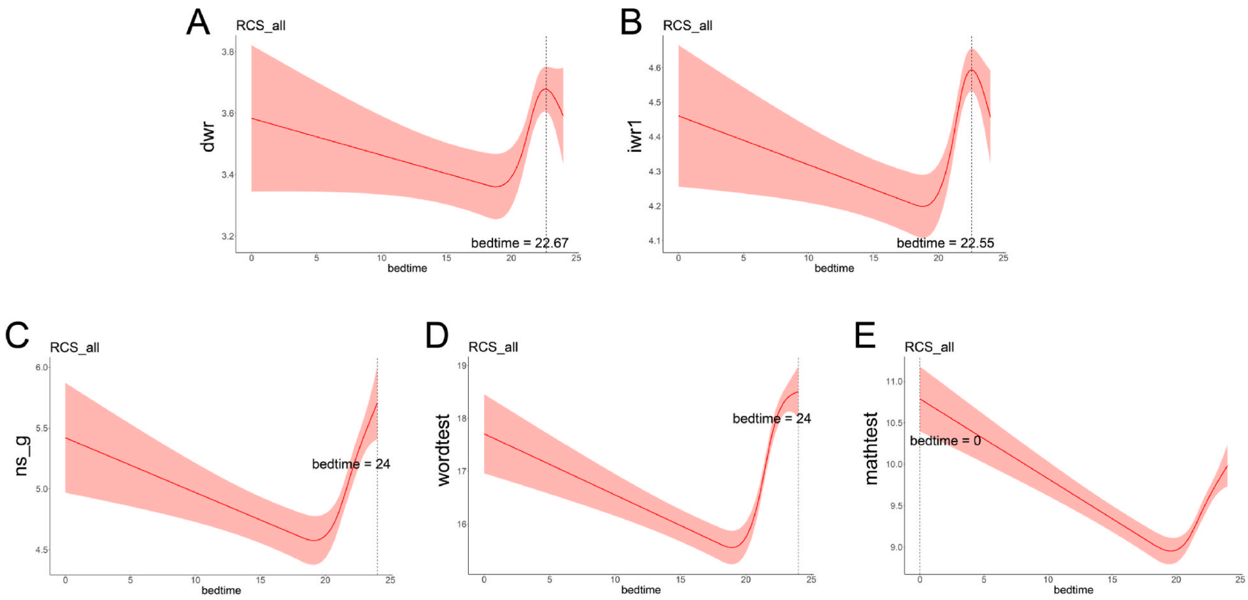

Fig. 3. Restricted cubic spline for associations of bedtime with cognitive ability.
Model adjusted for age, gender, and education level. A. Immediate word recall; B. Delayed word recall; C. Number series test; D. Vocabulary test score; E. Mathematic test score.

3.5. Associations of sleep duration and bedtime with cognition in subgroups

To further investigate the effects in different populations, we conducted subgroup analyses based on age, gender, and urban residence. The optimal sleep duration differed between younger and older age groups. For example, regarding IWR, the optimal sleep duration was 7.21 h for people under 65 years old and 5.99 h for those over 65 years old. No significant gender differences were observed. Interestingly, urban residents had an optimal sleep duration of 8.04 h, Interestingly, urban residents required an optimal sleep duration of 8.04 h, while non-urban residents had an optimal sleep duration of 6.75 h. Different educational levels did not appear to influence these results. (Fig. 4)

3.6. Propensity score matching (PSM) analysis

To enhance the credibility of our results, we performed PSM analysis to further match confounding factors, including age, gender, education attainment, marital status, smoking behavior, drinking behavior, midday rest, hukou (household registration) and BMI. After matching, confounding factors were significantly reduced (Fig. 5A–E). Taking those who slept for 6–7 h as a baseline, after accounting for other confounding variables, there were no marked differences in scores for Immediate Word Recall, Delayed Word Recall, or the Number Series Test in terms of cognitive performance. This may be due to the smaller number of individuals included in these tests after matching. However, for Vocabulary Test and Mathematical Test scores, which had a larger sample size, individuals with a sleep duration of 6–7 h still had higher scores and significant differences were observed. Regarding bedtime, regardless of the outcome measure used, going to bed between 22:00–23:00 remained optimal.

4. Discussion

In this investigation, we delved into participant characteristics and identified potential ideal sleep durations and bedtimes impacting cognitive performance. Furthermore, we scrutinized the longitudinal impacts of sleep habits on cognitive prowess and meticulously examined the interplay between cognitive function, bedtime, and sleep duration, all while adjusting for potential intervening factors. Moreover, we carried out subgroup evaluations focused on variables such as age, gender, and urban living to examine the impact on diverse demographic groups. Ultimately, we executed PSM analysis to bolster the reliability of our findings.

To explore the influence of sleep duration on cognitive prowess, the RCS approach was put to use. Our findings indicated that the best sleep durations for distinct cognitive tests fluctuated slightly, predominantly hovering around 6–7 h. However, for the vocabulary test, the optimal sleep duration was 6.39 h, while for the mathematics test, it was 8.06 h. The data suggests that an optimal amount of sleep can benefit cognitive abilities. Previous studies have demonstrated that the relationship between sleep length and cognitive function variations remains contentious. Some studies suggest that LSD at baseline may result in a quicker deterioration of cognitive skills, whereas others indicate it doesn't lead to a rapid decrease in these abilities. A previous research highlighted that both brief and extended sleep durations might be linked to poorer cognitive results, evidenced by a U-shaped or non-linear correlation between the

Table 3
Longitudinal impact of sleep duration and bedtime on cognitive function (n = 1310).

	Immediate word recall				Delayed word recall				Number series test			
	Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
	IRR (95 % CI)	*p-value*	*IRR (95 % CI)*	*p-value*	*IRR (95 % CI)*	*p-value*	*IRR (95 % CI)*	*p-value*	*IRR (95 % CI)*	*p-value*	*IRR (95 % CI)*	*p-value*
Duration <6h	0.900 (0.831,0.975)	**0.010**	0.966 (0.891,1.047)	0.397	0.840 (0.770,0.916)	**<0.001**	0.926 (0.849,1.011)	0.087	0.890 (0.825,0.960)	**0.003**	1.022 (0.947,1.102)	0.583
Duration 6–7h	reference											
Duration 7–8h	0.972 (0.903,1.047)	0.454	0.958 (0.889,1.031)	0.252	0.927 (0.855,1.004)	0.061	0.902 (0.833,0.977)	**0.012**	0.952 (0.887,1.022)	0.175	0.959 (0.893,1.030)	0.246
Duration >8h	0.788 (0.723,0.859)	**<0.001**	0.835 (0.765,0.911)	**<0.001**	0.738 (0.671,0.811)	**<0.001**	0.783 (0.712,0.861)	**<0.001**	0.681 (0.624,0.742)	**<0.001**	0.812 (0.744,0.886)	**<0.001**
Lagged-Duration <6h	1.051 (0.925,1.200)	0.452	0.984 (0.865,1.126)	0.815	1.076 (0.935,1.246)	0.314	0.964 (0.836,1.118)	0.617	0.828 (0.740,0.929)	**0.001**	0.783 (0.698,0.880)	**<0.001**
Lagged-Duration 6–7h	reference											
Lagged-Duration 7–8h	1.011 (0.864,1.184)	0.894	0.945 (0.808,1.108)	0.485	0.957 (0.804,1.142)	0.620	0.863 (0.724,1.030)	0.100	0.887 (0.772,1.022)	0.095	0.795 (0.691,0.916)	**0.001**
Lagged-Duration >8h	1.006 (0.847,1.195)	0.950	1.008 (0.849,1.199)	0.924	1.000 (0.827,1.210)	1.000	0.990 (0.818,1.199)	0.916	0.706 (0.598,0.832)	**<0.001**	0.710 (0.601,0.837)	**<0.001**
	reference											
Bedtime≤22:00	0.899 (0.823,0.983)	**0.019**	0.994 (0.909,1.088)	0.888	0.836 (0.761,0.921)	**<0.001**	0.959 (0.872,1.057)	0.395	0.805 (0.741,0.875)	**<0.001**	0.976 (0.898,1.062)	0.572
Bedtime>22:00 to 23:00	reference											
Bedtime>23:00 to 1:00	0.988 (0.847,1.147)	0.871	0.900 (0.772,1.045)	0.170	1.009 (0.856,1.185)	0.913	0.893 (0.758,1.048)	0.171	1.091 (0.952,1.248)	0.205	0.866 (0.756,0.991)	**0.037**
Bedtime >1:00	1.267 (0.829,1.852)	0.247	1.020 (0.659,1.510)	0.926	1.258 (0.798,1.885)	0.294	0.927 (0.577,1.417)	0.740	1.748 (1.252,2.374)	**0.001**	1.080 (0.757,1.497)	0.659
Lagged-Bedtime≤22:00	0.858 (0.791,0.933)	**<0.001**	0.941 (0.866,1.024)	0.154	0.892 (0.815,0.978)	**0.014**	0.999 (0.913,1.096)	0.989	0.791 (0.732,0.855)	**<0.001**	0.976 (0.902,1.057)	0.544
Lagged-Bedtime>22:00 to 23:00	reference											
Lagged-Bedtime>23:00 to 1:00	1.016 (0.869,1.184)	0.836	1.058 (0.905,1.232)	0.472	0.951 (0.797,1.127)	0.566	1.006 (0.845,1.192)	0.944	0.836 (0.720,0.967)	**0.018**	0.886 (0.764,1.025)	0.107
Lagged-Bedtime>1:00	0.984 (0.542,1.640)	0.954	1.199 (0.653,2.030)	0.528	1.206 (0.661,2.020)	0.509	1.567 (0.844,2.691)	0.126	0.915 (0.544,1.440)	0.718	1.156 (0.672,1.876)	0.577

	Vocabulary test				Mathematic test			
	Model 1		Model 2		Model 1		Model 2	
	IRR (95 % CI)	*p-value*	*IRR (95 % CI)*	*p-value*	*IRR (95 % CI)*	*p-value*	*IRR (95 % CI)*	*p-value*
Duration <6h	0.922 (0.903,0.941)	**<0.001**	1.046 (1.025,1.068)	**<0.001**	0.861 (0.835,0.889)	**<0.001**	1.008 (0.977,1.041)	0.609
Duration 6–7h	reference							
Duration 7–8h	1.017 (0.997,1.038)	0.104	1.003 (0.983,1.024)	0.766	1.043 (1.012,1.076)	**0.007**	1.009 (0.978,1.041)	0.575
Duration >8h	0.814 (0.795,0.835)	**<0.001**	0.921 (0.898,0.944)	**<0.001**	0.853 (0.822,0.885)	**<0.001**	0.967 (0.932,1.004)	0.079
Lagged-Duration <6h	0.886 (0.867,0.905)	**<0.001**	0.927 (0.908,0.948)	**<0.001**	0.903 (0.873,0.933)	**<0.001**	0.929 (0.899,0.961)	**<0.001**
Lagged-Duration 6–7h	reference							
Lagged-Duration 7–8h	0.939 (0.916,0.962)	**<0.001**	0.969 (0.945,0.994)	**0.013**	0.980 (0.944,1.018)	0.305	1.003 (0.965,1.042)	0.881
Lagged-Duration >8h	0.812 (0.788,0.836)	**<0.001**	0.899 (0.873,0.926)	**<0.001**	0.860 (0.822,0.899)	**<0.001**	0.940 (0.899,0.983)	**0.007**
	reference							
Bedtime≤22:00	0.823 (0.806,0.839)	**<0.001**	0.974 (0.955,0.994)	**0.011**	0.789 (0.765,0.814)	**<0.001**	0.975 (0.946,1.006)	0.108
Bedtime>22:00 to 23:00	reference							
Bedtime>23:00 to 1:00	1.030 (0.998,1.063)	0.067	0.972 (0.941,1.003)	0.080	1.032 (0.983,1.083)	0.201	0.957 (0.911,1.004)	0.071
Bedtime >1:00	0.903 (0.814,0.998)	0.050	0.925 (0.833,1.023)	0.135	0.818 (0.691,0.960)	**0.016**	0.847 (0.716,0.995)	**0.048**
Lagged-Bedtime≤22:00	0.844 (0.827,0.861)	**<0.001**	0.978 (0.958,0.998)	**0.028**	0.854 (0.828,0.881)	**<0.001**	1.010 (0.980,1.042)	0.516
Lagged-Bedtime>22:00 to 23:00	reference							
Lagged-Bedtime>23:00 to 1:00	0.961 (0.928,0.994)	**0.023**	0.993 (0.959,1.028)	0.689	0.979 (0.929,1.032)	0.427	1.017 (0.964,1.071)	0.540
Lagged-Bedtime>1:00	0.934 (0.852,1.021)	0.137	0.944 (0.861,1.032)	0.212	0.974 (0.847,1.113)	0.701	0.982 (0.854,1.122)	0.791

Note. Model 1: crude model, Model 2: adjusted age, gender, education level.

Table 4
Characteristics of study participants with other variables. Data were presented as means ± SD for normally distributed variables and numbers (percentages) for categorical variables.

Variables	Overall	2014	2016	2018	2020
Sample size	16,950	8481	1197	5463	1809
Age, years	52.67 (20.22)	51.89 (20.53)	21.42 (4.29)	59.93 (15.94)	55.05 (16.19)
Male, n (%)	6343 (37.4)	3054 (36.0)	465 (38.8)	1951 (35.7)	873 (48.3)
Education level, years	7.17 (4.91)	7.24 (4.89)	12.09 (2.89)	6.52 (4.74)	5.56 (4.58)
Smoking, n (%)	3104 (18.3)	1438 (17.0)	94 (7.9)	1054 (19.3)	518 (28.6)
Drinking, n (%)	1673 (9.9)	759 (8.9)	32 (2.7)	596 (10.9)	286 (15.8)
Rural, n (%)	10,260 (60.5)	4789 (56.5)	902 (75.4)	3110 (56.9)	1459 (80.7)
Snap, n (%)	9875 (58.3)	4762 (56.1)	669 (55.9)	3385 (62.0)	1059 (58.5)
Marriage, n (%)	11,987 (70.7)	5886 (69.4)	283 (23.6)	4311 (78.9)	1507 (83.3)
BMI, kg/m^2	22.70 (3.68)	22.47 (3.61)	21.01 (3.21)	23.31 (3.68)	23.09 (3.79)
Sleep duration, hours	7.60 (1.78)	7.73 (1.82)	8.12 (1.36)	7.33 (1.84)	7.50 (1.48)
Bedtime, n (%)					
≤22:00	12,691 (74.9)	6418 (75.7)	592 (49.5)	4225 (77.3)	1456 (80.5)
>22:00 to 23:00	2894 (17.1)	1433 (16.9)	382 (31.9)	852 (15.6)	227 (12.5)
>23:00 to 1:00	1263 (7.5)	588 (6.9)	209 (17.5)	354 (6.5)	112 (6.2)
>1:00	102 (0.6)	42 (0.5)	14 (1.2)	32 (0.6)	14 (0.8)
Immediate word recall score	4.95 (2.09)		6.35 (1.47)		4.02 (1.92)
Delayed word recall score	4.33 (2.27)		5.71 (1.83)		3.41 (2.06)
Number series test score	6.67 (4.85)		10.11 (3.91)		4.40 (4.00)
Vocabulary test score	16.74 (11.25)	16.78 (11.52)		16.68 (10.82)	
Mathematic test score	8.99 (6.51)	10.09 (7.00)		7.29 (5.22)	

Table 5
Joint associations of sleep duration and bedtime with cognitive ability.

	Immediate word recall						Delayed word recall						Number series test					
	Model 1		Model 2		Model 3		Model 1		Model 2		Model 3		Model 1		Model 2		Model 3	
	IRR (95% CI)	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*
Duration <6h	0.857 (0.813,0.904)	**<0.001**	0.973 (0.922,1.027)	0.322	0.972 (0.921,1.026)	0.306	0.814 (0.766,0.864)	**<0.001**	0.946 (0.893,1.003)	0.061	0.945 (0.892,1.002)	0.057	0.759 (0.683,0.844)	**<0.001**	1.002 (0.930,1.079)	0.960	1.002 (0.930,1.078)	0.965
Duration 6-7h	reference																	
Duration 7-8h	1.020 (0.977,1.065)	0.367	0.953 (0.913,0.995)	**0.028**	0.955 (0.914,0.997)	**0.035**	1.005 (0.958,1.054)	0.844	0.925 (0.883,0.968)	**0.001**	0.926 (0.884,0.969)	**0.001**	1.062 (0.974,1.158)	0.173	0.948 (0.893,1.006)	0.077	0.955 (0.899,1.013)	0.125
Duration >8h	0.943 (0.899,0.990)	**0.018**	0.911 (0.868,0.957)	**<0.001**	0.915 (0.871,0.961)	**<0.001**	0.931 (0.882,0.983)	**0.009**	0.886 (0.841,0.933)	**<0.001**	0.888 (0.843,0.935)	**<0.001**	0.890 (0.808,0.980)	**0.017**	0.890 (0.832,0.952)	**0.001**	0.899 (0.841,0.962)	**0.002**
Bedtime≤22:00	0.784 (0.754,0.815)	**<0.001**	0.998 (0.957,1.040)	0.906	0.999 (0.958,1.041)	0.953	0.764 (0.731,0.799)	**<0.001**	1.008 (0.965,1.054)	0.719	1.006 (0.962,1.052)	0.794	0.558 (0.515,0.604)	**<0.001**	0.958 (0.905,1.013)	0.134	0.968 (0.914,1.025)	0.261
Bedtime>22:00 to 23:00	reference																	
Bedtime>23:00 to 1:00	1.023 (0.967,1.082)	0.425	0.976 (0.923,1.033)	0.404	0.968 (0.915,1.025)	0.269	1.028 (0.965,1.095)	0.396	0.975 (0.918,1.035)	0.402	0.969 (0.913,1.030)	0.312	1.077 (0.960,1.207)	0.205	0.928 (0.859,1.002)	0.057	0.930 (0.861,1.005)	0.066
Bedtime >1:00	1.113 (0.955,1.298)	0.170	1.033 (0.886,1.205)	0.678	1.016 (0.870,1.186)	0.841	1.225 (1.036,1.449)	**0.018**	1.123 (0.960,1.314)	0.147	1.105 (0.944,1.295)	0.214	1.357 (0.982,1.876)	0.064	1.057 (0.856,1.305)	0.606	1.046 (0.847,1.291)	0.679

	Vocabulary test						Mathematic test					
	Model 1		Model 2		Model 3		Model 1		Model 2		Model 3	
	IRR (95% CI)	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*	*IRR (95% CI)*	*p-value*
Duration <6h	0.999 (0.971,1.027)	0.920	1.057 (1.030,1.085)	**<0.001**	1.062 (1.034,1.090)	**<0.001**	0.842 (0.814,0.872)	**<0.001**	0.980 (0.955,1.004)	0.104	0.986 (0.962,1.011)	0.281
Duration 6-7h	reference											
Duration 7-8h	1.037 (1.010,1.065)	**0.007**	1.013 (0.988,1.038)	0.311	1.018 (0.994,1.043)	0.139	1.039 (1.007,1.073)	**0.018**	1.000 (0.977,1.022)	0.966	1.005 (0.982,1.028)	0.668
Duration >8h	0.999 (0.967,1.033)	0.969	0.993 (0.964,1.023)	0.636	1.004 (0.975,1.034)	0.788	0.961 (0.925,0.998)	**0.038**	0.977 (0.952,1.003)	0.081	0.991 (0.966,1.017)	0.505
Bedtime≤22:00	0.819 (0.796,0.843)	**<0.001**	0.939 (0.915,0.963)	**<0.001**	0.940 (0.916,0.964)	**<0.001**	0.708 (0.685,0.731)	**<0.001**	0.953 (0.932,0.974)	**<0.001**	0.959 (0.939,0.980)	**<0.001**
Bedtime>22:00 to 23:00	reference											
Bedtime>23:00 to 1:00	1.055 (1.010,1.103)	**0.017**	0.958 (0.921,0.997)	**0.035**	0.962 (0.925,1.001)	0.054	1.102 (1.047,1.160)	**<0.001**	0.956 (0.924,0.989)	**0.009**	0.960 (0.928,0.993)	**0.018**
Bedtime >1:00	1.124 (0.984,1.284)	0.084	1.032 (0.915,1.164)	0.607	1.048 (0.929,1.181)	0.445	1.058 (0.901,1.242)	0.494	0.930 (0.835,1.035)	0.184	0.928 (0.833,1.033)	0.173

Note. Model 1: crude model. Model 2: adjusted age, gender, education level. Model 3: adjusted age, gender, education level + smoke, drinking, snap, marriage, and BMI.

length of sleep and cognitive performance [2,15]. Our research verified the U-shaped correlation between the length of sleep and alterations in cognitive abilities, precisely determining the optimal sleep duration to be around 6–7 h. This provides strong support for guiding people's lives.

Our results indicated that the optimal bedtimes for most cognitive function tests fell within the range of 22:00–23:00. However, for the vocabulary test and mathematics test, the optimal bedtime was consistently 24:00. Interestingly, this implies that retiring early for the night might adversely affect cognitive abilities, challenging popular beliefs. Our study diverges in some ways from prior research. Some studies have been done on the effect of bedtime on cognitive function, but no conclusive conclusions have been reached [16]. A

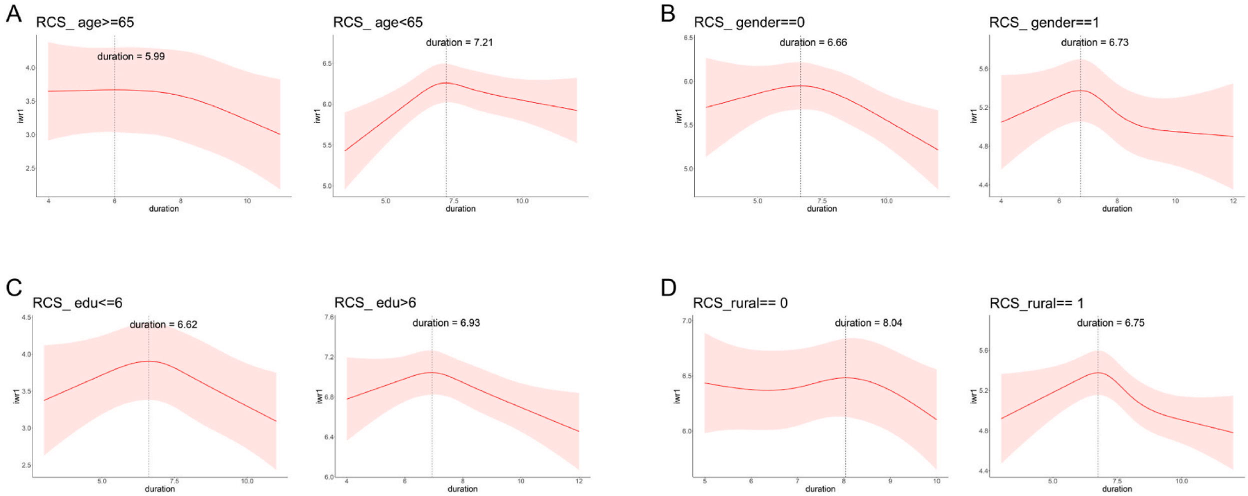

Fig. 4. Subgroup analyze of restricted cubic spline for associations of sleep duration with cognitive ability.
Immediate word recall Model adjusted for age, gender, education level. A. Age B. Gender C. Education level D. Rural.

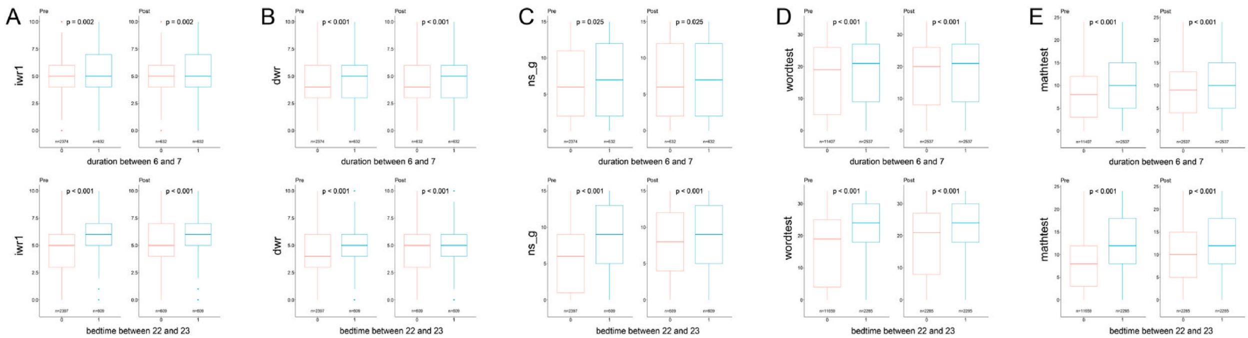

Fig. 5. Propensity score matching for associations of sleep duration, bedtime with cognitive ability.
Model adjusted for age, gender, education level, smoke, drinking, snap, marriage, and BMI. A. Immediate word recall; B. Delayed word recall; C. Number series test; D. Vocabulary test score; E. Mathematic test score.

study revealed a significant correlation between retiring early and the midpoint of sleep with the occurrence of AD [17]. A study conducted over time revealed an absence of a significant link between sleep patterns and cognitive skills [18]. It's pivotal to highlight that other determinants could be playing a role in this observation, warranting further in-depth study to decipher the inherent causes. Sleep duration is greatly influenced by regional lifestyle habits. Our study focused on the lifestyle habits of Chinese individuals and identified the optimal bedtime, providing evidence to support the reduction of cognitive impairments occurrence.

The longitudinal analysis revealed that sleep duration four years ago had a significant impact on current cognition for some cognitive function tests. Notably, those who rested for under 6 h, between 7 and 8 h, or beyond 8 h demonstrated lower scores in vocabulary and math tests as opposed to individuals who slept in the 6–7 h range. However, sleep duration four years ago did not significantly impact Immediate Word Recall and Delayed Word Recall scores. This underscores the idea that the effect of sleep length on cognition might differ based on the specific cognitive area under consideration. Comparable findings have been documented in other research endeavors [2,15,19]. However, most of their studies concluded that the optimal sleep duration is between 6 and 8 h, while our results indicate it to be around 6–7 h. Various possible explanations can be proposed for their discrepancy. Firstly, a shorter sleep duration can lead to increased levels of stress hormones , which is associated with a decline in cognitive abilities. Secondly, longer durations of sleep might increase inflammatory marker levels [20] and mental disorders such as anxiety or depression [21,22] , which can further contribute to a decline in cognitive function. Additionally, a shorter sleep duration with average sleep quality is also detrimental to cognitive abilities. Short durations of sleep may interfere with the body's internal clock, which is linked to decreased cognitive capabilities [23].

Bedtime four years ago did not have a significant impact on most cognitive function tests, except for the vocabulary test and mathematics test. Individuals who went to bed before 22:00 had lower scores in these tests compared to those with bedtime between 22:00–23:00. This unexpected finding indicates the presence of other factors that may interact with bedtime and affect cognitive function. Regarding the optimal sleep timing, there has been relatively little research conducted in the past. The scarcity of research on the ideal sleep timing could be due to major factors like regional differences, educational backgrounds, and cultural variances. The optimal bedtime may vary across different regions. Our study focuses on the specific circumstances of the Chinese population and has identified the optimal sleep timing, providing a reference range for the Chinese population.

To control for the confounding effects of confounding variables, we implemented measures to control for these factors. Numerous research papers have indicated that disturbances in the circadian rhythm can result in disorders associated with the body's internal clock, which can manifest as issues like raised blood sugar levels, weight gain, hypertension, and abnormal blood lipid levels [24]. It's recognized that all these circumstances correlate with cognitive performance. When we accounted for potential intervening factors like smoking habits, alcohol consumption, daytime naps, marital status, living in urban settings, and BMI, we noticed pronounced links between sleep length, bedtime, and cognitive capacities. In particular, we identified that sleep durations of 7–8 h and beyond 8 h correlated with diminished cognitive scores in certain tests (IWR, WDR) relative to those who got 6–7 h of rest. Additionally, individuals who went to bed before 10:00 p.m. scored lower on the vocabulary tests and mathematics test. Studies have illuminated that both insufficient and extended sleep durations, coupled with erratic circadian patterns, can predispose individuals to neural disorders, including dementia [25]. According to reports, sleep-related circadian rhythms can influence aspects tied to neurodegenerative changes, such as the dynamics of Aβ, toxic protein clearance, synaptic homeostasis, the function of the blood-brain barrier, and neuroinflammation [26]. In light of our research, it further implied that the sleep's effect on cognitive performance isn't reliant on other risk factors such as smoking and obesity. This accentuates the need to amplify knowledge regarding the pivotal role of sleep.

Subgroup analyses based on age, gender, and urban residence yielded interesting findings. The optimal sleep duration differed between younger and older age groups, with younger individuals requiring more sleep for optimal cognitive function. This aligns with prior research outcomes. Some investigations have highlighted a link between longer sleep and enhanced cognitive performance in children [27]. Conversely, extended sleep in the elderly has been linked to a decline in cognitive capabilities [28]. The rationale behind this link suggests that longer sleep can indicate fragmented sleep or signs of neurodegeneration [29]. Moreover, extended sleeping periods may lead to disruptions in circadian rhythms associated with sleep disorders and cognitive impairments [30,31]. Regarding IWR, the optimal sleep duration was 7.21 h for people under 65 years old and 5.99 h for those over 65 years old. In previous studies, there have been observed gender-based variations in cognitive performance and sleep habits, but the results from studies have not always been consistent [32]. For example, one research indicated that lack of sleep affects the working memory in females but not in male [32]. However, another study suggests that sleep deprivation in males may have a greater impact on certain aspects of cognition. But our research suggests that no significant gender differences were observed in optimal sleep duration. Urban residents had a longer optimal sleep duration compared to non-urban residents. Levels of education didn't seem to impact the connection between sleep and cognitive performance. Earlier research has identified a link between residing in metropolitan regions, possessing advanced education, and superior mental health and memory function scores [28]. The brain possesses the capability to adjust to difficulties, suggesting that cognitive abilities can be amplified by engaging in intellectually stimulating activities that challenge the brain [33,34]. In comparison to those in rural settings, urban dwellers typically have a higher education level and are expected to exhibit better cognitive performance. However, our study did not find such differences. One possible reason for this could be that people living in urban areas are exposed to additional potential cognitive-impairing factors that counteract the positive effects of education.

In order to mitigate concerns regarding the impact of the sample heterogeneity on our findings, we additionally performed PSM analysis to control for confounding factors. After matching, individuals who slept between 6 and 7 h consistently outperformed others in Vocabulary Test and Mathematical Test, underscoring the strong link between sleep duration and cognitive abilities. By utilizing PSM analysis, we demonstrated that this association is independent of a range of traditional risk factors for cognitive impairment. Bedtime between 22:00–23:00 remained optimal regardless of the outcome measure used. Limited studies have delved into the relationship between sleep and cognitive performance through the lens of a PSM methodology. Our research is an important supplement to the literature because we rigorously minimized the potential effects of confounding variables on the results, enhancing the credibility of our study.

Overall, previous research on sleep and cognitive function not only had certain limitations but also failed to reach a consensus. Additionally, past studies on sleep and cognitive functions were mostly conducted in affluent countries, with scant data from developing countries like China. Our study, drawing from Chinese databases, re-evaluates the U-shaped correlation between sleep duration and cognitive function in the Chinese cohort; explores the enduring link (long-term connection) between baseline sleep patterns and cognitive function; identifies the optimal sleep duration for Chinese individuals as 6–7 h rather than the 6–8 h suggested by most previous research; and uncovers other factors that influence the sleep-cognition link.

However，our study is subject to a number of limitations that should be considered. Firstly, the selection of control variables is limited. It's impossible to control all variables completely; for instance, individual talents cannot be precisely measured, thus the issue of heterogeneity remains unresolved. Individual talent, being an unobservable variable, will inevitably be included in the disturbance term, leading to the existence of heterogeneity issues. We can only minimize the impact of heterogeneity on the results as much as possible, with specific measures such as controlling for individuals' education levels. In subsequent studies, more sophisticated technological methods could be employed to address the issue of heterogeneity. Secondly, there are limitations in data collection. Relying on a single dataset might be influenced by the researcher's subjective bias. However, our current efforts are constrained by the limitations in data collection. In the future, if more datasets are available, the results could be re-validated.

5. Conclusion

In our investigation, we have gained valuable insights into the attributes of the study participants and their influence on cognitive function. We have identified potential favorable sleep duration and bedtime patterns related to cognitive function and have examined the longitudinal and subgroup associations between sleep, bedtime, and cognition. The results indicate that maintaining an intermediate sleep duration of 6–7 h and adhering to a bedtime range of 22:00–23:00 are linked to optimal cognitive function. However, in order to gain a comprehensive understanding of the underlying mechanisms and potential interplay between sleep and other contributing factors affecting cognition, further research is warranted.

6. Ethics declarations

The study adhered to the ethical guidelines of the Declaration of Helsinki and received approval from the Ethics Committee of Peking University (No. IRB00001052–14010) for all procedures involving human subjects. Written informed consent was secured from all participants. Upon reasonable request to the corresponding author, the database used in this study is available for research purposes.

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Data availability statement

The datasets utilized and/or analyzed within this research are accessible through the CFPS database (https://www.isss.pku.edu.cn/cfps/en/data/public/index.htm) and can be obtained from the corresponding authors.

Consent for publication

The authors hereby grant permission to submit the manuscript for publication.

CRediT authorship contribution statement

Mengqian Ouyang: Writing – original draft, Validation, Software, Methodology. **Tao Chen:** Writing – original draft, Software, Methodology, Data curation. **Jiawei Chen:** Writing – original draft, Software, Methodology. **Chongxu Liu:** Software, Methodology, Investigation. **Haoyu Luo:** Software, Methodology. **Shaoqing Yang:** Methodology. **Wang Liao:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Methodology, Funding acquisition, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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