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Dose-response relationship between nighttime sleep duration and intrinsic capacity declines among Chinese elderly: a cross-sectional study from CHARLS

Baiyun Zhou[1,2†], Ruijie Ma[1,2†], Mang Wang[3] and Yanmei Wang[1*]

Abstract

Background Intrinsic capacity is a crucial indicator of adverse outcomes and has predictive value for diseases and mortality. The objective of this study is to assess the association between nighttime sleep duration and intrinsic capacity in older Chinese adults.

Methods Data were collected from the China Health and Retirement Longitudinal Study (CHARLS) spanning the years 2008–2020. Minimally sufficient adjustment was made for confounding factors identified through a Directed Acyclic Graphs (DAGs), and multivariate logistic regression analysis was conducted to determine the relationship between nighttime sleep duration and intrinsic capacity. Restricted cubic splines (RCS) were used to assess the nonlinear relationship between nighttime sleep duration and intrinsic capacity in this population. Finally, subgroup analysis and interaction effect analysis were performed.

Results Among the 4994 older adults, 3118 (62.4%) experienced a decline in intrinsic capacity. After adjusting for confounding factors, nighttime sleep duration was associated with an increased risk of intrinsic capacity decline ($P < 0.001$), exhibiting a nonlinear J-shaped pattern.

Conclusions For Chinese older adults, increased nighttime sleep duration shows a nonlinear, J-shaped dose-response relationship with the risk of intrinsic capacity decline. Our study provides important insights into the intrinsic capacity and health self-management of older adults.

Keywords Older adults, Nighttime sleep duration, Intrinsic capacity, Restricted cubic spline splines

†Baiyun Zhou and Ruijie Ma contributed equally to this work.

*Correspondence:
Yanmei Wang
284626875@qq.com
[1]Department of Nursing, Gongli Hospital of Shanghai Pudong New Area, 219 Miao Pu Road, Shanghai 200135, China
[2]School of Nursing, Ningxia Medical University, Yinchuan, Ningxia 750004, China
[3]Department of Orthopedics, The Second Hospital of Jingzhou & The Geriatric Hospital of Jingzhou, Jingzhou, Hubei 434000, China

Introduction

The world is confronted with the escalating challenge of population aging. By 2050, the global population of individuals aged ≥ 60 years is anticipated to reach 2.1 billion [1]. China, in particular, has witnessed a surge in its older adults, which now stands at 264 million, accounting for 18.7% of the total population, according to the seventh national census [2]. In response, the World Health Organization (WHO) emphasizes intrinsic capacity—a multidimensional construct integrating locomotion, hearing, vision, vitality, cognition, and psychology - as a cornerstone of healthy aging [3]. This paradigm shift emphasizes preserving functional ability rather than merely extending lifespan.

Emerging evidence suggests that a strong correlation has been observed between intrinsic capacity scores and mortality risk. Specifically, a one-unit increase in the intrinsic capacity score corresponds to a roughly 2% reduction in the likelihood of death within 14 years [4]. Furthermore, the decline in intrinsic capacity often predicts adverse health outcomes, such as the deterioration of activities of daily living (ADL) and instrumental ADL (IADL) [5, 6]. Interventions such as structured exercise programs demonstrate short-term efficacy in enhancing intrinsic capacity [7], yet sustainability remains problematic. Concurrently, research has unveiled potential associations between inflammatory markers (e.g., C-reactive protein, homocysteine) and biomarkers (e.g., NT-proBNP) and intrinsic capacity [8, 9]. These findings offer new avenues for early detection and prevention of intrinsic capacity decline.

Despite progress, critical knowledge gaps persist. First, research on intrinsic capacity is still in its nascent stage with a conspicuous dearth of empirical studies centered on older adults in China. Second, while behavioral factors like physical activity are well-documented [7], sleep - a modifiable yet understudied determinant - may play a pivotal role in intrinsic capacity maintenance. Existing literature links both short (< 6 h) and prolonged (> 9 h) sleep durations to cardiovascular morbidity, cognitive decline, and immune dysfunction in older adults [10, 11]. A study conducted in Taiwan found a negative correlation between sleep duration and intrinsic capacity but with marginal statistical significance, and the sample size was limited [12]. Furthermore, this study assumed a linear relationship between sleep and health, neglecting potential threshold effects, despite the biological plausibility of nonlinear associations [13].

To address these gaps, we hypothesize a nonlinear relationship between nighttime sleep duration and intrinsic capacity decline in Chinese older adults. Leveraging CHARLS, we employ restricted cubic splines to model threshold effects. This approach diverges from conventional linear models, offering novel insights into optimal sleep duration ranges for preserving intrinsic capacity. Therefore, our study aims to pinpoint critical thresholds in nighttime sleep duration associated with the decline of intrinsic capacity among older adults, with the goal of providing information for precise sleep interventions tailored to China's aging population, ultimately promoting healthy ageing.

Methods

Study design and population

This cross-sectional study utilizes data from the nationally representative CHARLS project, which is committed to generating a comprehensive and high-quality dataset. The database captures demographic characteristics of Chinese individuals and households aged 45 years and older, encompassing both urban and rural populations across diverse geographic regions and including various ethnic groups, thereby enhancing the study's generalizability. Additionally, the study employs objective health assessments and validated questionnaires to reduce recall and measurement biases.

Initiated in 2011, the CHARLS national baseline survey collected data from 17,000 individuals residing in approximately 10,000 households, spanning 150 districts and 450 villages, ensuring broad representation. Following this, biennial surveys have been consistently conducted, with the most recent iteration concluded in 2020, maintaining a remarkable response rate exceeding 80% across all waves. Ethical approval was obtained for the study, which adhered to the STROBE checklist for reporting observational studies.

Due to the unavailability of BMI data in the 2018 survey, our analysis utilized the 2015 CHARLS dataset. To ensure data integrity, we merged and harmonized relevant modules from 2015. Participants were subsequently screened, and those failing to meet the following criteria were excluded: (1) individuals aged < 60 years; (2) those with incomplete information pertaining to nighttime sleep duration, intrinsic capacity, and key covariates (as illustrated in Fig. 1). Our decision to define the study population as individuals aged ≥ 60 years aligns with China's national aging policy framework, specifically the official classification standard for older adults in the Seventh National Census [2] and the *Standards for the Evaluation of Healthy Aging in China* (2019–2022) (2019–2022) [14]. After rigorous selection, the final analytical sample comprised 4494 participants.

For a comprehensive understanding of CHARLS' data collection methodologies and accomplishments, we encourage readers to peruse the official website (available at: http://charls.pku.edu.cn/).

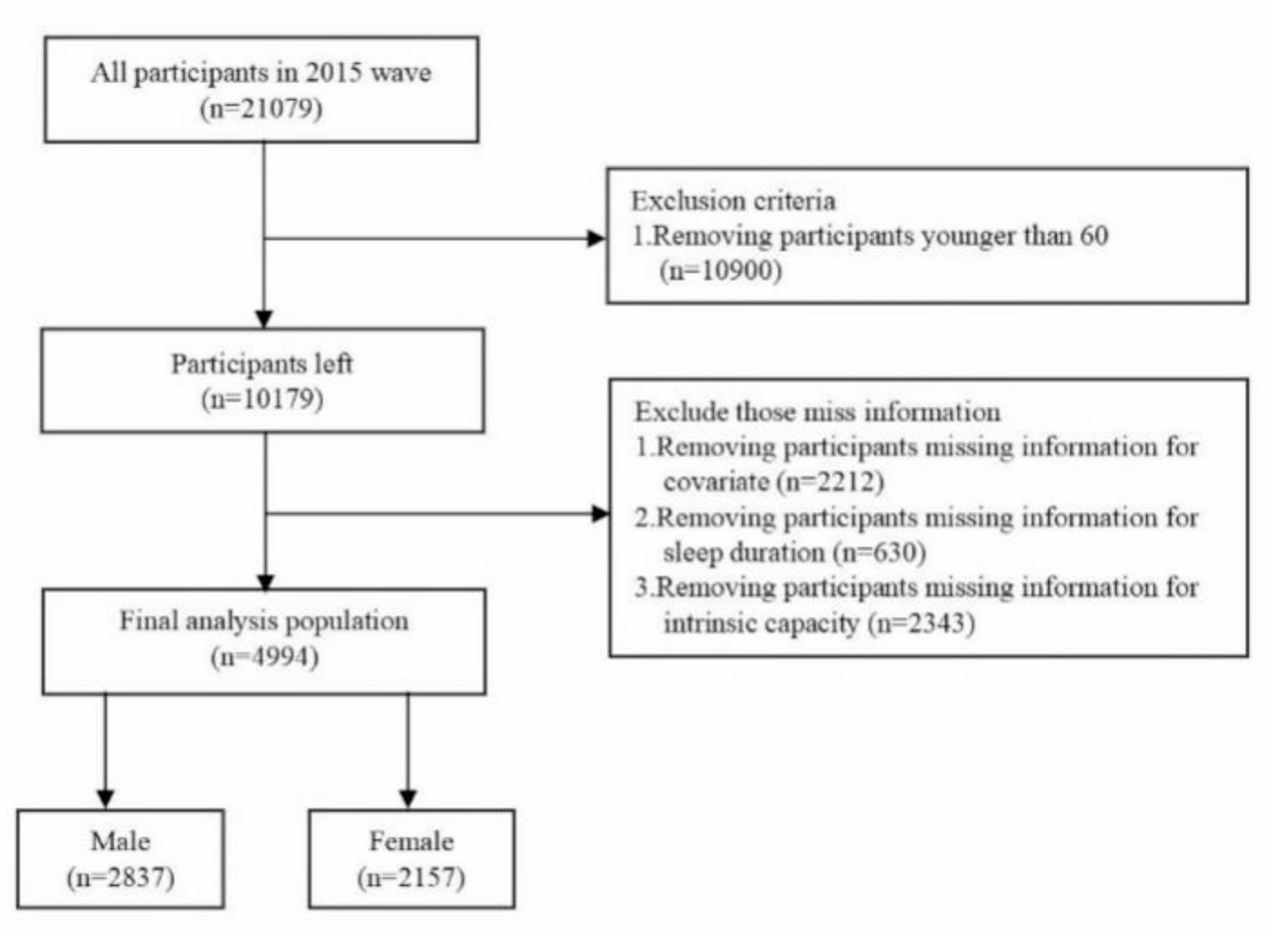

Fig. 1 Flow chart of study participants

Variable measurement

Measurement of nighttime sleep duration

The self-reported data regarding nightly sleep duration were derived from the 2015 CHARLS follow-up questionnaire. Participants were asked: *"Over the past month, what was the average number of hours of actual sleep you obtained per night? (Note: This may be less than the total hours you spent in bed)"* (Question ID: DA049). The recorded sleep durations spanned a range of 0 to 24 h/day.

Intrinsic capacity

Operational definition of intrinsic capacity Intrinsic capacity refers to the composite of physical and mental resources available to an individual at any time. As defined by the WHO [3], it encompasses five core domains: locomotion, sensory function (hearing and vision), vitality, cognition, and psychological well-being. This construct holistically reflects the functional status of older adults. Each domain was dichotomized into intact function (1 point) or impaired function (0 point) based on validated thresholds. Since sensory function comprises hearing and vision as separate components, the total intrinsic capacity score ranges from 0 to 6, with higher scores indicating stronger capacity. A score ≤ 5 was classified as intrinsic capacity decline [13, 15]. This measurement approach aligns with a recently published methodology validated using the China Health and Retirement Longitudinal Study (CHARLS) dataset [15].

Measurement of intrinsic capacity

(1) Locomotion

A score of 1 was awarded for the completion of FTSTS in 14 s or less, while a score of zero was given for a time exceeding 14 s (No stopping in between and without using arms to push off) [16].

(2) Vitality

The BMI was calculated. The threshold for BMI was based on the Malnutrition Universal Screening Tool

(MUST). Participants with BMI ≤ 18.5 kg/m² scored 0 points, whereas those with BMI > 18.5 kg/m² scored 1 point [17].

(3) Hearing

The participants were queried as to the state of their hearing. If participants reported hearing impairment or used hearing aids, a score of zero was attributed. In the event of a response indicating a level of hearing that was perceived to be "fair," "good," "very good," or "excellent" the participant was awarded one point.

(4) Vision

Participants were asked "*How good is your eyesight for seeing things at a distance?*" and "*How good is your eyesight for seeing things up close?*" A rating of "fair," "good," "very good," or "excellent" to both questions was awarded one point; conversely, a rating of "poor" to either question resulted in a score of zero points.

(5) Cognition

Consistent with previous research findings, cognitive function was evaluated through two primary domains: episodic memory and mental integrity [18, 19]. Episodic memory was assessed via a word recall test, wherein participants were presented with a list of ten randomly chosen words and subsequently instructed to recall as many words as possible immediately (immediate recall). The number of accurately recalled words was documented and served as an indicator of immediate recall ability. Following a ten-minute interval, participants were again prompted to recall the same list of words (delayed recall). The episodic memory score was computed as the mean of the immediate and delayed recall counts, with a potential score range of 0 to 10. Mental intactness was determined using selected components from the mental status questions of the Telephone Interview of Cognitive Status (TICS) battery, an instrument designed to evaluate cognitive status. In the CHARLS study, mental status questions encompassed serial subtraction of 7 from 100 (up to five iterations), identification of the current date (month, day, and year), day of the week, season, and completion of the intersecting pentagon copying test. Responses to these questions were aggregated to yield a mental intactness score, ranging from 0 to 11.

The global cognitive score was derived by summing the episodic memory and mental intactness scores, with a possible range of 0 to 21. In our study, the critical value was established using the mean minus one standard deviation. A total cognitive score ≤ 5.018 was indicative of cognitive decline and assigned a score of 0, whereas scores exceeding this threshold denoted normal cognitive ability and were scored as 1.

(6) Psychology

The psychological capacity was quantitatively assessed utilizing the 10-item Center for Epidemiologic Studies Depression Scale (CES-D-10) [20], which has been used to measure depressive symptoms among older adults and was validated among older respondents in China. The total score of this scale spans from 0 to 30, with an upward trend in scores reflecting an intensification of depressive symptoms. Specifically, a score threshold of 10 or below is interpreted as the absence of depressive symptoms and assigned a value of 1, whereas scores exceeding 10 signify the presence of depressive symptoms and are accordingly scored as 0 [21].

Assessment of covariates

Trained interviewers collected data using structured questionnaires. Confounding variables were selected based on prior literature and the 2015 CHARLS dataset, including: (1) Demographics: Age (continuous), gender (male/female), marital status (married, separated, divorced, widowed, unmarried), education (below primary/primary/middle school/high school or above). (2) Health behaviors: Smoking (yes/no), alcohol use (yes/no), chronic disease (yes/no). (3) Sociological factors: Health insurance (yes/no), pension (yes/no), residence (urban/rural).

Statistical analyses

Continuous data adhering to a normal distribution were reported as the mean ± standard deviation (SD), whereas data exhibiting a non-normal distribution were expressed as the median with an interquartile range (P_{25}, P_{75}). Categorical data were characterized by frequencies and proportions. To compare two groups of qualitative data, either the chi-square test or the Fisher-Freeman-Halton test was applied. When comparing groups of ordinal data, the Mann-Whitney U test served as the appropriate statistical method. As for continuous data comparisons between two groups, the t-test was utilized for normally distributed data, while skewed data were analyzed using the Mann-Whitney U test.

The selection of confounding factors for this study was informed by a literature review pertinent to the research topic, and a DAG was constructed using DAGitty software (Fig. 2). The DAG served as a visual and qualitative tool to illustrate the complex relationships among various risk factors [22]. Arrows in the DAG indicated pathways between two variables, and pre-established rules were applied to determine the minimum set of variables requiring adjustment. Following the application of DAG

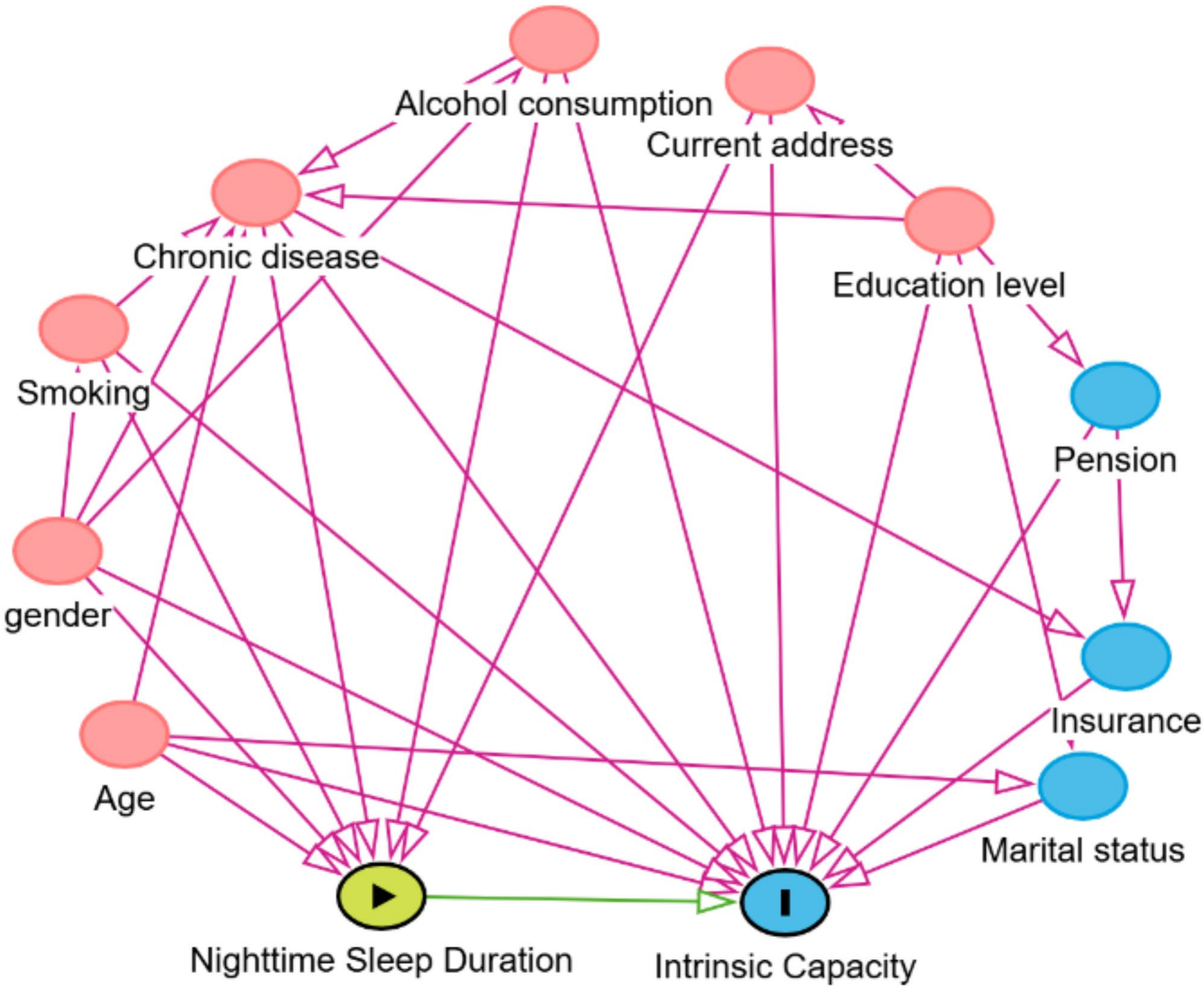

Fig. 2 Acyclic graph directed to the association between nighttime sleep duration and the intrinsic capacity

rules, the minimum adjustment set for the association between nighttime sleep duration and intrinsic capacity in older adults comprised: age, gender, smoking, chronic conditions, alcohol consumption, and current address. Education level was considered an ancestral variable and was therefore not included in the confounding factor adjustment, as illustrated in Fig. 2. For the first time, we systematically applied the DAG to the field of intrinsic capability research, providing a paradigm for addressing the challenging issue of causal inference in observational studies.

To delve into the association between nighttime sleep duration and the intrinsic capacity of older adults, logistic regression models were implemented. The outcome variable was defined as the decline in the intrinsic capacity of older adults (yes/no, recoded as 1/0). Odds ratios (ORs) and 95% confidence intervals (CIs) were computed to contrast the group with declined intrinsic capacity against the normal group. Four logistic models were formulated: Model 1 represented the unadjusted scenario; Model 2 incorporated adjustments for demographic characteristics, encompassing age, gender; Model 3 further integrated health-related information, such as smoking, alcohol consumption, chronic diseases, and current address, based on Model 2. To gain deeper insights into the relationship between nighttime sleep duration and the intrinsic capacity of older adults, nighttime sleep duration was stratified into quartiles, and analyses were performed based on variations in this duration. RCS were employed to visualize the overall pattern of the relationship between nighttime sleep duration and the intrinsic capacity of older adults. As a smoothing technique, RCS effectively captures nonlinear relationships while maintaining local structure independence [23].

All statistical analyses, including data cleaning, were performed using R version 4.4.0 (R Foundation for

Statistical Computing). A significance level of $P < 0.05$ was adopted. The reporting was guided by the STROBE checklist.

Result

Primary result

Baseline characteristics

The study was meticulously designed with stringent inclusion and exclusion criteria, ultimately enrolling 4,994 eligible participants, constituting the core sample for this research endeavor. An in-depth examination of these participants revealed a concerning prevalence of declining intrinsic capacity, with a staggering 62.4% ($n = 3{,}118$) of older adults exhibiting varying degrees of decline.

To gain a nuanced understanding of this phenomenon, we categorized the intrinsic capacity into distinct dimensions. Notably, the vitality dimension emerged as the most affected, with 92.9% ($n = 4{,}638$) of participants experiencing a decline. This was closely followed by the cognitive dimension, impacting 91% ($n = 4{,}586$) of the sample. Locomotion was also significantly affected, with 89.4% ($n = 4{,}463$) reporting a decline, while hearing and vision impairments were evident in 84.0% ($n = 4{,}195$) and 67.4% ($n = 3{,}366$) of the participants, respectively. Equally important, a significant decline was also observed at the psychological level, affecting 67.0% ($n = 3{,}384$) of older adults. Demographic analysis of the study population revealed a mean age of 66 years, with a range of 63–71 years. Notably, females constituted a larger proportion at 43.2% ($n = 2{,}157$).

The characteristics of older adults with declining intrinsic capacity are evident, with the majority being older, female, non-smokers, suffering from chronic diseases, and having a higher proportion residing in rural areas. To control the Type I error rate in multiple comparisons, we applied the Bonferroni correction by adjusting the significance threshold according to the formula $P = 0.05/[k(k-1)/2]$, where k represents the number of groups within each variable. For marital status comparisons (k = 3), the adjusted significance level was $P < 0.005$; for educational level comparisons (k = 4), it was $P < 0.008$. The proportion of widowed older adults with declining intrinsic capacity was significantly higher than that of married individuals ($P < 0.001$ (adjusted $P < 0.005$)). Furthermore, among individuals with declining intrinsic capacity, the proportion of those with a below-primary school education level was significantly higher than that of those with a junior high school education ($P < 0.001$ (adjusted $P < 0.008$)), a middle school education ($P < 0.001$ (adjusted $P < 0.008$)), and an education level above high school ($P < 0.001$ (adjusted $P < 0.008$)). Additionally, the proportion of individuals with a primary school education was also higher than that of those with a middle school education within the group with declining intrinsic capacity ($P = 0.002$ (adjusted $P < 0.008$)). These findings underscore the complexity of factors contributing to the decline of intrinsic capabilities among older adults and provide invaluable insights into the current situation. These findings are summarized in Table 1.

Association between nighttime sleep duration and intrinsic capacity declines

This study established a significant negative correlation between nighttime sleep duration and intrinsic capacity decline in older adults of China through multivariable-adjusted logistic regression analyses. Categorizing sleep duration into four clinically meaningful strata (≤ 5 h, 5.5–6 h, 6.5–8 h, ≥ 8.5 h/day), the analysis revealed risk reduction patterns that persisted across sequential model adjustments. In the unadjusted model (Model 1), compared to the ≤ 5 h/day reference group, longer sleep durations demonstrated protective effects: 5.5–6 h (OR = 0.515, 95%CI:0.436–0.609), 6.5–8 h (OR = 0.416, 0.360–0.480), and ≥ 8.5 h (OR = 0.621, 95%CI:0.499–0.773), with all associations statistically significant ($P < 0.001$). Following adjustment for age and sex (Model 2), and subsequent inclusion of behavioral and clinical confounders (smoking, alcohol use, chronic diseases, and residential location in Model 3), the negative relationship remained robust, exhibiting 41.3%, 53.0%, and 35.5% risk reductions for the respective sleep duration categories compared to the reference group (all $P < 0.001$). The fully adjusted Model 3 specifically demonstrated optimal protection at 6.5–8 h/day (OR = 0.470, 0.405–0.564), with confidence intervals across all categories strictly below unity, confirming the negative correlation of this association. (Refer to Table 2 for detailed findings.)

Non-linear relationship between nighttime sleep duration and intrinsic capacity

Utilizing the RCS model, we examined the association between nighttime sleep duration and intrinsic capacity among the older adults. The horizontal axis depicted variations in nighttime sleep duration, whereas the vertical axis represented the adjusted odds ratio (OR) values for each sleep duration, accounting for confounding factors. Following adjustment, the RCS model unveiled a J-shaped relationship between nighttime sleep duration and intrinsic capacity decline in older adults, with overall trend and nonlinearity achieving statistical significance ($P < 0.01$ and P for non-linearity < 0.001) (Fig. 3a). As sleep duration increased, the risk of intrinisc capacity decline decreased until reaching a nadir at 6.7 h/day, after which the risk reaches a plateau phase.

Upon stratifying the sample by gender and readjusting for confounding factors, a similar J-shaped pattern emerged ($P < 0.01$ and P for non-linearity < 0.001). For

Table 1 Baseline characteristics of declining intrinsic capacity in Chinese elderly

Characteristics	Total (*n* = 4994)	Normal IC (*n* = 1876)	Low IC (*n* = 3118)	*P*
Gender				< 0.001
Female	2157 (43.2)	653 (30.3)	1504 (69.7)	
Male	2837 (56.8)	1223 (43.1)	1614 (56.9)	
Age	66 (63, 71)	65 (62, 69)	66 (63, 72)	< 0.001
Marital status				< 0.001[a]
Married#	4052 (81.1)	1609 (39.7)	2442 (60.3)	
Separated	151 (3.0)	51 (33.8)	100 (66.2)	
Divorced	26 (0.5)	9 (34.6)	17 (65.4)	
Widowed#	732 (14.7)	199 (27.2)	533 (72.8)	
Unmarried	34 (0.7)	8 (23.5)	26 (76.5)	
Education				< 0.001
Below Primary School$^{\#\leftarrow\upsilon}$	2409 (48.2)	709 (29.4)	1700 (70.6)	
Primary school$^{\#\lambda}$	1398 (28.0)	573 (41.0)	825 (59.0)	
Middle school$^{\leftarrow\lambda}$	808 (16.2)	386 (47.8)	422 (53.3)	
High school and above$^{\upsilon}$	379 (7.6)	208 (54.9)	171 (45.1)	
Smoking				0.053
Yes	1574 (31.5)	622 (39.5)	952 (60.5)	
No	3420 (68.5)	1254 (36.7)	2166 (63.3)	
Alcohol consumption				< 0.001
Yes	1875 (37.5)	808 (43.1)	1067 (56.9)	
No	3119 (62.5)	1068 (34.2)	2051 (65.8)	
Chronic disease				< 0.001
Yes	4167 (83.4)	1442 (34.6)	2725 (65.4)	
No	827 (16.6)	434 (52.5)	393 (47.5)	
Pension				0.419
Yes	4126 (82.6)	1541 (37.3)	2585 (62.7)	
No	868 (17.4)	335 (38.6)	533 (61.4)	
Insurance				
Yes	4710 (94.3)	1778 (37.7)	2932 (62.3)	0.273
No	284 (5.7)	98 (34.5)	186 (65.5)	
Current address				
Urban	1787 (35.8)	821 (45.9)	966 (54.1)	< 0.001
Rural	3207 (64.2)	1055 (32.9)	2152 (67.1)	
Nighttime sleep duration	6 (5, 8)	7 (6, 8)	6 (5, 8)	< 0.001[a]

[a] Mann-Whitney U test; the remainder are chi-square tests; Same symbols ($^{\#\leftarrow\upsilon\lambda}$) denote statistically significant differences in pairwise comparisons

Table 2 Relationship between nighttime sleep duration and intrinsic capacity in older adults

Variable	Model 1[a]		Model 2[b]		Model 3[c]	
	OR (95%CI)	*P*	OR (95%CI)	*P*	OR (95%CI)	*P*
Nighttime sleep duration	0.857 (0.832–0.884)	< 0.001	0.871 (0.844–0.899)	< 0.001	0.872 (0.845–0.901)	< 0.001
The nighttime sleep duration, quartile						
≤ 5	Reference (1.00)		Reference (1.00)		Reference (1.00)	
5.5-6	0.515 (0.436–0.609)	< 0.001	0.556 (0.469–0.659)	< 0.001	0.587 (0.494–0.698)	< 0.001
6.5-8	0.416 (0.360–0.480)	< 0.001	0.451 (0.390–0.522)	< 0.001	0.470 (0.405–0.564)	< 0.001
≥ 8.5	0.621 (0.499–0.773)	< 0.001	0.658 (0.526–0.821)	< 0.001	0.645 (0.514–0.810)	< 0.001

[a] Model 1 was unadjusted

[b] Model 2 was adjusted for age, sex

[c] Model 3 was adjusted for age, sex, smoking, alcohol consumption, and chronic diseases, and current address

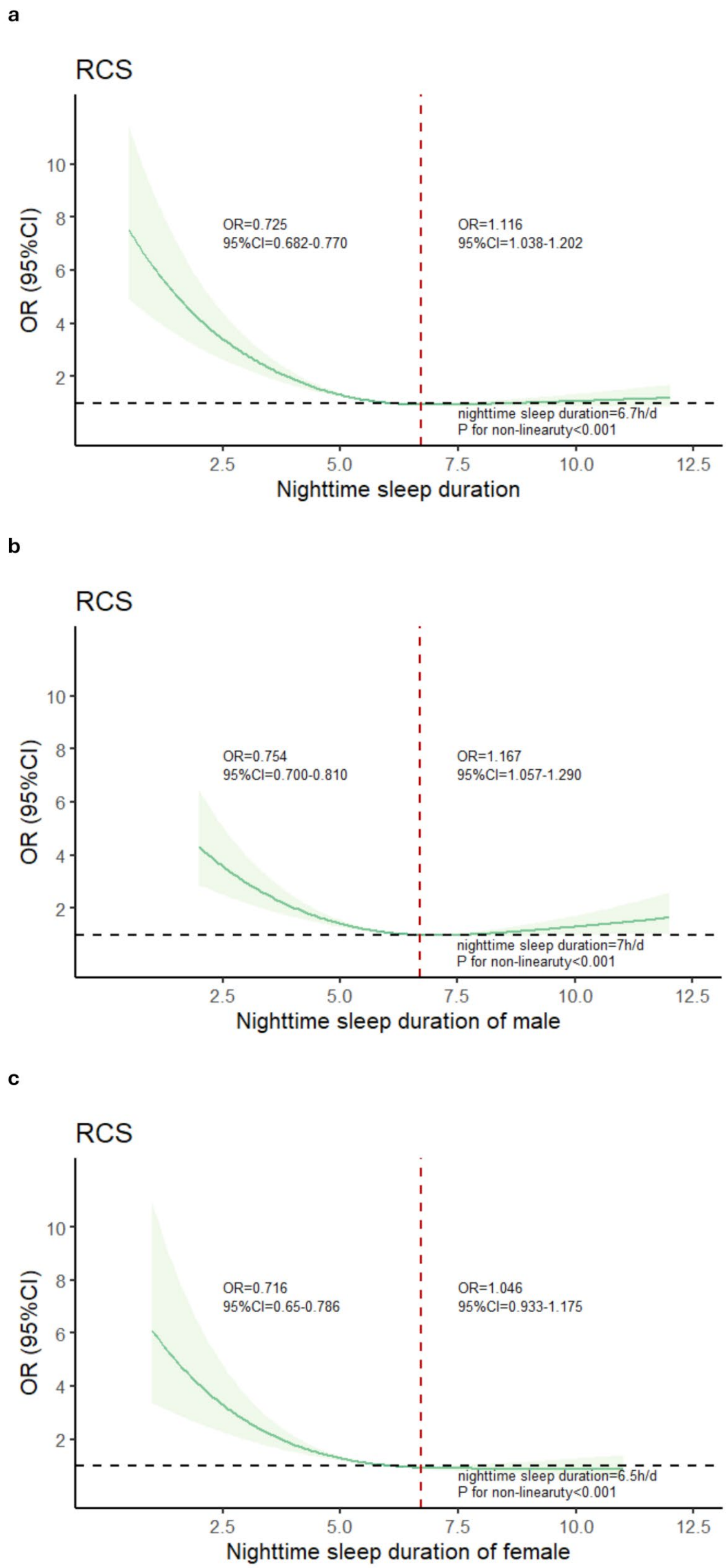

Fig. 3 **a** Non-linear relationship between nighttime sleep duration and intrinsic capacity; **b** Non-linear relationship between nighttime sleep duration of males and intrinsic; **c** Non-linear relationship between nighttime sleep duration of females and intrinsic

males, the inflection point occurred at 7 h of nighttime sleep. Below this threshold, the risk of IC decline diminished with increasing sleep duration (OR = 0.754, 95% CI: 0.700–0.810). However, once exceeding 7 h/day, the risk reaches a plateau phase where further extension of nighttime sleep duration provides limited incremental benefits to intrinsic capacity (Fig. 3b). For females, the inflection point was observed at 6.5 h (Fig. 3c). Detailed findings are outlined in Table 3.

Secondary analyses

Subgroup analysis

In our analysis, we employed the half-hours as the metric to quantify nighttime sleep duration in the sample data. Subsequently, guided by the identified inflection point, we stratified the nighttime sleep duration into two distinct categories: ≤ 6.5 h/day and > 6.5 h/day. To reduce the risk of Type I error, we applied the Bonferroni correction to adjust *P* values. The results of the subgroup analysis revealed that the negative correlation between nighttime sleep duration and intrinsic capacity among Chinese older adults was significant across genders and individuals aged ≤ 70 years. (adjusted *P* value < 0.001; *P* for interaction < 0.05), as illustrated in Fig. 4.

Discussion

Principal findings

We conducted a cross-sectional survey involving 4,994 Chinese older adults aged ≥ 60 years to explore the relationship between nighttime sleep duration and intrinsic capacity. We used restricted cubic spline regression to reveal for the first time a negative J-shaped relationship between nighttime sleep duration and intrinsic capacity decline in Chinese older adults, and identified 6.7 h/day as the optimal inflection point. The inflection point provides a concrete target for sleep interventions in aging populations, informing guidelines such as the Chinese Healthy Sleep Initiative.

Current status of intrinsic capacity among Chinese older adults

Intrinsic capacity, defined as a multidimensional construct for assessing geriatric functional reserves, has emerged as a critical metric in aging research [1]. While prior studies reported a wide range of prevalence for intrinsic capacity decline among Chinese older adults (39.9-93.4%) [9, 24], our analysis of nationally representative data from the CHARLS 2015 cohort identified an intermediate prevalence of 62.4%. This discrepancy likely stems from methodological heterogeneity in population sampling (e.g., clinical vs. community-dwelling cohorts) and regional healthcare disparities. Furthermore, we found that the proportion of female participants with declined intrinsic capacity (69.7%) was significantly higher than that of male participants (56.9%), consistent with findings from studies such as Beard et al. [5]

Our research further analyzed the multidimensional decline of intrinsic capacity in Chinese older adults,

Table 3 Analysis of the threshold effect of nighttime sleep duration on intrinsic capacity decline

	Adjusted OR (95% CI), *P*-value
Nighttime sleep duration	
Model 1 Fitting model by standard linear regression	0.872(0.845-0.900) < 0.001
Model 2 Fitting model by two-piecewise linear regression	
Inflection point	6.7
< 6.7	0.725(0.682–0.77) < 0.001
> 6.7	1.116(1.038–1.202) 0.003
P for likelihood ratio test	< 0.001
Nighttime sleep duration of male	
Model 1 Fitting model by standard linear regression	0.895(0.858–0.934) < 0.001
Model 2 Fitting model by two-piecewise linear regression	
Inflection point	7
< 7	0.754(0.700–0.810) < 0.001
> 7	1.167(1.057–1.290) 0.002
P for likelihood ratio test	< 0.001
Nighttime sleep duration of female	
Model 1 Fitting model by standard linear regression	0.842(0.801–0.885) < 0.001
Model 2 Fitting model by two-piecewise linear regression	
Inflection point	6.5
< 6.5	0.716(0.650–0.786) < 0.001
> 6.5	1.046(0.933–1.175) 0.446
P for likelihood ratio test	< 0.001

Note: Adjusted for age, gender, smoking, alcohol consumption, chronic diseases, and current address

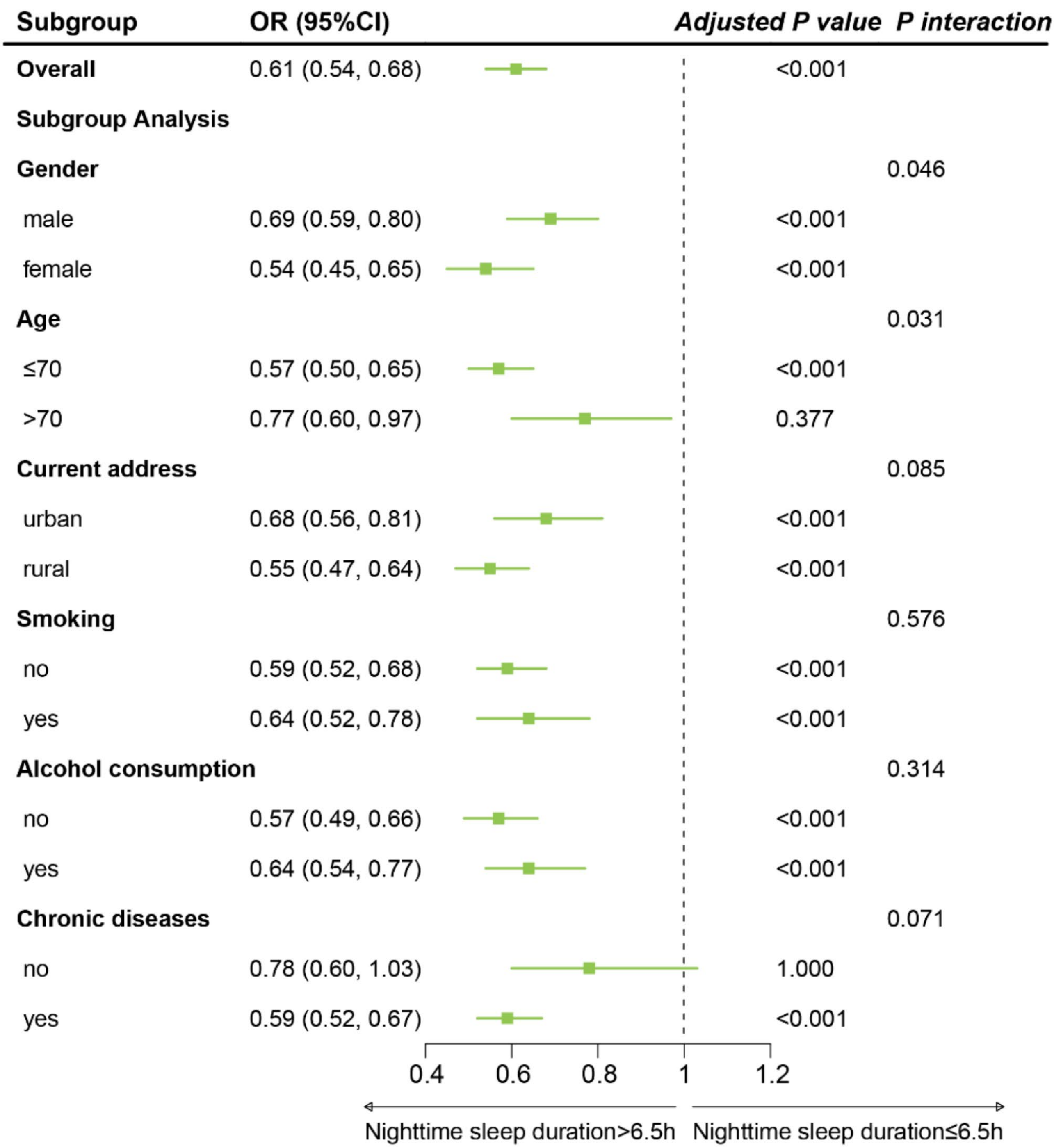

Fig. 4 Forest plots of stratified analyses of nighttime sleep duration and intrinsic capacity

revealing significant differences across domains. Specifically, the decline in the vitality dimension was the most significant, reaching 92.9%, indicating a particularly marked decline in daily activities and physical abilities among older adults. Conversely, although the decline in the psychological dimension was the smallest compared to the other five dimensions, it still reached a notable 67.0%, reflecting a significant decrease in the psychological state of older adults. Taken together, these data demonstrated that the situation regarding the intrinsic capacity of Chinese older adults was severe and warrants widespread attention and concern.

Currently available research

There has been much discussion and controversy in the academic community regarding the impact of sleep on health, and poor health outcomes are closely related to declines in intrinsic capacity [25]. While some studies suggest that extended sleep duration may confer health benefits, others propose a nonlinear association. For instance, Li et al. [26] reported that approximately 7 h/day optimizes health outcomes, whereas both insufficient and excessive sleep correlate with adverse effects. It is noteworthy that Lauderdale et al. observed that nighttime sleep duration < 6 h is significantly associated with adverse health outcomes in older adults, whereas sleep exceeding population averages showed no direct harm [27]. Furthermore, a systematic review found that long sleep duration is associated with increased levels of inflammatory markers in the body, a phenomenon not observed in short sleepers, although short sleep duration is also closely linked to health problems [28]. Additionally, Wang et al. [29] demonstrated that sleep durations > 8 h in Chinese community-dwelling adults were positively correlated with reduced gait speed. A Taiwan-based study explored sleep quality and intrinsic capacity decline [30], reporting a marginally significant negative correlation between long sleep duration and intrinsic capacity impairment. However, its single-city sampling limited generalizability and and yielded marginal statistical significance.

We used a large, nationally representative sample from the CHARLS database and a rigorous methodological approach. By formalizing causal assumptions via DAGS, we avoided bias caused by adjusting for exposure-affected variables [22]. In our study, Directed Acyclic Graphs (DAGs) were utilized for the systematic selection of confounding factors. The analysis revealed a consistent negative correlation between prolonged nighttime sleep duration and the decline in intrinsic capacity, even after adjusting for multiple variables. Furthermore, we applied restricted cubic spline (RCS) regression, revealing for the first time a J-shaped nonlinear association between nighttime sleep duration and intrinsic capacity decline (inflection point at 6.7 h/day), with the inflection point slightly lower in older females than in males. This J-shaped relationship demonstrates that when nighttime sleep duration falls below 6.7 h/day, the risk of intrinsic capacity decline diminishes rapidly with increasing sleep duration. However, once exceeding 6.7 h/day, the risk reaches a plateau phase where further extension of nighttime sleep duration provides limited incremental adverse effects to intrinsic capacity decline. Nevertheless, regression analysis results imply that prolonged sleep duration may still exert modest positive effects on maintaining intrinsic capacity stability in older adults.

The possible mechanisms

The current mechanisms underlying the relationship between nighttime sleep duration and the decline in intrinsic capacity remain unclear. Firstly, insufficient sleep impairs cerebrospinal fluid circulation, leading to hindered clearance of neurotoxic substances such as β-amyloid. This results in neuronal damage and reduced synaptic plasticity, directly compromising the cognitive domain of intrinsic capacity [31, 32]. Secondly, inflammatory processes may explain the link between sleep duration and intrinsic capacity. Sleep deprivation activates the NF-κB pathway, increasing the secretion of pro-inflammatory cytokines (e.g., IL-6, TNF-α) and inducing systemic low-grade inflammation [33, 34], which is strongly associated with poor intrinsic capacity [8]. Thirdly, sleep deficiency weakens prefrontal regulation of emotional control centers, exacerbating anxiety and depressive tendencies [35]. Additionally, it disrupts circadian rhythm gene expression, causing desynchronization of immune and metabolic rhythms. This establishes a vicious cycle of "inflammation-oxidative stress-metabolic dysregulation," ultimately accelerating intrinsic capacity decline through dual pathways: direct neurodegeneration and indirect chronic disease progression [36]. These findings underscore the necessity of prioritizing sleep hygiene in geriatric care and identifying modifiable factors influencing sleep patterns, which could inform strategies to mitigate intrinsic capacity decline.

Implication for geriatric care

Sleep problems, often overlooked in contemporary medical practice, are the focus of this study, which delves into the relationship between sleep duration and intrinsic capacity among older adults. We emphasize the importance of maintaining balanced sleep duration, cautioning against both excessive and insufficient sleep. Personalized intervention strategies tailored to the existing sleep patterns of older adults are paramount.

To improve sleep health in this population, we advocate for the establishment of a comprehensive sleep education framework, complemented by structured training programs and targeted health literacy endeavors. This approach aims to enhance older adults' understanding of sleep science and encourage proactive identification of sleep disturbances, thereby empowering individuals to optimize sleep management strategies and informing clinical practice [37].

Given the profound influence of sleep quality and emotional well-being on the intrinsic capacity of seniors, we stress the need to strengthen screening protocols for negative emotions. By harnessing the expertise of mental health institutions, we can coordinate collaborative efforts among primary healthcare providers, family doctor services, and older adults health screening programs to undertake systematic mental health screening, assessment, and subsequent management. Prompt preventive measures are crucial in mitigating negative emotions and forestalling the onset of mental health challenges like depression, ultimately enhancing sleep patterns and intrinsic capacity.

Furthermore, for sleep disorders prevalent among older adults, we prioritize non-pharmacological interventions as the first-line treatments. Notably, Cognitive Behavioral Therapy for Insomnia (CBT-I) is recommended as an efficacious strategy, encompassing sleep hygiene guidance, stimulus control, sleep restriction, relaxation techniques, and cognitive restructuring. This holistic approach to insomnia treatment boasts minimal adverse effects, effectively ameliorating insomnia symptoms, bolstering sleep quality, curtailing sleep onset latency, minimizing nocturnal awakenings, and augmenting sleep efficiency in older adults. When non-pharmacological adherence is suboptimal, judicious use of pharmacological agents—carefully tailored to individual needs—may be considered as an adjunctive therapy to achieve treatment goals.

Strengths and limitations

The present study boasts several notable advantages. Primarily, in contrast to prior investigations that scrutinized factors influencing intrinsic capacity, our research adopted a superior methodology for assessing the potential impacts of nighttime sleep duration on this crucial domain. Specifically, we harnessed the restricted cubic spline regression model, which exhibits substantial statistical powers in unraveling complex dose-response relationships while efficiently preserving data integrity and analytical strength. This innovative approach allowed us to meticulously delineate the intricate, nonlinear association between sleep duration during the night and intrinsic capacity within older adults. Moreover, our study incorporated a vast, nationwide sample of senior adults sourced from a rigorously validated database, and we diligently controlled for pivotal confounding variables, including age, educational attainment, chronic disease status, and place of residence. This meticulous approach not only underscores the scientific rigor and credibility of our findings but also fosters their wider applicability.

Nonetheless, our investigation is not devoid of limitations. Foremost among them is its reliance on cross-sectional survey data collected nationwide, which inherently confines our ability to establish causal linkages. In light of this constraint, future longitudinal studies are imperative to delve deeper into the causal dynamics between the variables and devise targeted interventional strategies based on these insights. Additionally, some variables in our study were based on self-report from participants, potentially introducing a degree of information bias. Furthermore, the direct deletion of missing data may lead to a reduction in sample size and a decrease in statistical power. In our study, the deletion approach could introduce selection bias and increase the risk of Type II errors.

Despite these caveats, our study represents a significant endeavor to explore the linkage between sleep duration and intrinsic capacity among older adults, offering a theoretical cornerstone for the formulation of pertinent policies and clinical interventions.

Conclusion

Our empirical investigation underscores the nonlinear correlation between sleep duration and intrinsic capacity among older adults, featuring a distinct threshold point. Consequently, it is imperative for older adults to meticulously maintain an optimal sleep duration throughout the night, eschewing both excessive and inadequate sleep, to sustain a robust level of intrinsic capacity and thereby foster healthy aging processes. This approach underscores the pivotal role of sleep regulation in preserving functionality and enhancing the overall well-being of senior citizens.

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Author contributions

BYZ and RJM are co-first authors responsible for this manuscript's study concept, design, and writing. BYZ, RJM, and YMW were responsible for the study concept, design, oversight, and revision. M W is responsible for statistics. BYZ, RJM, MW and YMW contributed to the concept, design, and editing of the manuscript. All authors actively contributed to the execution of this study and have endorsed the final version of the manuscript. YMW serves as the guarantor of this work.

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Data availability

This study used data from the 2015 wave of the CHARLS. The dataset is publicly available through the CHARLS project website (https://charls.charlsdata.com/pages/Data/2015-charls-wave4/zh-cn.html). The cleaned database and the final dataset utilized for analysis are available upon request from the corresponding author.

Declarations

Ethics approval and consent to participate

The original CHARLS survey data were approved by the Peking University Institutional Review Board (No. IRB00001052-11015), with all participants having provided informed consent.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

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