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Association between sleep duration and intrinsic capacity in older adults: evidence from a longitudinal cohort study and Bayesian network analyses

Caixuan Xie[1], Yuting Zhang[2], Lei Zhu[3*] and Guanyang Zou[1*]

Abstract

Background With China's rapidly aging population, intrinsic capacity (IC) impairment among older adults has emerged as a critical public health issue, significantly contributing to increased disease burden and mortality. Currently, most studies focus on the impact of sleep duration on a single domain of IC in older adults; however, the overall association between sleep duration and IC remains largely unexplored. This study aims to investigate the relationship between sleep duration and IC in older adults and analyze the interrelationships across IC domains using Bayesian Network (BN).

Methods Data were retrieved from the China Health and Retirement Longitudinal Study (CHARLS) covering the period from 2011 to 2020. A total of 5,430 participants without IC impairment at baseline were followed up to assess the prevalence of IC impairment across different sleep duration groups. Additionally, BN analysis was conducted on 42,746 participants between 2010 and 2020 to examine the relationship between sleep duration and five domains of IC.

Results The prevalence of IC impairment in 2011 was 21.4%. Between 2011 and 2020, an additional 1,682 participants developed IC impairment, resulting in a morbidity of 44.8% in 2020. The prevalence of IC impairment in both the short sleep (< 7 h) and long sleep (> 9 h) groups consistently exceeded that of the moderate sleep (7–9 h) group. BN analysis revealed a more complex relationship: psychological and locomotion function were directly related to sleep duration, whereas vitality, cognition, and sensory were indirectly related. Among the five domains of IC, cognition displayed the highest probability of impairment. And short sleep duration predominantly negatively affected psychological function, whereas excess sleep duration impaired sensory most.

Conclusions Both short and long sleep were associated with higher IC impairment. Short sleep negatively affected psychological function, while excess sleep impaired sensory. Maintaining 7–9 h' sleep is important for preserving IC in older adults.

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Trial registration not applicable.

Keywords Intrinsic capacity, Sleep duration, Bayesian network, Healthy aging

Background

Intrinsic Capacity (IC), as defined by the World Health Organization (WHO) in its *World Report on Aging and Health (2015)*, represents the composite of an individual's physical and mental capacities across five domains: cognition, vitality, locomotion, sensory, and psychological function [1].

As global populations age, preserving and enhancing IC in older adults has become a central focus of public health initiatives. IC represents a paradigm shift in geriatric care, transitioning from a narrow focus on illness and disability to a broader understanding of health and well-being. Identifying and understanding the determinants and interactions that affect IC in older adults is crucial for optimizing health outcomes and extending life expectancy. Many factors including low parental education, poor child health, environment [2], physical activity [3], advanced age, low educational attainment, and widowhood [4] affect IC.

Sleep disturbances are also highly prevalent among older adults [5, 6], and accumulating evidence suggests that sleep duration is associated with various domains of IC. For instance, analyses based on the English Longitudinal Study of Ageing and the China Health and Retirement Longitudinal Study (CHARLS) revealed an inverse U-shaped relationship between sleep duration and cognitive decline, indicating that deviations from approximately seven hours of sleep accelerate cognitive deterioration [7]. Sleep duration has been linked to the regulation of energy balance [8], while both short (< 7 h) and long (> 9 h) sleep durations have been identified as risk factors for depression in later life [9]. Furthermore, insufficient and excessive sleep have been associated with sensory [10] and locomotion impairment [11] among older adults.

Despite these findings, comprehensive investigations of the association between sleep duration and overall IC remain limited. One study reported a marginally significant relationship between the two [12], but evidence remains inconclusive. Given that IC is a multidimensional construct encompassing diverse functional domains, it offers a valuable framework for understanding the health trajectories of older adults. However, most existing studies are cross-sectional and focus on single IC domains, lacking integrative assessments or exploration of potential causal pathways.

Bayesian Network (BN) analysis offers a robust methodological framework for causal inference. Also known as a Directed Acyclic Graph (DAG), the BN is a probabilistic graphical model grounded in Bayes' theorem [13]. In recent years, BN approaches have shown distinct advantages in complex variable analysis. Unlike traditional statistical methods that rely on p-values to test hypotheses [13], BN enables causal reasoning through prior and conditional probabilities. Once the network structure and conditional probability distributions are specified, BN can estimate posterior probabilities for unobserved data, facilitating diagnostic, predictive, and classification analyses [14–16].

In summary, preserving and enhancing IC is fundamental to promoting healthy aging. Given the complexity of the association between sleep duration and IC in older adults, coupled with a lack of comprehensive research on the topic, this study assessed IC in older adults according to Integrated Care for Older People (ICOPE) guidelines established by the WHO in 2016, and conducted a longitudinal cohort analysis using CHARLS follow-up data (waves 1–5) from 2011 to 2020. A BN analysis was employed to elucidate the complex relationship between sleep duration and five domains of IC. The findings aim to provide insights into the risk of IC impairment associated with different sleep duration and inform early intervention strategies.

Methods

Study population and data source

The data for this study were derived from the CHARLS [17], an ongoing longitudinal survey that examines the socioeconomic status, health, and healthcare of middle-aged and older adults aged 45 years and above in China. The national baseline survey of CHARLS was conducted in 2011 using a multi-stage, Proportional to Population Size (PPS) sampling method at both the county/district and village levels. This approach encompassed 150 county-level units and 450 village-level units, ensuring comprehensive representation across the country. Follow-up surveys have been conducted biennially since then.

Fig. 1 shows the flowchart on how we identified our study samples. We used 2011–2020 survey data. We first excluded those younger than 60 and having over 20% missing values of covariates [18, 19]. This results in 42,746 samples. This is our cross-sectional study sample. We used this sample to conduct Bayesian Network analysis. We started with the 2011 baseline cohort to study the prevalence rate of IC impairment and compared the baseline descriptive summary between those with and without IC impairment. In addition, to understand how IC impairment evolves over time, we identified a subcohort of 5430 participants who had no IC impairment

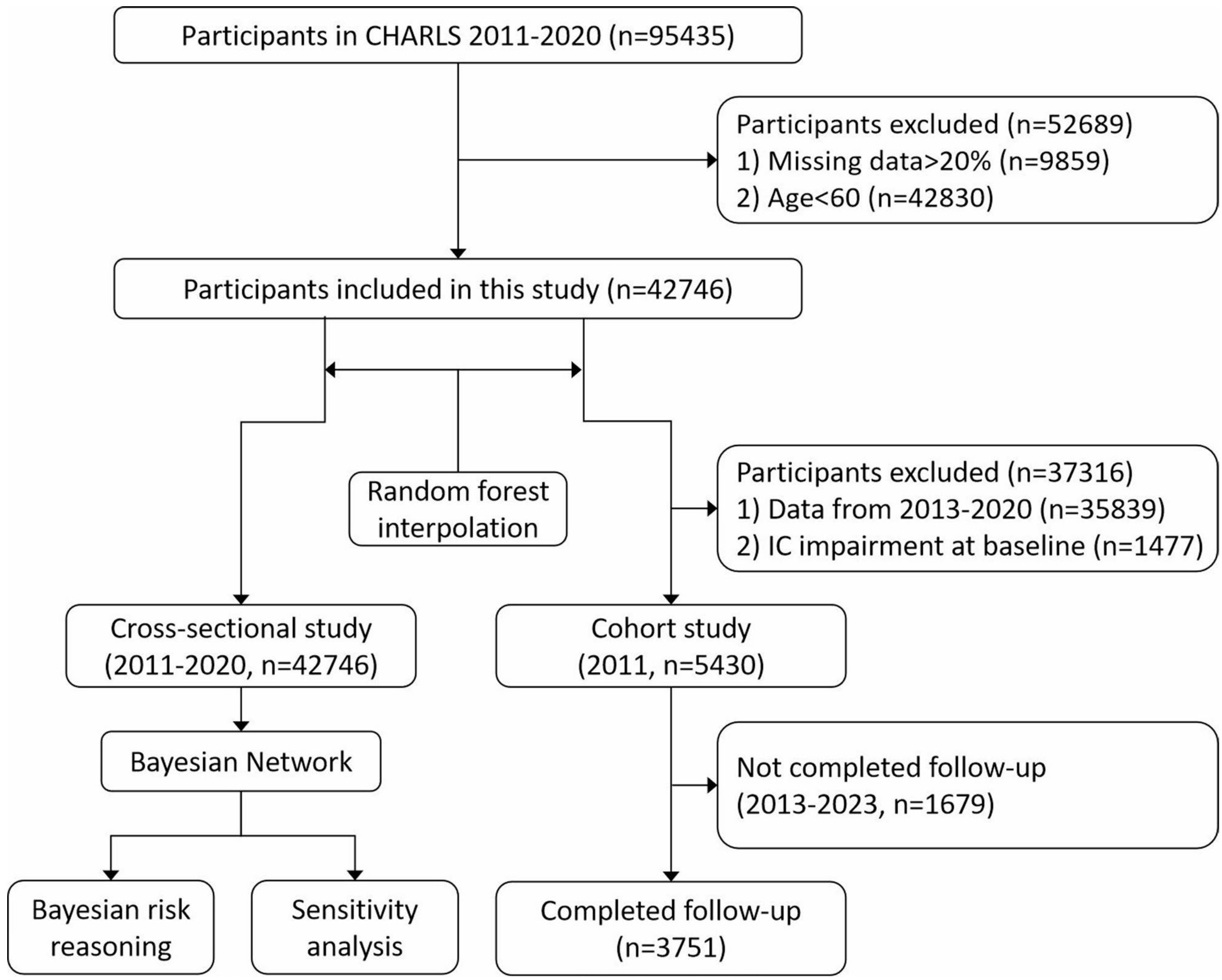

Fig. 1 Research flowchart

in 2011 and created a longitudinal study sample of 3751 participants. Multiple Imputation by Chained Equations was applied to handle the partial missing sample data during follow-up. The imputed values closely resembled the original data distributions, indicating good imputation quality and reliable data (see Additional file 1–2).

Assessment of intrinsic capacity

In accordance with the ICOPE guidelines, IC was evaluated across five domains: cognition, vitality, locomotion, psychological, and sensory. Each domain was assessed dichotomously, with results categorized as either 1 (impaired) or 0 (normal). A total IC score, ranging from 0 to 5, was obtained by summing the individual domain scores. Scores of 3–5 were classified as 1 (impaired), while scores of 0–2 were classified as 0 (normal) [20].

Cognition

Cognition represents an individual's ability to process information, reason, remember, and make decisions. Cognition was assessed using the CHARLS cognitive module, adapted from the Health and Retirement Study [21]. Participants underwent face-to-face evaluations across four dimensions—orientation (5 points), calculation (5 points), memory (20 points), and drawing (1 point)—yielding a total score of 31 points [21, 22]. Thresholds were established based on education levels: 16/17 for illiterate individuals, 19/20 for those with 1–6 years of education, and 23/24 for those with 7 or more years of education [23]. Scores below these thresholds indicated cognitive impairment (assigned a value of 1), while scores meeting or exceeding the thresholds indicated normal cognition (assigned a value of 0).

Vitality

Vitality reflects overall physiological reserve, metabolic function, and nutritional status. Currently, there is no universally accepted method for assessing vitality. Evidence indicates that eating difficulties can reduce food intake and lead to malnutrition [24], making them a key indicator of diminished vitality. In this study, vitality was assessed based on reported eating difficulties, with any reported difficulty assigned a value of 1 (impaired) and no reported difficulty assigned a value of 0 (normal).

Locomotion

Locomotion indicates physical mobility, balance, and muscular strength. Locomotion was evaluated using the Activities of Daily Living (ADL) scales, focusing on locomotion tasks such as transferring to a bed and standing up from a squatting position [25]. Difficulty with any task was classified as impaired locomotion (assigned a value of 1), while no difficulty was classified as normal (assigned a value of 0).

Psychological

Psychological function captures emotional well-being, mood regulation, and mental resilience. Psychological function was assessed using the 10-item Short Form of the Center for Epidemiologic Studies Depression (CES-D-10) scale, as used in CHARLS [26, 27]. A score greater than 10 indicated impaired psychological (assigned a value of 1), while a score of 10 or less was classified as normal (assigned a value of 0) [28].

Sensory

Sensory function denotes the capacity to perceive and respond to environmental stimuli through vision and hearing. Sensory was evaluated through self-reported hearing and visual impairments [29]. Any reported impairment classified the sensory as impaired (assigned a value of 1), while no impairment was classified as normal (assigned a value of 0).

Assessment of sleep duration

Sleep duration was measured using the CHARLS questionnaire items DA030 (Wave 2020) and DA049 (Waves 2011–2018), which asked, "During the past month, how many hours of actual sleep did you get at night (average hours per night)? (This may be shorter than the number of hours spent in bed.)". Sleep duration was categorized into three groups: Short Sleep (SS; <7 h), Moderate Sleep (MS; 7–9 h), and Long Sleep (LS; >9 h) [30, 31].

Covariates

Based on literature review, nine covariates related to demographic factors and lifestyle behaviors were included in the BN analysis [32–34]: age, gender, residence type, education, marital status, smoke, drink, employment, nap. The detailed variable assignments are provided in Additional file 3.

Statistical analyses

We first used the baseline 2011 sample ($n = 6{,}907$) to study the prevalence of IC impairment in the baseline and compared descriptive summary statistics between those with and without IC impairment in the baseline using chi-squared tests (Table 1).

To analyze development of IC impairment over time, we identified a sample without IC impairment in 2011 and followed them up until 2020 in the longitudinal cohort who were in all waves between 2011 and 2020 ($n = 3{,}751$). We used logistic regression analyses to study the risk of short and long sleep on IC impairment, relative to moderate sleep. This was conducted for each follow-up period separately.

IBM SPSS Statistics 22 was used for statistical descriptive analyses, logistic regression, and chi-squared tests. A significance level of $P < 0.05$ was used for all statistical tests.

Finally, using a cross-sectional study sample ($n = 42{,}746$), we conducted Bayesian Network (BN) to estimate the relationship between sleep duration and IC impairment, by allowing complex interrelationship structures.

In this study, BN construction was implemented using Python 3.8 and followed two main steps: (1) Structure learning: The Bayesian Information Criterion (BIC) was employed as the scoring function, and the Hill-Climb algorithm was used to identify topological relationships between variables, forming the DAG [35]. (2) Parameter learning: Maximum Likelihood Estimation (MLE) was applied to learn parameters and construct the Conditional Probability Distribution (CPD), which was then integrated into the BN structure [36]. In BN, parent and child nodes are defined based on the conditional dependencies between variables. A parent node is a variable that influences the probability distribution of its child node. The network structure is depicted by arcs (i.e., arrows) pointing from parent to child nodes, signifying that the parent node conditionally affects the probability distributions of its children, whose distributions are conditional on the parent. The determination of nodes and arcs is based on two main steps: structure learning and parameter learning.

GeNIe 4.0, a software tool for BN visualization, was utilized to display the constructed BN. After completing the BN construction in Python 3.8, the parent-child node relationships were organized in GeNIe 4.0 according to the DAG, and the CPD was imported to complete the BN visualization. The software also enabled risk reasoning based on Bayes' theorem and facilitated the analysis of interactions between variables.

Table 1 Baseline characteristics of participants in 2011

Characteristic		Total; n (%)	Intrinsic Capacity Impairment		P Value (chi-squared)
			No; n (%)	Yes; n (%)	
Number of participants		6907	5430 (78.6%)	1477 (21.4%)	-
Age					< 0.001
	[60, 70)	4325 (62.6%)	3564 (65.6%)	761 (51.5%)	
	[70, 80)	2058 (29.8%)	1536 (28.3%)	522(35.3%)	
	[80, -]	524 (7.6%)	330 (6.1%)	194 (13.1%)	
Gender					< 0.001
	female	3427 (49.6%)	2573 (47.4%)	854 (57.8%)	
	male	3480 (50.4%)	2857 (52.6%)	623 (42.2%)	
Residence type					< 0.001
	village	5274 (76.4%)	3979 (73.3%)	1295 (87.7%)	
	city	1633 (23.6%)	1451 (26.7%)	182 (12.3%)	
Education					< 0.001
	junior high school	6400 (92.7%)	4970 (91.5%)	1430 (96.8%)	
	junior college	442 (6.4%)	401 (7.4%)	41 (2.8%)	
	college	65 (0.9%)	59 (1.1%)	6 (0.4%)	
Marital status					< 0.001
	others	1466 (21.2%)	1029 (19.0%)	437 (29.6%)	
	married	5441 (78.8%)	4401 (81.0%)	1040 (70.4%)	
Sleep duration					< 0.001
	< 7 h	3809 (55.1%)	2840 (52.3%)	969 (65.6%)	
	7–9 h	2783 (40.3%)	2360 (43.5%)	423 (28.6%)	
	> 9 h	315 (4.6%)	230 (4.2%)	85 (5.8%)	
Nap					0.109
	no napping	3068 (44.4%)	2372 (43.7%)	696 (47.1%)	
	short napping	661 (9.6%)	522 (9.6%)	139 (9.4%)	
	moderate napping	2145 (31.1%)	1706 (31.4%)	439 (29.7%)	
	extended napping	1033 (15.0%)	830 (15.3%)	203 (13.7%)	
Smoke					0.056
	no	3993 (57.8%)	3107 (57.2%)	886 (60.0%)	
	yes	2914 (42.2%)	2323 (42.8%)	591 (40.0%)	
Drink					< 0.001
	no	4841 (70.1%)	3726 (68.6%)	1115 (75.5%)	
	yes	2066 (29.9%)	1704 (31.4%)	362 (24.5%)	
Employment					< 0.001
	no	3416 (49.5%)	2575 (47.4%)	841 (56.9%)	
	yes	3491 (50.5%)	2855 (52.6%)	636 (43.1%)	

Results

Baseline descriptive statistics summary

At baseline, the sample included 6,907 participants, with a mean age of 68.3 years (SD = 6.8), 49.6% were female, and 76.4% resided in rural areas. The baseline sample included 3,480 males (50.4%) and 3,427 females (49.6%). The overall prevalence of impaired IC was 21.4% in 2011. Of the 6,907 participants, 3,809 (55.1%) slept less than 7 h (categorized as short sleep group, SS group); 2,783 (40.3%) slept between 7 and 9 h (categorized as moderate sleep group, MS group); and 315 (4.6%) slept more than 9 h (categorized as long sleep group, LS group). IC impairment prevalence differed across sleep groups, with 15.2% in the MS group, 25.4% in the SS group, and 27.0% in the LS group.

Prevalence of intrinsic capacity impairment by sleep duration from logistic regression results

In our baseline sample who did not have IC impairment in 2011, 3751 participants completed the follow-up period between 2011 and 2020. Among them, 1,682 participants developed IC impairment for the first time during an average 4.96 years, yielding a morbidity of 44.8%. The cumulative prevalence of IC impairment over the 9-year follow-up period was 83.1%. Fig. 2 shows the raw prevalence of IC impairment by sleep duration, as well as the results from logistic regressions. IC impairment was consistently higher in both the SS and LS groups compared to the MS group. In 2013, for example, the prevalence of IC impairment in the SS group was 16.5% (95% CI: 14.9%-18.1%), a 2.272-fold increased risk of

Follow-up	Total	Group	IC impaired	Prevalence (95% CI)	OR (95% CI)	*P* Value
2013						
	2181	SS	360	16.5% (14.9%, 18.1%)	2.272 (1.822, 2.833)	<0.001
	1449	MS	116	8.0% (6.6%, 9.4%)	ref	ref
	121	LS	20	16.5% (9.8%, 23.2%)	2.276 (1.358, 3.812)	0.002
2015						
	2002	SS	420	21.0% (19.2%, 22.8%)	1.925 (1.597, 2.320)	<0.001
	1551	MS	188	12.1% (10.5%, 13.7%)	ref	ref
	198	LS	39	19.7% (14.1%, 25.3%)	1.778 (1.214, 2.606)	0.003
2018						
	2134	SS	618	29.0% (27.0%, 30.9%)	1.718 (1.459, 2.023)	<0.001
	1382	MS	265	19.2% (17.1%, 21.3%)	ref	ref
	235	LS	68	28.9% (23.1%, 34.8%)	1.716 (1.256, 2.345)	0.001
2020						
	2270	SS	675	29.7% (27.9%, 31.6%)	1.511 (1.287, 1.775)	<0.001
	1266	MS	277	21.9% (19.6%, 24.2%)	ref	ref
	215	LS	70	32.6% (26.2%, 38.9%)	1.724 (1.258, 2.361)	0.001

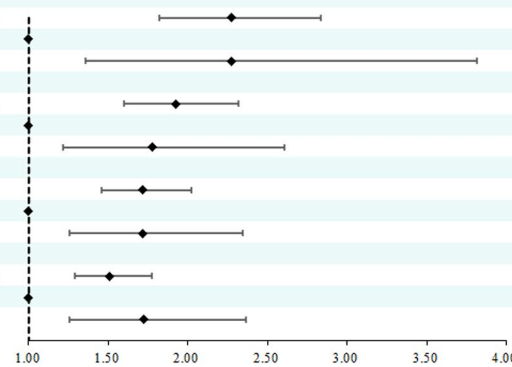

Fig. 2 Forest plot of logistic regression analyses between sleep duration and IC: from 2013–2020 follow-up results. *Logistic regression analyses and forest plot visualizations were conducted on data from the four follow-up visits conducted between 2013 and 2020, with a total of 3751 participants. SS=Short Sleep (< 7 h), MS=Moderate Sleep (7–9 h), LS=Long Sleep (> 9 h)

IC impairment compared to the MS group (Odds Ratio [OR]: 2.272, P <0.001). In the LS group, 20 participants developed IC impairment in 2013, with a prevalence of 16.5% (95% CI: 9.8%-23.2%) and a 2.276-fold increased risk compared to the MS group (OR: 2.276, P = 0.002).

Results from Bayesian network analyses

BN learning was conducted using data from the CHARLS from 2011 to 2020, encompassing 42,746 samples. The mean age of participants was 68.4 years (SD = 6.7). To explore the complex relationships between sleep duration and IC, BN learning was performed for each of the five IC domains. Fig. 3 illustrates the BN constructed for sleep duration, IC domains, and covariates, consisting of 15 nodes and 50 arcs, where each node represents a variable and each arc indicates a probabilistic dependency, illustrating the influence of one variable on another. The structure of the nodes and arcs were determined through structure learning (Hill-Climb Algorithm) and parameter learning (Maximum Likelihood Estimation), which identifies the most probable dependencies between the variables. The rectangular boxes within the nodes display prior probabilities. For example, the prior probabilities for the "psychological" variable were $\mathrm{P}_{psychological=yes} = 0.404$, $\mathrm{P}_{psychological=no} = 0.596$. Variables such as gender, education, smoke, vitality, sleep duration, cognition, sensory, marital status, drink, locomotion, and residence type were directly associated with psychological function. Among these, gender, education, smoke, and vitality were identified as parent nodes of the psychological function.

The BN revealed a strong correlation between sleep duration and IC domains. Psychological and locomotion were identified as parent nodes for sleep duration, while vitality was indirectly associated with sleep duration through psychological and locomotion. Sleep duration was also indirectly associated with cognition and sensory via age. Among the IC domains, cognition showed the highest impairment rate, with a prior probability of $\mathrm{P}_{cognition=yes} = 0.914$. The parent nodes for cognition—age, psychological, and residence type—were all associated with cognition impairment. As shown in Additional file 4, the conditional probability table indicated that rural residents aged over 80 years with psychological impairment had the highest risk of cognition impairment, with a probability of 99.23%.

Bayesian risk reasoning for intrinsic capacity

In the constructed BN, Bayesian risk reasoning, grounded in prior probabilities, was employed to update the probability distributions of the variables, revealing changes in the posterior probabilities across different sleep duration groups. In this process, the prior probabilities represent the initial probability distributions of each variable before the incorporation of new data, while the posterior probabilities reflect the updated distributions based on the observed data (e.g., changes in sleep duration). If the state of sleep duration is specified (i.e., with a probability of 100%), the nodes associated with it will perform probabilistic reasoning based on the identified state. For those with short sleep, (see Additional file 5), the probabilities of cognition impairment, vitality impairment, locomotion impairment, psychological impairment, and sensory impairment increased by 0.4%, 0.6%, 3.1%, 7.2%, and 0.5%, respectively, indicating that short sleep predominantly adversely affects psychological function. For those with moderate sleep (see Additional file 6), the probabilities of cognition impairment, vitality impairment, locomotion impairment, psychological impairment, and sensory impairment decreased by 0.7%, 0.9%, 5.1%, 11.1%, and 1.1%, respectively. For those with long sleep duration (see Additional file 7), the probabilities of cognition impairment, vitality impairment, locomotion impairment, and sensory impairment increased by 1.0%,

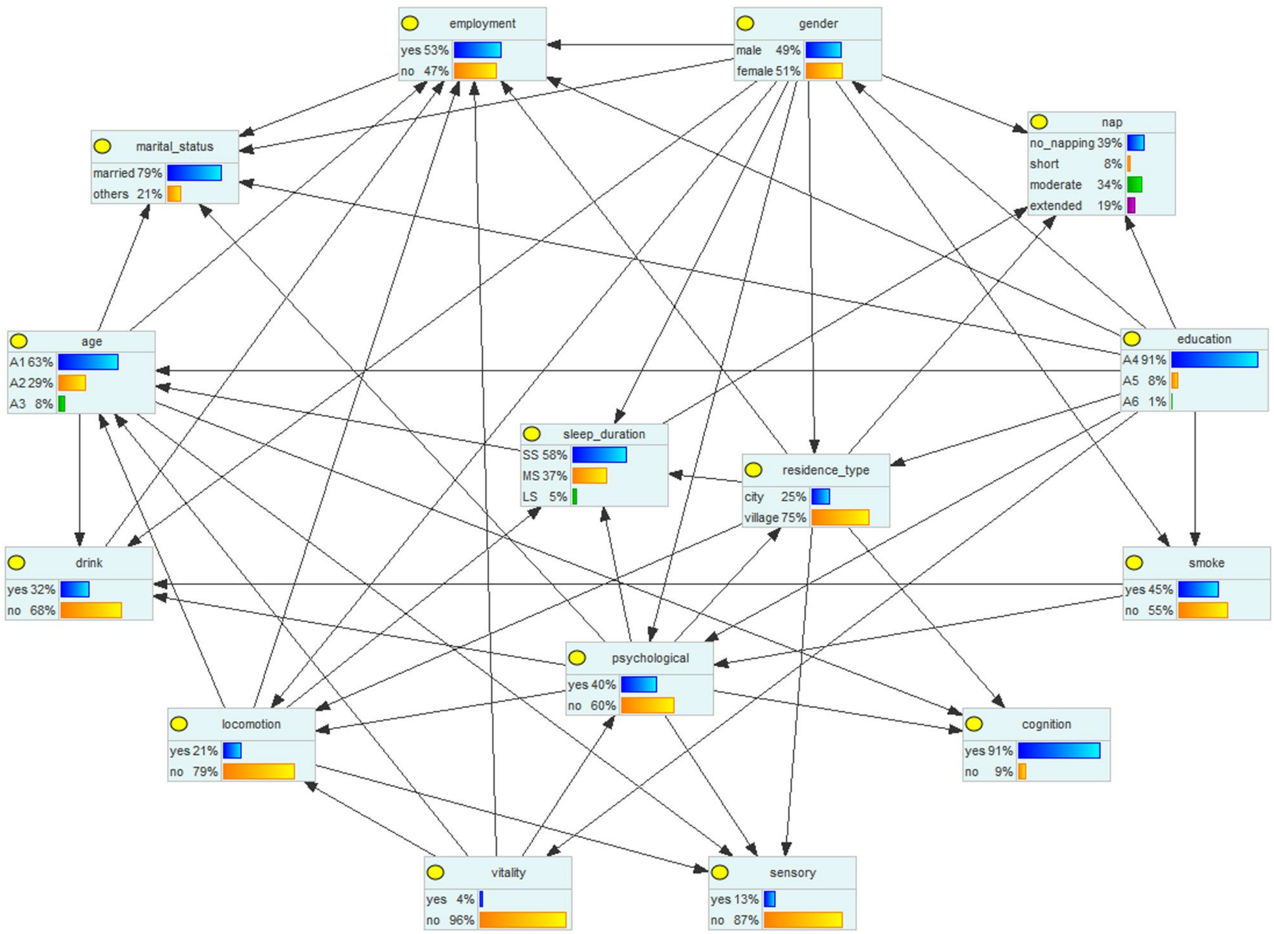

Fig. 3 Sleep duration and IC domains of impairment in BN. *A1=[60,70), A2=[70,80), A3=[80,-], A4 ≥ Junior high school, A5 ≥ Junior college, A6 ≥ College, SS=Short Sleep (< 7 h), MS=Moderate Sleep (7–9 h), LS=Long Sleep (> 9 h)

0.3%, 1.7%, and 1.9%, respectively, while the probability of psychological impairment decreased by 1.9%. These results collectively suggest that long sleep exerts a predominantly negative effect on sensory.

Sensitivity analysis

To further evaluate whether sleep duration could serve as a sensitivity index for IC in older adults, we conducted sensitivity analysis of the constructed BN using GeNIe 4.0 software. In this analysis, the five domains of IC were designated as target nodes, incorporating all relevant covariates for a comprehensive examination. Fig. 4 presented the results of the sensitivity analysis, with shading areas indicating the degree of influence—darker red hues signified a more substantial impact. The findings revealed that sleep duration remained a viable indicator for sensitivity evaluation of IC (marked in red), even after accounting for the effects of covariates. In other words, sleep duration remains a significant factor in evaluating IC sensitivity, even when other variables are accounted for, as visually represented by the red shading in the figure.

Discussion

The cumulative prevalence of IC impairment over the 9-year follow-up period was 83.1%. Longitudinal analyses showed that 44.8% of participants developed their first IC impairment within an average follow-up of 4.96 years, representing over one-third of the cohort and indicating a substantial decline in IC among Chinese older adults. Compared with moderate sleep, both short and long sleep durations were associated with increased IC impairment. BN analysis revealed that among the five IC domains, cognition exhibited the highest probability of impairment. Bayesian risk reasoning further indicated that short sleep duration predominantly impaired psychological function, whereas long sleep duration mainly affected the sensory.

These findings align with previous research on the prevalence and longitudinal evolution of IC impairment among older adults. For instance, Zhang et al., using data from the National Institute for Longevity Sciences-Longitudinal Study of Aging (NILS-LSA) in Japan and the Longitudinal Aging Study of Taipei (LAST), reported IC impairment rates of 54.9% and 37.3%, respectively

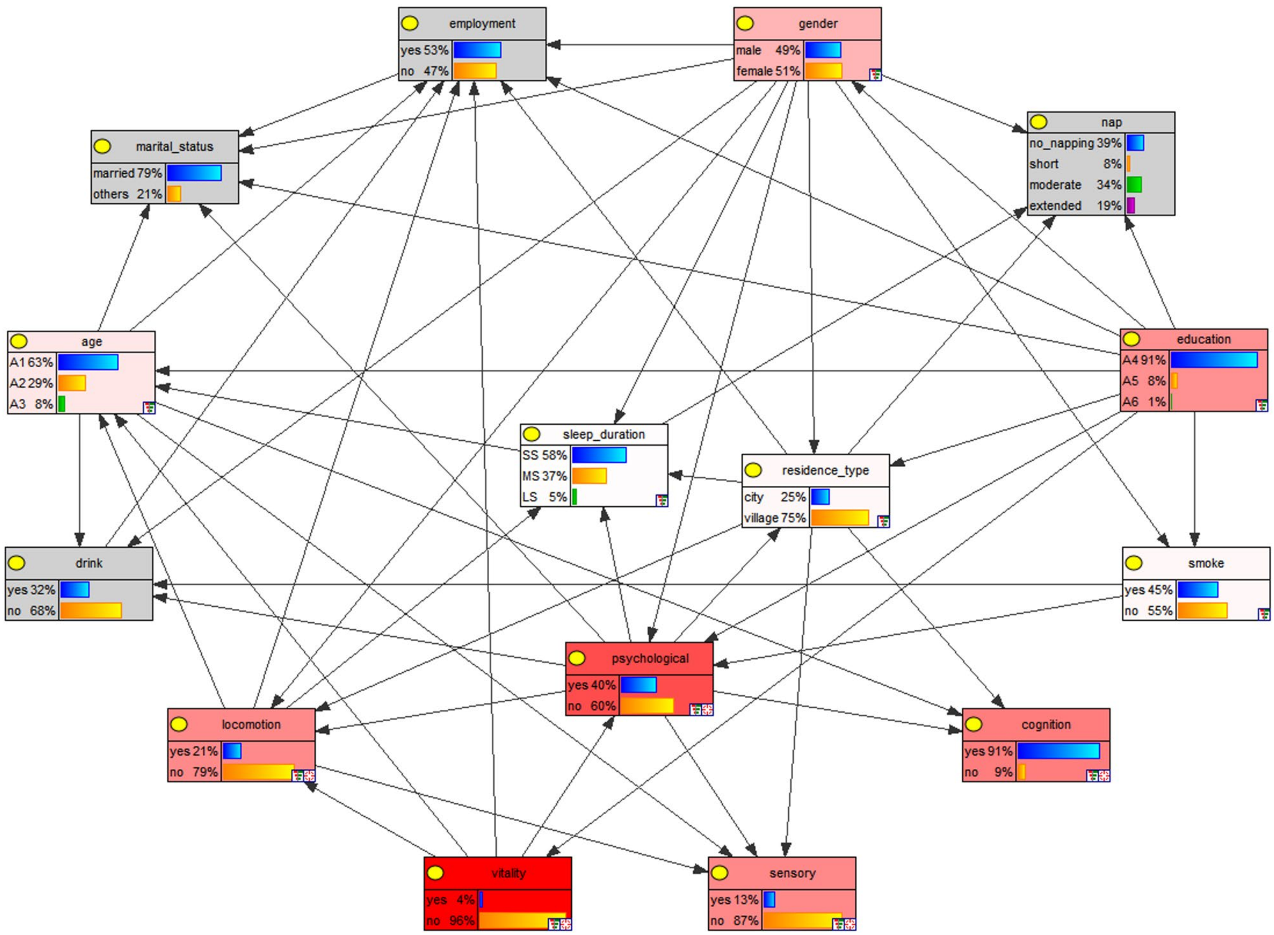

Fig. 4 Sensitivity analysis in BN. *A1=[60,70), A2=[70,80), A3=[80,-], A4 ≥ Junior high school, A5 ≥ Junior college, A6 ≥ College, SS=Short Sleep (<7 h), MS=Moderate Sleep (7–9 h), LS=Long Sleep (>9 h)

[37]. Similarly, Liu et al. found that 50.8% of older adults without baseline IC impairment developed new impairments in a Beijing community cohort [38]. Compared with these studies, our results based on the nationally representative CHARLS cohort provide complementary evidence, underscoring that IC impairment is a prevalent issue across diverse populations and cultural contexts. Differences in prevalence may reflect heterogeneity in population characteristics, measurement tools, and sociocultural determinants influencing health and lifestyle behaviors.

Consistent with prior CHARLS-based studies, we observed a nonlinear association between nighttime sleep duration and the risk of IC impairment [39, 40]. Unlike most previous cross-sectional analyses, the longitudinal design of this study provides stronger evidence supporting a temporal association between sleep duration and IC decline. Moreover, sensitivity analyses confirmed that sleep duration remains a robust indicator for evaluating IC vulnerability. Among the IC domains, cognition emerged as the most frequently impaired, consistent with previous findings. Ma et al. reported that 69.1% of participants exhibited impairment in one or more domains, with cognition being the most affected, using the ICOPE screening instrument [41]. Similarly, Zhou et al. identified cognition as the most significantly impaired domain [4]. Mechanistically, excessive or insufficient sleep has been associated with chronic low-grade inflammation [42], circadian rhythm disruption [43], and impaired emotional, metabolic, and cardiovascular regulation [44], which may increase vulnerability in IC. These sleep-related alterations substantially overlap with established mechanisms of age-related cognitive decline, including reduced neuronal regeneration, diminished synaptic plasticity, arteriosclerosis, and cerebral small vessel disease [45, 46]. Collectively, these pathways provide a plausible mechanistic explanation for how abnormal sleep may contribute to IC decline, particularly within the cognitive domain.

Our Bayesian risk reasoning further revealed domain-specific effects of sleep duration. Short sleep primarily compromised psychological function, consistent with prior studies linking insufficient sleep to depression and poor mental health [47, 48]. For example, Dong et al., analyzing the National Health and Nutrition Examination Survey (NHANES) data (2009–2016), demonstrated that short sleep duration was independently associated with higher odds of depression [49]. Conversely, long sleep duration primarily impaired sensory function. Excessive sleep may disrupt circadian rhythms, alter retinal and vestibular function, and has been linked to an elevated risk of neurodegenerative disorders, all of which may further compromise sensory capacity [50]. These domain-specific associations carry important clinical implications. Evidence from previous studies indicates that tailored sleep interventions—including cognitive behavioral therapy [51], sleep hygiene education [52], regular physical activity [53], and light therapy [54]—can improve physical and mental health among older adults. Although our data are observational and do not establish causality, they suggest that optimizing sleep duration may help preserve specific IC domains: improving sleep health among short sleepers may protect psychological function, while monitoring and optimizing sleep duration among long sleepers could help maintain sensory function. Clinically, these findings highlight the potential value of integrating sleep assessment and domain-specific IC management into comprehensive strategies aimed at maintaining multidimensional functional capacity in older adults. Future research should examine these mechanisms longitudinally and across populations from different regions, using more refined IC assessments and objective sleep measures. Such efforts will help clarify causal pathways and guide targeted interventions to promote healthy aging.

Strength and limitation

This study provides a robust longitudinal analysis using a nationally representative sample from China, employing a PPS random sampling method. A BN approach was utilized to further investigate the potential causal relationship between sleep duration and five domains of IC. The findings of this study provide a scientific foundation for the future optimization of sleep intervention strategies in the elderly population, particularly when developing health promotion measures aimed at improving sleep, considering its significant impact on psychological function. However, there are some limitations. First, our data rely on self-reported sleep duration which may be inaccurate due to recall bias. Second, sleep quality was not assessed in this study, which may have influenced IC impairment but could not be accounted for in the analysis. In addition, we excluded individuals with over 20% missing data in covariates to ensure data quality and analytical validity. However, this exclusion may have introduced selection bias, particularly if those excluded differ systematically from the included participants in unobserved ways. Finally, this study was limited by the measurement constraints of the CHARLS dataset. For example, vitality was assessed solely based on eating difficulties, and psychological function was measured using depressive symptoms. These indicators may not fully reflect the multidimensional characteristics of their respective domains. Future studies incorporating more comprehensive and validated assessments could yield a deeper understanding of IC.

Conclusions

Both short and long sleep durations were negatively associated with IC, relative to moderate sleep. Thus, to prevent IC impairment and promote healthy aging, it is crucial to ensure moderate sleep duration and to actively pursue the monitoring and management of sleep duration in older adults.

Abbreviations

IC	Intrinsic Capacity
WHO	World Health Organization
ICOPE	Integrated Care for Older People
CHARLS	China Health and Retirement Longitudinal Study
BN	Bayesian Network
DAG	Directed Acyclic Graph
PPS	Proportional to Population Size
ADL	Activities of Daily Living
CES-D-10	Center for Epidemiologic Studies Depression Scale-10
BIC	Bayesian Information Criterion
MLE	Maximum Likelihood Estimation
CPD	Conditional Probability Distribution
OR	Odds Ratio
NILS-LSA	National Institute for Longevity Sciences-Longitudinal Study of Aging
NHANES	National Health and Nutrition Examination Survey

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-026-07103-8.

Additional file 1. Comparison of distribution before and after interpolation of intrinsic capacity. Additional file 2. Comparison of distribution before and after interpolation by follow-up year. Additional file 3. Description of variable assignment. Additional file 4. Cognition conditional probability table. Additional file 5. Bayesian risk reasoning network of short sleep. Additional file 6: Bayesian risk reasoning network of moderate sleep. Additional file 7. Bayesian risk reasoning network of long sleep.

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Authors' contributions

C.X.: Writing - original draft, Methodology, Investigation, Formal analysis, Data curation, Visualization, and Conceptualization. Y.Z.: Writing - review & editing, Formal analysis, Data curation, Validation, and Methodology. L.Z.: Writing - review & editing, Validation, and Supervision. G.Z.: Writing - review & editing, Methodology, Supervision, Resources, Project administration, Formal analysis, and Conceptualization. L.Z. and G.Z. contributed equally as the corresponding authors of this manuscript.

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Data availability
To download the data used in these analyses, please visit the China Health and Retirement Longitudinal Study at https://charls.charlsdata.com/pages/data/111/zh-cn.html.

Declarations

Ethics approval and consent to participate
The original CHARLS was approved by the Biomedical Ethics Committee of Peking University (Approval number: IRB00001052-11015). Informed consent was obtained from all participants at the time of the original CHARLS data collection. This study is a secondary analysis of the de-identified CHARLS public data, no additional ethics approval or informed consent was required. The CHARLS study, and this secondary analysis, adhered to the ethical principles outlined in the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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