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Association of Sleep Characteristics with Incident Slow Gait in Chinese Older Adults: A 4-Year Longitudinal Analysis

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Research Article

Keywords: sleep, gait speed, older adults, longitudinal cohort study, CHARLS

Posted Date: September 2nd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10661305/v1

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Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Discover Public Health on November 14th, 2026. See the published version at https://doi.org/10.1186/s12982-026-03322-x.

Abstract

Background

Gait speed is a core marker of physical function in older adults. This study aimed to examine the longitudinal associations of nocturnal sleep duration and sleep quality with incident slow gait in Chinese community-dwelling older adults.

Methods

We analyzed data from the China Health and Retirement Longitudinal Study (CHARLS) 2011 baseline and 2015 follow-up. Participants aged ≥ 60 years with normal gait speed at baseline were included. Sleep duration was categorized as short (< 6 h), normal (6–8 h), or long (> 8 h). Sleep quality was classified as good/fair or poor based on self-report. Incident slow gait was defined as gait speed falling below one sex- and age-group-specific standard deviation of the mean at follow-up. Multivariable logistic regression models were used to estimate odds ratios (ORs) and 95% confidence intervals (CIs).

Results

Of 3,195 participants, 441 (13.8%) developed incident slow gait over 4 years. Compared with normal sleep duration, short sleep was associated with an increased risk of incident slow gait in the fully adjusted model (OR = 1.25, 95% CI: 1.01–1.55, P = 0.044). Long sleep duration and poor sleep quality showed no significant association with incident slow gait in the fully adjusted model. Subgroup analyses revealed no significant effect modification by sex, age, education, marital status, or residence.

Conclusion

Short nocturnal sleep duration (< 6 hours) was independently associated with incident slow gait in Chinese older adults. These findings suggest that short sleep may represent a potential target for preserving physical function in aging populations.

1. Introduction

Gait speed is a comprehensive indicator of physical function and a core marker of health in older adults. It strongly predicts fall risk, incident disability, and all-cause mortality[1–3]. Maintaining gait speed depends on intact neuromuscular control, adequate energy metabolism, and effective integration across multiple physiological systems[4]. As the global population ages rapidly, identifying and intervening on modifiable risk factors for gait speed decline has become a priority in geriatric medicine and public health[5].

In recent years, the role of sleep health in preserving functional ability among older adults has attracted growing attention. Adequate, high-quality sleep is essential for neurological repair, inflammatory regulation, hormonal homeostasis, and energy restoration[6–10]. Accumulating cross-sectional evidence suggests that both extreme sleep durations and poor subjective sleep quality are associated with worse physical performance[11–16]. However, several important limitations persist in the existing literature. First, most evidence comes from cross-sectional designs, which cannot establish temporal precedence or confirm longitudinal associations between sleep characteristics and gait speed decline[17, 18]. Second, operational definitions of the multidimensional construct of “sleep quality” vary widely across studies, and joint analyses of sleep quality together with sleep duration remain sparse[11, 19]. Third, systematic investigations specifically focused on the relationship between sleep parameters and gait speed trajectories in the Chinese older population are scarce[11].

Therefore, this study aims to systematically investigate the associations of nocturnal sleep duration and sleep quality with gait speed among older Chinese adults using data from a large, nationally representative longitudinal cohort. We utilized longitudinal follow-up data to examine whether baseline sleep characteristics predict the risk of future incident slow gait. The findings are expected to provide crucial epidemiological evidence from the perspective of sleep health for the early identification of populations at high risk of gait speed decline and for the development of targeted non-pharmacological intervention strategies.

2. Methods

2.1 Study Population

The data for this study were derived from the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative longitudinal survey of middle-aged and older adults (aged 45 years and above) in China. CHARLS employed a multistage probability-proportionate-to-size sampling design and covered approximately 12,000 households across 28 provinces, autonomous regions, and municipalities. The study protocol was approved by the Institutional Review Board of Peking University (IRB00001052-11015), and written informed consent was obtained from all participants prior to data collection. The CHARLS data are publicly available at http://charls.pku.edu.cn/.

This study used data from the 2011 baseline survey and the 2015 follow-up survey. Participants aged 60 years or older at baseline who had completed both gait speed assessments and sleep-related questionnaires were included. We excluded individuals with self-reported memory-related diseases (including Alzheimer's disease, brain atrophy, and Parkinson's disease), those with disability in activities of daily living (ADL), and those with missing baseline gait speed or sleep data. To investigate incident slow gait, we further excluded participants who already exhibited slow gait at baseline, defined as gait speed below 1 standard deviation of the sex- and age-group-specific mean. Among the remaining participants, we additionally excluded those with missing gait speed at the 2015 follow-up and those with biologically implausible values for anthropometric measurements (body mass index < 10 or > 80

kg/m^2, systolic blood pressure < 60 or > 250 mmHg, diastolic blood pressure < 40 or > 150 mmHg, and waist circumference < 50 or > 200 cm).

2.2 Sleep Variables

Two sleep-related questions were collected through face-to-face interviews: (1) nocturnal sleep duration: Sleep duration was assessed based on the question: “During the past month, how many hours of actual nocturnal sleep did you get on average?” It was treated as a continuous variable and further categorized based on commonly used clinical cutoffs into three groups: short sleep (< 6 hours), normal sleep (6–8 hours), and long sleep (> 8 hours). (2) Sleep quality: Sleep quality was assessed based on the question: “I slept poorly.” Responses of “Rarely or none of the time (< 1 day)” and “Some or a little of the time (1–2 days)” were defined as “good/fair sleep quality”, while responses of “Occasionally or a moderate amount of the time (3–4 days)” and “Most or all of the time (5–7 days)” were defined as “poor sleep quality”.

2.3 Gait Speed Measurement and Outcome Definition

Gait speed was measured in an open space approximately 4 meters long without carpeting, with a 2.5-meter line marked as the walking path. Interviewers instructed respondents to walk this path twice and accompanied them during the test. Respondents started walking from the test starting point by lifting their leg at the commencement of the test.

Baseline slow gait was defined as a gait speed below 1 standard deviation (SD) of the sex- and age-group-specific mean at the 2011 baseline assessment. Specifically, sex-specific means and SDs were calculated for two age groups (60–74 years and ≥ 75 years) using the baseline data, and the threshold for slow gait was determined as the mean minus 1 SD for each stratum. Participants with baseline slow gait were excluded from the longitudinal analysis.

Incident slow gait, the primary longitudinal outcome of this study, was defined as progression to slow gait at the 2015 follow-up among participants who had normal gait speed at baseline. The same sex- and age-group stratification and the same 1 SD criterion were applied to define the slow gait threshold at follow-up, using the follow-up data to calculate the stratum-specific means and SDs. Participants with normal gait speed at both baseline and follow-up were classified as the maintained normal gait group.

2.4 Covariates

Based on previous literature and clinical relevance, the following baseline covariates were adjusted for in the statistical analyses: age (continuous, in years), sex (male/female), education (primary or below/high school/college+), marital status (married/unmarried), smoking status (no/yes), frequency of alcohol consumption (never, less than once a month, and more than once a month), and body mass index (kg/m^2). Regarding chronic medical history, hypertension was defined as systolic blood pressure ≥ 140mmHg or diastolic blood pressure ≥ 90mmHg, or self-reported physician-diagnosed hypertension, or current use of antihypertensive medications. Diabetes mellitus was defined as fasting blood glucose ≥ 126 mg/dL (≥ 7.0 mmol/L), or self-reported physician-diagnosed diabetes, or use of glucose-lowering

medications. Heart disease and dyslipidemia were defined based on self-reported physician-diagnosed disease history. Model 2 and Model 3 were further adjusted for continuous baseline gait speed to control for ceiling effects and regression to the mean. Additionally, several blood biomarkers (including cystatin C, CRP, blood urea nitrogen, creatinine, and lipid profiles) were measured at baseline and are presented in Table 1 for descriptive comparisons between groups; however, they were not included as covariates in the primary multivariable models due to their potential role as intermediates rather than confounders in the pathway between sleep and physical function.

Table 1
Baseline Characteristics of the Study Population.

Age (mean (SD))	**Maintained Normal Gait group (n = 2754)**	**Incident Slow Gait group (n = 441)**	**P value**
	66.71 (5.74)	**68.16 (6.32)**	**< 0.001**
Sex (Female, %)	1333 (48.4)	235 (53.3)	0.064
BMI (mean (SD))	22.93 (3.86)	22.81 (4.10)	0.547
WC (mean (SD))	84.94 (10.01)	84.68 (10.78)	0.61
SBP (mean (SD))	133.29 (21.87)	136.80 (23.77)	0.002
DBP (mean (SD))	74.43 (11.26)	74.88 (12.15)	0.439
Education (%)			0.022
primary or below	2606 (94.6)	428 (97.1)	
high school	108 (3.9)	13 (2.9)	
college or above	40 (1.5)	0 (0.0)	
Marital (unmarried, %)	539 (19.6)	110 (24.9)	0.011
Residence (urban, %)	177 (6.4)	20 (4.5)	0.153
Smoking (%)	1198 (43.5)	180 (40.8)	0.315
Drinking (%)			0.089
None of these	1860 (67.5)	321 (72.8)	
Drink less than once a month	175 (6.4)	24 (5.4)	
Drink more than once a month	719 (26.1)	96 (21.8)	
Hypertension (%)	1299 (47.2)	226 (51.2)	0.123
Diabetes (%)	420 (15.3)	67 (15.2)	0.999
Heart disease (%)	362 (13.1)	83 (18.8)	0.002
Hyperlipidemia (%)	263 (9.5)	41 (9.3)	0.936
Glucose (mean (SD))	111.02 (34.84)	110.69 (29.34)	0.869
TG (mean (SD))	126.12 (93.87)	121.45 (114.97)	0.407
HDL (mean (SD))	52.04 (15.57)	53.51 (16.18)	0.107

Note: Due to the small number of participants with college-level education or above in the incident slow gait group (n = 0), the education variable was retained as a three-level ordinal variable in the primary analyses, but results should be interpreted with caution for the highest category.

Age (mean (SD))	Maintained Normal Gait group (n = 2754)	Incident Slow Gait group (n = 441)	P value
	66.71 (5.74)	**68.16 (6.32)**	**< 0.001**
LDL (mean (SD))	118.55 (34.87)	116.58 (36.42)	0.334
TC (mean (SD))	195.07 (38.14)	192.24 (42.37)	0.208
CRP (mean (SD))	2.65 (6.42)	3.30 (7.25)	0.087
BUN (mean (SD))	16.30 (4.43)	16.36 (4.96)	0.811
Creatinine (mean (SD))	0.81 (0.20)	0.80 (0.21)	0.416
Cystatin C (mean (SD))	1.07 (0.25)	1.15 (0.32)	< 0.001
Nocturnal sleep duration (mean (SD))	6.25 (1.94)	5.96 (2.12)	0.004
Sleep quality category (%)			0.005
Rarely or none of the time	1355 (49.2)	182 (41.3)	
Some or a little of the time	465 (16.9)	74 (16.8)	
Occasionally or a moderate amount of the time	412 (15.0)	75 (17.0)	
Most or all of the time	522 (19.0)	110 (24.9)	

Note: Due to the small number of participants with college-level education or above in the incident slow gait group (n = 0), the education variable was retained as a three-level ordinal variable in the primary analyses, but results should be interpreted with caution for the highest category.

2.5 Statistical Analysis

All statistical analyses were performed using R software (version 4.5.1). Continuous variables were presented as mean ± standard deviation, and categorical variables as frequencies and percentages. Participants were classified into the incident slow gait group and the maintained normal gait group according to their gait speed status at the 2015 follow-up; between-group comparisons were performed using the two-sample t-test for continuous variables and the chi-square test for categorical variables.

Multivariable logistic regression models were employed to examine the associations between baseline sleep characteristics and incident slow gait at follow-up. Three progressively adjusted models were constructed: Model 1 was unadjusted; Model 2 adjusted for age, sex, and continuous baseline gait speed; Model 3 further adjusted for education, marital status, smoking status, frequency of alcohol consumption, body mass index, hypertension, diabetes, heart disease, and hyperlipidemia based on Model 2. Results were expressed as odds ratios (ORs) with their 95% confidence intervals (CIs).

To evaluate the robustness of the associations across different population subgroups, subgroup analyses were performed stratified by sex (male/female), age group (60–74 years, ≥ 75 years),

educational level (primary school or below, high school), marital status (married/unmarried), and residence (rural/urban). Due to zero events in the college-or-above category within the incident slow gait group, education was dichotomized into primary school or below and high school or above for subgroup analyses. Within each subgroup, multivariable-adjusted logistic regression models were fitted separately, and forest plots were generated. Interactions between subgroup variables and sleep exposures were assessed using likelihood ratio tests comparing models with and without interaction terms, and P values for interaction were calculated. A two-sided P value < 0.05 was considered statistically significant.

3. Results

3.1 Baseline Characteristics of the Study Population

The participant selection process is detailed in Fig. 1. Of the 3,195 participants with normal gait speed at baseline, 2,754 (86.2%) maintained normal gait speed at the 4-year follow-up, while 441 (13.8%) developed incident slow gait. Baseline characteristics of the two groups are presented in Table 1. Compared with participants who maintained normal gait speed, those who developed slow gait were older (mean age 68.16 vs. 66.71 years, P < 0.001), had higher systolic blood pressure (136.80 ± 23.77 vs. 133.29 ± 21.87mmHg, P = 0.002), and were more likely to have lower educational attainment (primary school or below: 97.1% vs. 94.6%, P = 0.022), be unmarried (24.9% vs. 19.6%, P = 0.011), and have prevalent heart disease (18.8% vs. 13.1%, P = 0.002). Mean serum cystatin C level was also higher in the incident slow gait group (1.15 ± 0.32 vs. 1.07 ± 0.25 mg/L, P < 0.001). Regarding sleep parameters, the incident slow gait group had shorter mean nocturnal sleep duration at baseline (5.96 ± 2.12 vs. 6.25 ± 1.94 hours, P = 0.004) and a higher proportion reporting poor sleep quality (responses of “most or all of the time”: 24.9% vs. 19.0%, P = 0.005). No statistically significant between-group differences were observed for sex, body mass index, waist circumference, diastolic blood pressure, smoking status, alcohol consumption, diabetes, or lipid profile (all P > 0.05).

3.2 Longitudinal Associations of Sleep Characteristics with Incident Gait Speed

Multivariable logistic regression results are summarized in Table 2. Using normal sleep duration (6–8 hours) as the reference, short sleep duration (< 6 hours) was significantly associated with an elevated risk of incident slow gait in the unadjusted model (OR = 1.36, 95% CI: 1.10–1.68, P = 0.004). This association remained significant after adjustment for age, sex, and baseline gait speed (OR = 1.26, 95% CI: 1.02–1.56, P = 0.036), and was essentially unchanged with additional adjustment for education, marital status, smoking, alcohol consumption, body mass index, hypertension, diabetes, heart disease, and hyperlipidemia (OR = 1.25, 95% CI: 1.01–1.55, P = 0.044). Long sleep duration (> 8 hours) was not significantly associated with incident slow gait in any model (fully adjusted OR = 0.95, 95% CI: 0.64–1.42, P = 0.818).

Table 2
Longitudinal associations of baseline nocturnal sleep duration and sleep quality with incident slow gait over 4 years of follow-up

Sleep variants	Model1		Model2		Model3	
	OR (95%CI)	P value	OR (95%CI)	P value	OR (95%CI)	P value
Nocturnal sleep duration						
6–8(ref)	reference		reference		reference	
< 6	1.36 (1.10–1.68)	0.004	1.26 (1.02–1.56)	0.036	1.25 (1.01–1.55)	0.044
> 8	0.96 (0.65–1.42)	0.852	0.96 (0.65–1.43)	0.848	0.95 (0.64–1.42)	0.818
Poor sleep quality	1.41 (1.15–1.73)	0.001	1.25 (1.01–1.55)	0.037	1.22 (0.99–1.51)	0.066

Note: Data are presented as odds ratio (95% confidence interval). Model 1 was unadjusted. Model 2 adjusted for age, sex, and continuous baseline gait speed. Model 3 additionally adjusted for education, marital status, smoking status, alcohol consumption, body mass index, hypertension, diabetes, heart disease, and hyperlipidemia. The education variable was categorized as primary or below, high school, and college or above. Owing to zero events in the college-or-above category within the incident slow gait group, estimates for this level may be unstable; however, the overall variable was retained as specified in the analytical plan.

Poor sleep quality, compared with good/fair sleep quality, was associated with incident slow gait in the unadjusted model (OR = 1.41, 95% CI: 1.15–1.73, P = 0.001) and after adjustment for age, sex, and baseline gait speed (OR = 1.25, 95% CI: 1.01–1.55, P = 0.037). However, after full covariate adjustment, the association was attenuated and did not reach statistical significance (OR = 1.22, 95% CI: 0.99–1.51, P = 0.066).

3.3 Subgroup Analyses

Subgroup analyses examined the consistency of the associations across strata of sex, age group, education level, marital status, and residence (Figs. 2 and 3). For short sleep duration, likelihood ratio tests for interaction yielded P values of 0.212 for sex, 0.664 for age, 0.746 for education, 0.054 for marital status, and 0.221 for residence, indicating no statistically significant heterogeneity across these subgroups. Similarly, for poor sleep quality, the corresponding interaction P values were 0.558, 0.866, 0.910, 0.751, and 0.579, respectively, all exceeding the 0.05 threshold. These results suggest that the observed associations were generally consistent across the examined population subgroups.

4. Discussion

In this large-scale longitudinal cohort of Chinese older adults, we found that baseline nocturnal sleep duration of less than 6 hours was associated with an increased risk of incident slow gait over 4 years of

follow-up. This association remained robust after comprehensive adjustment for demographic characteristics, lifestyle factors, BMI, baseline gait speed and multiple chronic conditions. In contrast, long sleep duration (> 8 hours) showed no significant association with slow gait in the fully adjusted model. Poor sleep quality was associated with slow gait in unadjusted and partially adjusted models, but this association was attenuated and no longer statistically significant after full covariate adjustment. Subgroup analyses revealed no statistically significant evidence of heterogeneity across strata of sex, age, education, marital status, or residence.

Our findings further extend the evidence chain linking sleep to physical function, underscoring that sleep duration retains independent predictive value for maintaining gait speed even after controlling for traditional risk factors. Notably, we did not observe a significant association between long sleep duration and slower gait speed in the fully adjusted model, a finding that diverges from some previous studies[11]. Such discrepancies may stem from differences in population characteristics, definitions of long sleep, or the extent of adjustment for comorbidities. Interestingly, we observed an asymmetry, suggesting that the potential harms of short sleep may be more salient in our study. This is supported by recent research. Holingue et al. similarly found that only short sleep, but not long sleep, was associated with gait speed decline[20]. Li et al. demonstrated that short and long sleep have distinct genetic architectures, and that long sleep may be a consequence, rather than a cause, of various chronic diseases (e.g., neurodegenerative disorders)[21]. Therefore, the lack of association between long sleep and incident slow gait after full adjustment may reflect that the effect of long sleep is largely confounded or mediated by underlying health conditions or related body composition changes (e.g., sarcopenia, obesity). By rigorously adjusting for these factors, the independent effect of long sleep was no longer significant. This finding reinforces the hypothesis that long sleep may serve more as a marker of health risk than a direct causal factor.

Subgroup analyses did not detect statistically significant interactions, suggesting that the observed associations were generally consistent across the demographic and socioeconomic strata examined. Although the interaction P values were non-significant, the point estimates suggested potentially larger effect sizes among men, individuals with lower educational attainment, married participants, and rural residents. These patterns, while exploratory and not statistically confirmed, may offer hypothesis-generating directions for future investigations and should be interpreted with caution.

Regarding potential pathophysiological mechanisms, short sleep duration and poor sleep quality may influence gait speed through multiple pathways. First, deep sleep stages are crucial for growth hormone secretion and muscle protein synthesis; insufficient sleep may directly impair muscle repair and regeneration capacity, leading to decreased muscle strength[22]. Second, sleep deprivation is often accompanied by elevated systemic inflammation, with increased pro-inflammatory cytokines such as interleukin-6, and this chronic low-grade inflammatory state can accelerate muscle breakdown and affect neuromuscular function[22, 23]. Furthermore, sleep is essential for maintaining function in motor control brain regions including the prefrontal cortex and basal ganglia[22, 24]; inadequate sleep may impair motor coordination and executive function, thereby affecting gait control. Finally, sleep

disturbances can disrupt circadian rhythms and energy metabolism, increase daytime fatigue, and reduce activity tolerance[25].

This study has several strengths, including the use of a large-scale longitudinal cohort, objectively measured gait speed, and 4-year follow-up. Nevertheless, several limitations warrant consideration. First, the definition of slow gait speed was based on wave-specific, age-specific and sex-specific cutoffs derived from the CHARLS sample distribution. Although this approach has precedent in previous studies, it may introduce measurement variability across waves and cannot fully exclude potential survivorship bias. Second, sleep duration and quality were assessed via self-report through face-to-face interviews, which may be subject to recall and social desirability biases. Moreover, sleep quality was measured using a single item (“I slept poorly”) rather than a validated multidimensional instrument. These measurement constraints are inherent to the CHARLS dataset and may have attenuated the observed associations. Future studies incorporating objective sleep measures such as polysomnography and validated sleep quality instruments such as the Pittsburgh Sleep Quality Index would help to more comprehensively elucidate the relationship between sleep quality and gait. Third, despite adjusting for a broad range of covariates, residual confounding by unmeasured factors cannot be excluded. For example, physical activity level, medication use (particularly sedative-hypnotics and antidepressants), and dietary patterns were not included in our models and may confound the observed associations. The direction of this potential bias is unclear but could have either overestimated or underestimated the true associations. Fourth, although we excluded participants with baseline memory-related diseases and ADL disability, our sample may still represent a relatively healthier subset of the older population due to the exclusion of participants with missing follow-up gait data. This “healthy survivor” selection bias may limit the generalizability of our findings to more vulnerable populations and may have attenuated the strength of the observed associations. Finally, as the study sample was derived from a single cohort, the findings may not be directly generalizable to other racial, ethnic, or cultural populations. Replication in diverse populations is warranted to confirm the external validity of our results.

5. Conclusions

In this 4-year longitudinal study of community-dwelling older Chinese adults, short nocturnal sleep duration (< 6 hours) was independently associated with incident slow gait speed. These findings suggest that short sleep may represent a potential intervention target for preserving physical function in aging populations. Further research using objective sleep measures and rigorous causal inference frameworks is needed to confirm these associations and elucidate the underlying mechanisms.

Abbreviations

ADL	activities of daily living
BMI	body mass index
BUN	blood urea nitrogen
CHARLS	China Health and Retirement Longitudinal Study
CI	confidence interval
CRP	C-reactive protein
DBP	diastolic blood pressure
HDL	high-density lipoprotein cholesterol
IRB	Institutional Review Board
LDL	low-density lipoprotein cholesterol
OR	odds ratio
SBP	systolic blood pressure
SD	standard deviation
TC	total cholesterol
TG	triglycerides
WC	waist circumference

Declarations

Funding: This study was supported by The High-Quality Clinical Research Fund of Tongji Hospital (2024TJCR013 to X. Luo), Integrated Chinese and Western Medicine Project for Chronic Disease Management (CXZH2024014 to X. Luo), Interdisciplinarity research program of Huazhong University of Science and Technology (2023JCYJ030 to X. Luo), Medical innovation and transformation incubation project of Tongji Hospital (2022CXZH010 to X. Luo), the Chutian Talent Programme—Science and Technology Innovation Team to X. Luo. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Ethics declaration

Informed consent and patient details

Written informed consent to take part in the study and to publish the article has been obtained from all participants or their legal representatives. The privacy rights of participants have been observed.

Studies in Human

This study was performed in compliance with relevant laws, regulatory frameworks and guidelines where the research took place.

This study was conducted in accordance with the Declaration of Helsinki.

This study was approved by the the Institutional Review Board of Peking University.

(Approval No. IRB00001052-11015)

Author Contributions: Conceptualization, Q.K. and X.L.; methodology, J.L. and L.L.; formal analysis, Z.W. and X.Z.; investigation, Y.Z. and Y.X.; resources, Z.Y. and H.H.; data curation, Q.K.; writing—original draft preparation, Q.K.; writing—review and editing, all authors; visualization, Q.K.; supervision, H.H. and X.L.; project administration, X.L. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Data Availability Statement: The CHARLS data are publicly available at the official website of the China Health and Retirement Longitudinal Study: https://charls.pku.edu.cn/. All data used in this study can be accessed by researchers upon registration and approval from the CHARLS team.

Acknowledgments: We thank the China Center for Economic Research, the National School of Development of Peking University for providing the data.

Clinical trial number: not applicable.

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Figures

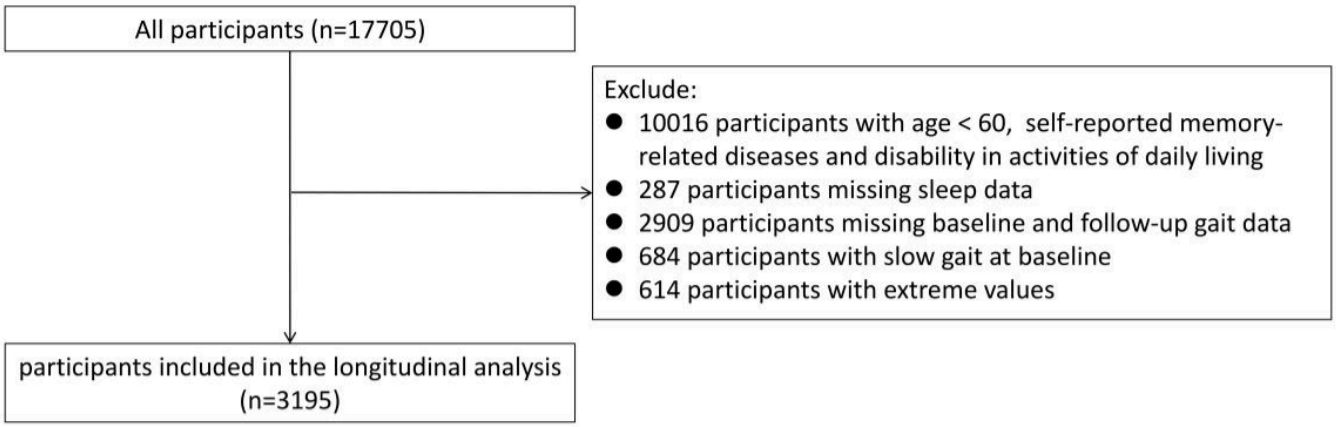


Figure 1

Flowchart of participant selection

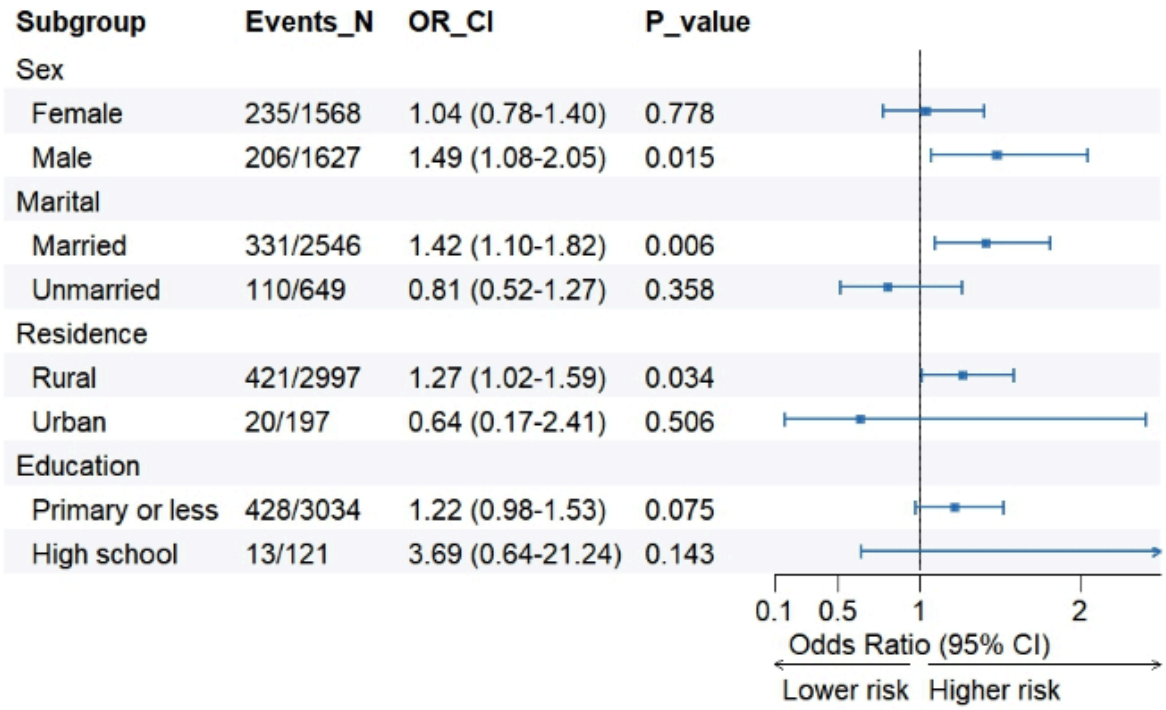


Figure 2

Subgroup analyses for the longitudinal associations of nocturnal sleep duration(<6h) with incident slow gait.

Note: P for interaction: sex = 0.212, age = 0.664, education = 0.746, marital status = 0.054, and residence = 0.221.

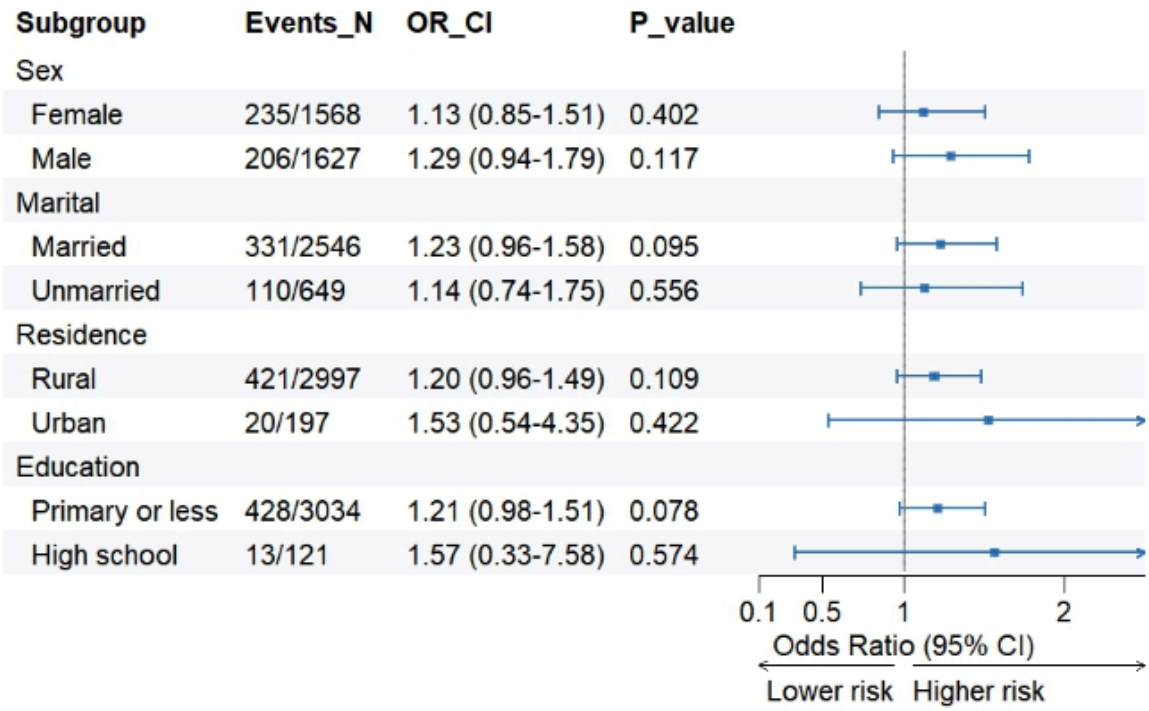


Figure 3

Subgroup analyses for the longitudinal associations of poor sleep quality with incident slow gait speed.

Note: P for interaction: sex = 0.558, age = 0.886, education = 0.910, marital status = 0.751, and residence = 0.579.