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Independent and Joint Associations of Social Isolation and Abnormal Sleep with Functional Disability Trajectories in Middle-aged and Older Adults

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Abstract

Background

Functional disability is a key precursor to loss of independence and reduced quality of life in middle-aged and older adults. This study examined the independent and joint associations of social isolation and abnormal nighttime sleep with long-term functional disability trajectories.

Methods

Data were collected from the China Health and Retirement Longitudinal Study (CHARLS) from 2011 to 2020. Group-based trajectory modelling (GBTM) was used to identify trajectories of functional disability. The main exposures were abnormal nighttime sleep (< 6 h or > 9 h) and social isolation. Multinomial logistic regression was used to examine the associations of abnormal sleep, social isolation, and their joint exposure with functional disability trajectories.

Results

Three functional disability trajectories were identified: low-stable (n = 11,062, 83.9%), moderate-increasing (n = 1,540, 11.7%), and high-increasing (n = 589, 4.5%). After full adjustment, social isolation was associated with higher relative likelihoods of the moderate-increasing (RRR = 1.54, 95%CI: 1.36–1.74) and high-increasing trajectories (RRR = 1.61, 95%CI: 1.31–1.99). Abnormal sleep was also associated with the moderate-increasing (RRR = 1.37, 95%CI: 1.21–1.56) and high-increasing trajectories (RRR = 1.95, 95%CI: 1.59–2.39). Participants with both exposures had the highest relative likelihoods of the moderate-increasing (RRR = 2.11, 95%CI: 1.77–2.50) and high-increasing trajectories (RRR = 3.14, 95%CI: 2.36–4.17). The association of abnormal sleep was stronger in women (P for interaction = 0.014).

Conclusions

Social isolation and abnormal sleep were associated with adverse functional disability trajectories, with the highest relative likelihood observed when both exposures coexisted. Promoting social participation and sleep health may help delay functional decline.

Introduction

Population ageing has made functional disability a central public health concern[1]. Functional disability compromises independence, increases health service use, raises the demand for long-term care and reduces quality of life. It is commonly assessed through basic activities of daily living (ADLs) and

instrumental activities of daily living (IADLs), which together provide a comprehensive measure of functional capacity[2].

Previous studies have often treated functional disability as a binary or cross-sectional outcome. However, functional decline is a dynamic and heterogeneous process. Some individuals maintain low levels of disability over time, whereas others experience gradual or rapid functional decline. Group-based trajectory modelling provides a useful method for identifying subgroups of individuals with similar longitudinal patterns[3]. This approach can reveal distinct developmental courses of disability and may help identify modifiable risk factors that precede more adverse functional trajectories.

Social isolation and sleep are two potentially modifiable determinants of healthy ageing. Social isolation has been associated with functional disability and mortality, while abnormal sleep duration has been linked to a range of adverse health outcomes[4–6]. In real-world ageing populations, these exposures may coexist. However, whether they are independently associated with long-term functional disability trajectories, and whether their coexistence identifies a higher-risk group, remains unclear in Chinese cohorts.

This study aims to identify functional disability trajectories among middle-aged and older Chinese adults and to examine the independent and joint associations of social isolation and abnormal nighttime sleep with these trajectories, as well as potential differences by age and sex.

Methods

Study population

This study used data from the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative longitudinal survey of Chinese adults. The baseline survey was conducted in 2011, with follow-up waves conducted every 2–3 years. The data collection for CHARLS was ethically approved by the Biomedical Ethics Review Committee of Peking University, with the approval number IRB00001052-11015, and is open to the academic community without the need for additional ethical approval[7].

The present study used five waves of data from 2011 to 2020. At baseline, 17,708 participants were enrolled. We excluded participants aged younger than 45 years (n = 648), participants with missing baseline functional disability data (n = 327), participants with missing social isolation data (n = 1,587), participants with missing nighttime sleep duration data (n = 125), and participants with fewer than two assessments of ADL/IADL information across the four follow-up waves (n = 1,830). 13,191 participants were included in final analysis, as shown in Fig. 1.

Functional disability and trajectory modelling

ADLs comprised six basic activities (dressing, bathing, eating, transferring in/out of bed, toileting, and continence), each scored 1 point, if the participant reported difficulty. IADLs were assessed across five tasks: housework, meal preparation, grocery shopping, medication management, and financial management. The total functional disability score ranged from 0 to 11, with higher scores indicating greater functional disability[8].

Group-based trajectory modelling (GBTM) was used to identify groups of participants with similar patterns of longitudinal data. The optimal number of groups and best-fitting model were determined based on the minimization of the absolute BIC, AIC and group size. The three-group model was retained as the final model (Fig S1).

Social isolation

Social isolation was measured using a composite score derived from four self-reported indicators in the 2011 survey[9]: (1) unmarried, including separated, divorced, widowed, or never married; (2) contact with all children less than once per week via in-person visits, phone calls, text messages, mail, or email; (3) no participation in any social activities; and (4) rural residence. Each item was scored 1 point, and a total score ≥ 2 was defined as social isolation.

Abnormal nighttime sleep

Nighttime sleep duration was assessed with the question: "During the past month, how many hours of actual sleep did you get every night? (mean hours per night)." Nighttime sleep duration less than 6 hours or more than 9 hours were classified as abnormal; 6–9 hours were considered normal[10]. The reliability of self-reported nighttime sleep duration has been validated in sleep epidemiology research[11].

Covariates

Baseline covariates included sociodemographic characteristics, health behaviours, and health status. Sociodemographic characteristics included age, sex, and educational level (below junior high school, senior high school and vocational school, college and above). Health behaviours included smoking status (ever smoking or never) and drinking status (ever drinking or never). Health status included physician-diagnosed hypertension, dyslipidemia, and diabetes, which were assessed by asking participants whether a doctor had ever told them that they had been diagnosed with these conditions. Body mass index (BMI) was calculated as weight in kilograms divided by height in metres squared (kg/m^2).

Statistical analysis

Baseline characteristics were compared across the three functional disability trajectories. Continuous variables were expressed as mean and standard deviation, while categorical variables were presented as frequencies and percentages. Continuous variables were compared using one-way analysis of variance (ANOVA), and categorical variables were analyzed using the chi-square test.

Multinomial logistic regression was used to estimate relative risk ratios (RRRs) and 95% confidence intervals in the moderate-increasing and high-increasing trajectories, using the low-stable trajectory as the reference. Model 1 was unadjusted. Model 2 was adjusted for age, sex, hypertension, dyslipidemia, diabetes, smoking, drinking, educational level and BMI. To examine joint associations, participants were classified into four exposure groups: no social isolation with normal sleep, social isolation with normal sleep, no social isolation with abnormal sleep, and both social isolation and abnormal sleep. All statistical analyses were performed using R (4.5.2). A two-sided P value less than 0.05 was considered statistically significant.

Results

Baseline characteristics of three trajectories of functional disability.

GBTM identified three distinct functional disability trajectory groups: a low-stable trajectory group (Group 1, n = 11,062, 83.9%), a moderate-increasing trajectory group (Group 2, n = 1,540, 11.7%), and a high-increasing trajectory group (Group 3, n = 589, 4.5%), as shown in Fig. 2. Compared with participants in the low-stable group, those in the moderate- and high-increasing trajectory groups were older, more likely to be female, had lower educational levels, and had higher proportions of being unmarried and living in rural areas. They also had higher prevalences of hypertension, dyslipidemia, and diabetes. BMI did not differ significantly across the three groups (P = 0.551). Social isolation and abnormal sleep showed increasing trends across the trajectory groups, with the highest prevalence observed in the high-increasing group (Table 1).

Table 1
Baseline characteristics of participants across three trajectory groups of functional disability.

Characteristic	Trajectory Group			P-value
	Low-stable (n = 11,062)	Moderate-increasing (n = 1,540)	High-increasing (n = 589)	
Age, years, mean (SD)	57.66 (8.54)	63.80 (9.73)	67.33 (9.91)	< 0.001
Sex, n (%)				< 0.001
Female	5650 (51.1)	993 (64.5)	335 (56.9)	
Male	5412 (48.9)	547 (35.5)	254 (43.1)	
Education, n (%)				< 0.001
Below junior high school	9640 (87.1)	1472 (95.6)	560 (95.1)	
Senior high school and vocational school	1225 (11.1)	57 (3.7)	25 (4.2)	
College and above	197 (1.8)	11 (0.7)	4 (0.7)	
Marital status, n (%)				< 0.001
Married	10019 (90.6)	1252 (81.3)	464 (78.8)	
Unmarried	1043 (9.4)	288 (18.7)	125 (21.2)	
Residence, n (%)				< 0.001
Urban	4314 (39.0)	466 (30.3)	184 (31.2)	
Rural	6748 (61.0)	1074 (69.7)	405 (68.8)	
BMI, kg/m², mean (SD)	23.56 (3.76)	23.60 (4.52)	23.37 (4.10)	0.551
Ever smoking, Yes, n (%)	4412 (39.9)	522 (33.9)	220 (37.4)	< 0.001
Ever drinking, Yes, n (%)	4438 (40.1)	506 (32.9)	210 (35.7)	< 0.001
Hypertension, Yes, n (%)	2533 (23.0)	564 (36.8)	269 (45.8)	< 0.001
Dyslipidemia, Yes, n (%)	1018 (9.4)	183 (12.1)	90 (15.6)	< 0.001
Diabetes, Yes, n (%)	581 (5.3)	134 (8.8)	54 (9.3)	< 0.001
Social isolation, Yes, n (%)	4222 (38.2)	814 (52.9)	344 (58.4)	< 0.001
Nighttime sleep, n (%)				< 0.001

Characteristic	Trajectory Group			P-value
	Low-stable (n = 11,062)	Moderate-increasing (n = 1,540)	High-increasing (n = 589)	
Normal	7637 (69.0)	875 (56.8)	268 (45.5)	
Abnormal	3425 (31.0)	665 (43.2)	321 (54.5)	

Independent associations of social isolation and abnormal sleep on functional disability trajectories.

In the unadjusted model, both social isolation and abnormal sleep duration were significantly associated with moderate- and high-increasing functional disability trajectories. After full adjustment, social isolation remained associated with the moderate-increasing trajectory (RRR = 1.54, 95% CI: 1.36–1.74; P < 0.001) and the high-increasing trajectory (RRR = 1.61, 95% CI: 1.31–1.99; P < 0.001). Compared with normal sleep, abnormal sleep was associated with higher relative likelihoods of the moderate-increasing trajectory (RRR = 1.37, 95% CI: 1.21–1.56; P < 0.001) and the high-increasing trajectory (RRR = 1.95, 95% CI: 1.59–2.39; P < 0.001). These findings indicate that social isolation and abnormal sleep were independently associated with adverse functional disability trajectories (Table 2).

Table 2
Independent associations of social isolation and abnormal sleep on functional disability trajectories.

Variables	Model 1		Model 2	
	Moderate-increasing vs. Low-stable	High-increasing vs. Low-stable	Moderate-increasing vs. Low-stable	High-increasing vs. Low-stable
Social isolation				
No social isolation	Ref.	Ref.	Ref.	Ref.
Social isolation	1.82 (1.63, 2.02)**	2.27 (1.92, 2.69)**	1.54 (1.36, 1.74)**	1.61(1.31, 1.99)**
Nighttime sleep				
Normal	Ref.	Ref.	Ref.	Ref.
Abnormal	1.70 (1.52, 1.89)**	2.67 (2.26, 3.15)**	1.37(1.21, 1.56)**	1.95 (1.59, 2.39)**
Model 1: unadjusted model;				
Model 2: adjusted for age, sex, hypertension, dyslipidemia, diabetes, smoking, drinking, educational level and BMI.				
**$P < 0.001$				

Joint associations of social isolation and abnormal sleep on functional disability trajectories.

Compared with participants without social isolation and with normal sleep, those with both social isolation and abnormal sleep had the highest relative likelihoods of adverse functional disability trajectories, with an RRR of 2.11 (95% CI: 1.77–2.50; P < 0.001) for the moderate-increasing trajectory and 3.14 (95% CI: 2.36–4.17; P < 0.001) for the high-increasing trajectory. Social isolation alone was associated with higher relative likelihoods of the moderate-increasing trajectory (RRR = 1.56, 95% CI: 1.32–1.83; P < 0.001) and the high-increasing trajectory (RRR = 1.63, 95% CI: 1.22–2.19; P < 0.001). Abnormal sleep alone was also associated with higher relative likelihoods of the moderate-increasing trajectory (RRR = 1.40, 95% CI: 1.17–1.68; P < 0.001) and the high-increasing trajectory (RRR = 1.98, 95% CI: 1.46–2.67; P < 0.001). For both trajectories, the joint exposure group showed the highest risk (Table 3).

Table 3
Joint associations of social isolation and abnormal sleep on functional disability trajectories.

Variables	Model 1		Model 2	
	Moderate-increasing vs. Low-stable	High-increasing vs. Low-stable	Moderate-increasing vs. Low-stable	High-increasing vs. Low-stable
No social isolation + normal sleep	Ref.	Ref.	Ref.	Ref.
Social isolation + normal sleep	1.80(1.56–2.07)**	1.91(1.50–2.44)**	1.56(1.32–1.83)**	1.63(1.22–2.19)**
No social isolation + Abnormal sleep	1.68(1.43–1.96)**	2.25(1.74–2.91)**	1.40(1.17–1.68)**	1.98(1.46–2.67)**
Social isolation + abnormal sleep	2.82(2.43–3.28)**	5.20(4.14–6.52)**	2.11(1.77–2.50)**	3.14(2.36–4.17)**
Model 1: unadjusted model;				
Model 2: adjusted for age, sex, hypertension, dyslipidemia, diabetes, smoking, drinking, educational level and BMI.				
**$P < 0.001$				

Subgroup Analysis

Subgroup analyses showed that the associations of joint exposure with adverse functional disability trajectories were generally consistent across age and sex subgroups. Although the estimates appeared stronger among participants aged 45–64 years and among women, the interactions of joint exposure with age and sex were not statistically significant (P for interaction = 0.337 and 0.141, respectively). In sex-stratified analyses, women with both social isolation and abnormal sleep had higher relative likelihoods of the moderate-increasing trajectory (RRR = 2.45, 95% CI: 1.97–3.04) and the high-increasing trajectory (RRR = 3.75, 95% CI: 2.54–5.52), whereas the corresponding RRRs in men were 1.60 (95% CI: 1.19–2.14) and 2.52 (95% CI: 1.64–3.87), respectively (Fig. 3). Notably, the interaction between sex and abnormal sleep was statistically significant (P for interaction = 0.014), suggesting that the association between abnormal sleep and adverse disability trajectories differed by sex and was more pronounced among women.

Sensitivity analysis

Sensitivity analysis were performed to test the robustness of the joint associations. First, social isolation was redefined by excluding rural residence from the composite score. With this redefined measure, the

joint exposure of social isolation and abnormal sleep remained significantly associated with both the moderate-increasing trajectory (RRR = 1.49, 95% CI: 1.15–1.93; P = 0.002) and the high-increasing trajectory (RRR = 2.24, 95% CI: 1.54–3.24; P < 0.001). Second, sleep duration was further classified as short (< 6 h), normal (6–9 h) and long (> 9 h). The joint association of social isolation and short sleep remained strongly associated with the moderate-increasing trajectory (RRR = 2.23, 95% CI: 1.86–2.66; P < 0.001) and the high-increasing trajectory (RRR = 3.08, 95% CI: 2.30–4.14; P < 0.001). The joint exposure of social isolation and long sleep was significantly associated with the high-increasing trajectory (RRR = 3.48, 95% CI: 2.04–5.93; P < 0.001), but not with the moderate-increasing trajectory, as shown in Supplementary Table S1.

Discussion

In this longitudinal study, we identified three distinct trajectories of functional disability from 2011 to 2020. Social isolation and abnormal sleep were independently associated with higher relative likelihoods of being in the moderate- and high-increasing disability trajectories. Participants with both exposures had the highest relative likelihoods of adverse trajectories, indicating a cumulative risk pattern.

Social isolation may contribute to functional decline through interrelated behavioural, social, and biological pathways. Socially isolated individuals may have fewer opportunities for social participation, less practical assistance, weaker access to health-related information, and lower levels of physical activity[12]. These processes can gradually reduce mobility, strength and independence. Prior evidence has linked weak social relationships with increased mortality risk, and longitudinal research in China has shown that social isolation and loneliness are associated with functional disability among older adults[13]. By extending the outcome to long-term trajectories, our study suggests that social isolation may shape the pattern of functional decline rather than merely correlate with disability at a single time point.

The association between abnormal sleep and adverse disability trajectories is also biologically plausible. Sleep is important for immune regulation, metabolic homeostasis, cognitive function and tissue repair. Human cohort studies support the relevance of sleep problems for functional outcomes. In the Italian InCHIANTI study, abnormal self-reported sleep duration and time in bed predicted subsequent decline in physical function[14]. In CHARLS-based studies, both short and long sleep duration were associated with subsequent IADL disability[15]. These findings are consistent with our observation that abnormal nighttime sleep was associated with adverse functional disability trajectories.

Notably, the sensitivity analysis separating short and long sleep duration suggested heterogeneous patterns. Social isolation combined with short sleep was associated with both moderate- and high-increasing disability trajectories, whereas social isolation combined with long sleep was associated only with the high-increasing trajectory. This finding suggests that short sleep may be a more consistent risk marker for progressive functional decline, while long sleep may partly reflect underlying morbidity, frailty or preclinical functional deterioration.

Mechanistic evidence from animal studies provides additional support. Social isolation stress has been shown to activate the hypothalamic-pituitary-adrenal axis and sympathetic-adrenal-medullary system, alter neurotransmitter systems and promote oxidative stress, mitochondrial dysfunction and inflammatory responses[16]. These changes may affect mood, cognition, activity motivation and physical recovery. Experimental studies of sleep disruption also indicate that sleep fragmentation can alter inflammatory markers and impair sleep structure in mice[17]. Chronic sleep fragmentation may induce neuroinflammation, increase blood-brain barrier permeability and impair cognitive function[18]. Together, these findings suggest potential pathways through which social isolation and abnormal sleep may contribute to progressive functional decline, although animal evidence cannot establish causality in human populations.

The joint exposure results are clinically and public-health relevant. Participants with both social isolation and abnormal sleep had higher risk of adverse disability trajectories than those with either exposure alone. This pattern suggests that social and behavioral risk factors may accumulate. Social isolation may reduce support for healthy routines and sleep management, while abnormal sleep may increase fatigue, emotional vulnerability and reduced activity participation. Over time, these processes may reinforce one another and lead to progressive loss of functional reserve. These findings support early screening and intervention for high-risk individuals, particularly those with both social isolation and abnormal sleep.

The significant sex interaction for abnormal sleep duration deserves attention. The association between abnormal sleep and disability trajectories was stronger among women. Several explanations are possible. Women in middle and later life may experience higher burdens of sleep disturbance, chronic pain, caregiving stress, depressive symptoms and musculoskeletal conditions, all of which could amplify the functional consequences of abnormal sleep[19, 20]. Social roles and gendered patterns of caregiving may also influence sleep quality, daytime fatigue and opportunities for recovery[21, 22]. Although the sex interaction for joint exposure was not statistically significant, the higher estimates among women suggest that future research and intervention strategies should consider sex-specific vulnerability to sleep-related functional decline.

This study has several strengths. First, it used nationally representative longitudinal data with a large sample size and a long follow-up period. Second, functional disability trajectories were identified using the total ADL/IADL score, which better captures heterogeneity in functional change than single-time-point outcomes. Third, we simultaneously examined social isolation, abnormal sleep, and their joint exposure, reflecting the coexistence of multiple risk factors in real-world populations. Fourth, age- and sex-specific subgroup analysis were conducted to help identify potentially high-risk subgroups. Several limitations should also be acknowledged. First, sleep duration was self-reported, which may have introduced information bias. Future studies incorporating wearable devices could provide more objective measures of sleep duration. Second, abnormal sleep combined both short and long sleep duration,

which may have different underlying mechanisms. Third, this study was based on a Chinese cohort, and future research using multinational cohorts is warranted.

Conclusion

This study showed that social isolation and abnormal nighttime sleep were independently associated with adverse functional disability trajectories among middle-aged and older Chinese adults. Their co-occurrence was associated with the highest risk of adverse trajectories, suggesting a cumulative risk pattern. Integrating social isolation screening and sleep health assessment into ageing-related health services may help identify individuals at risk of functional decline. Women and individuals exposed to both social isolation and abnormal sleep may warrant particular attention.

Declarations

Conflict of interest

The authors declare no conflicts of interest.

Ethics declaration

The data collection for CHARLS was approved by the Biomedical Ethics Review Committee of Peking University, with approval numbers IRB00001052-11015. The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all study participants. Clinical trial number: not applicable.

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Author Contribution

S-Y Y, Y-F C, Y-C Y and F H participated in the design of the research and proofreading of articles; S-Y Y, Y-F C and Y-C Y participated in the writing of the article; S-Y Y, Y-F C, Y-C Y and F H participated in the collection and proofreading of article data. The authors report no conflicts of interest and agree to submit this version of the article.

Data availability

The datasets analyzed in this study are publicly available from the CHARLS.

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Figures

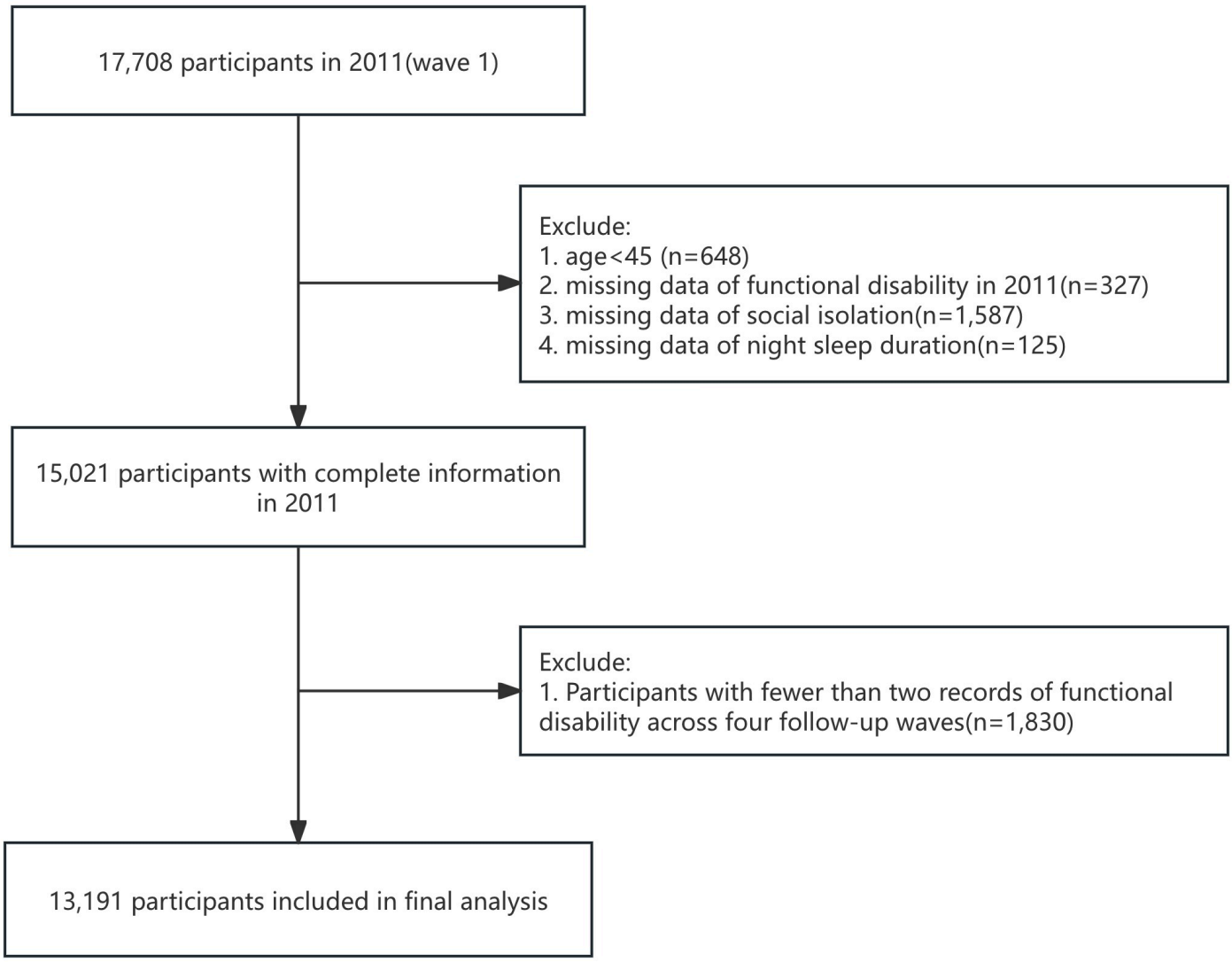


Figure 1

Flow chart.

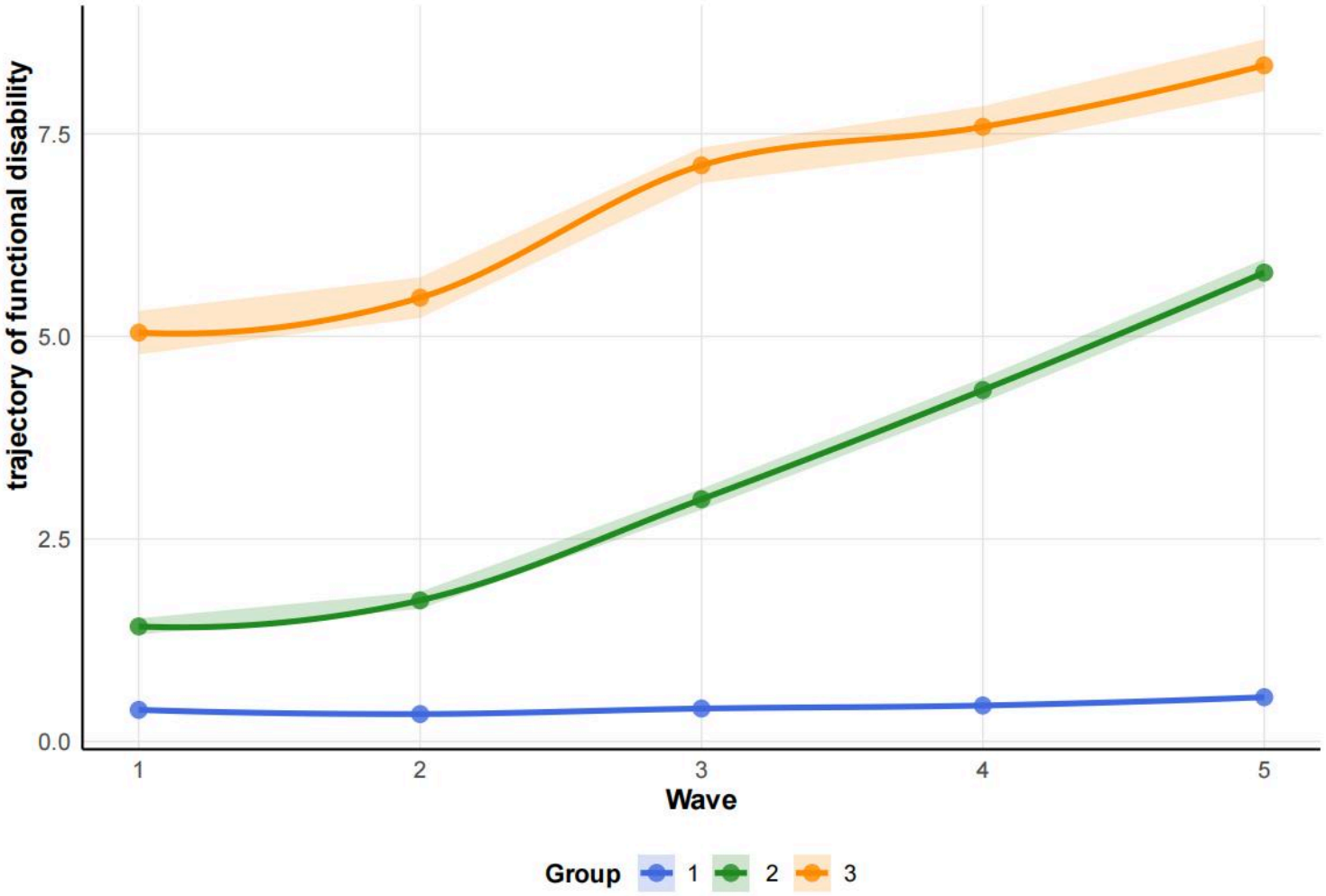


Figure 2

Three trajectory groups of functional disability. Group 1 represented the low-stable trajectory (n = 11,062, 83.9%), Group 2 represented the moderate-increasing trajectory (n = 1,540, 11.7%), and Group 3 represented the high-increasing trajectory (n = 589, 4.5%). Functional disability was assessed using the total ADL/IADL score, with higher scores indicating greater disability. Shaded areas indicate 95% confidence intervals.

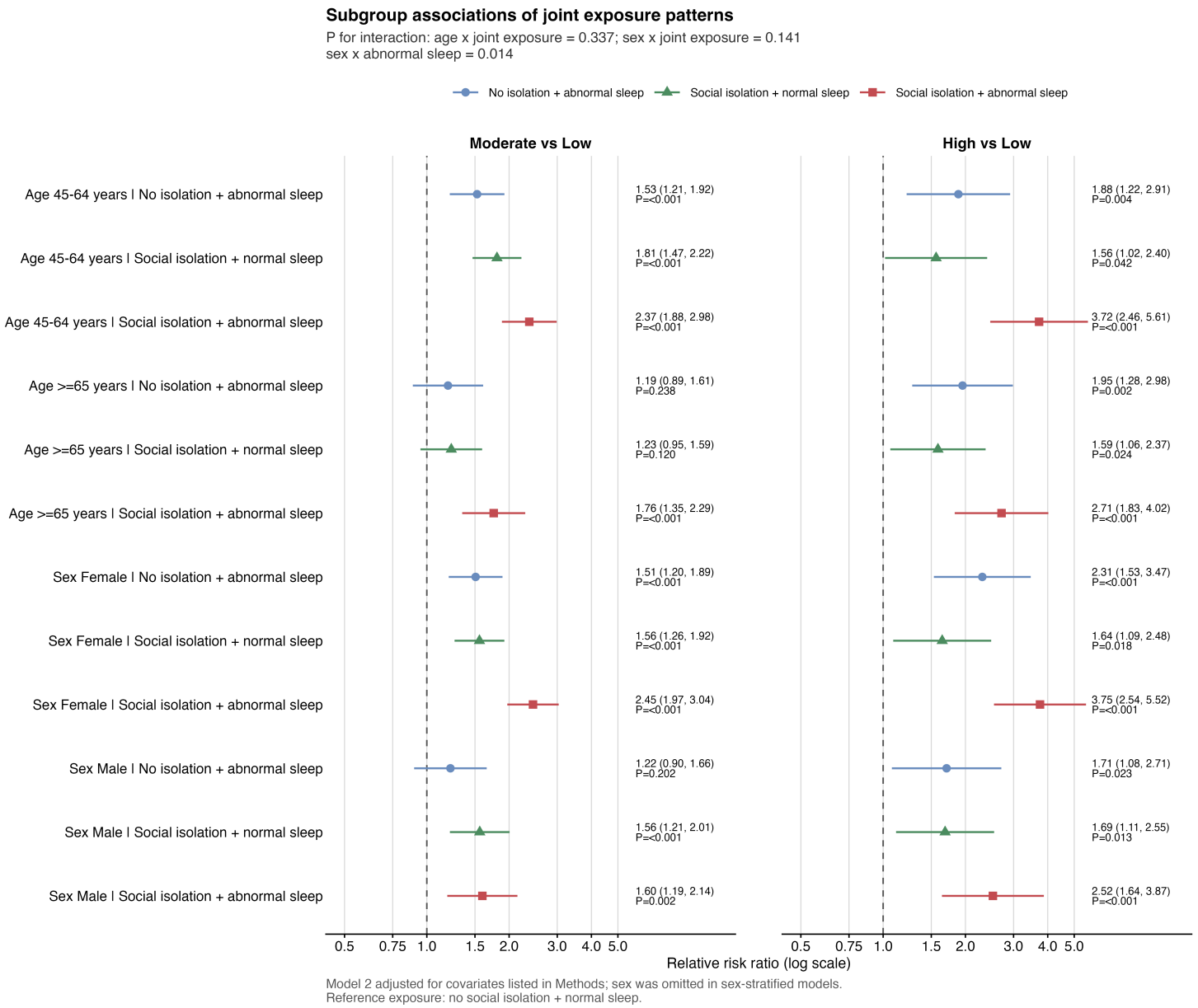


Figure 3

Subgroup analysis of joint exposures with functional disability trajectories. Forest plots show the associations of joint exposure to social isolation and abnormal sleep with moderate-increasing and high-increasing functional disability trajectories, using the low-stable trajectory as the reference group. The reference exposure group was participants without social isolation and with normal nighttime sleep. Relative risk and 95% confidence intervals were estimated using multinomial logistic regression.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementary.docx