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The association between sleep duration trajectories and successful aging: a population-based cohort study

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Abstract

Background Insufficient or excessive sleep duration are associated with increased risk of individual adverse outcomes. However, it remains largely unknown whether sleep duration trajectories are associated with overall health among older adults. This study aimed to examine the association between sleep duration trajectories and successful aging.

Methods In the China Health and Retirement Longitudinal Study (CHARLS), 3,306 participants without major chronic diseases at baseline and survived to aged 60 years and older at the end of follow-up were potentially eligible participants. Total sleep duration was assessed in 2011, 2013, and 2015, and successful aging was evaluated in 2020 and was defined as being free of major chronic diseases, no physical impairment, high cognitive function, good mental health, and active engagement with life. Latent class mixed model (LCMM) was used to identify sleep duration trajectories and logistic regression was performed to explore the association between these trajectories and successful aging.

Results During the 9-year follow-up, 455 individuals (13.8%) met the criteria for successful aging. Five sleep duration trajectories were identified: normal stable, long stable, decreasing, increasing, and short stable. Compared with the normal stable trajectory, the adjusted *ORs* (95% *CI*) for achieving successful aging for participants with long stable, decreasing, increasing, and short stable trajectories were 1.00 (0.77, 1.30), 0.64 (0.40, 1.03), 0.64 (0.45, 0.92), and 0.48 (0.35, 0.66), respectively. The stratified and sensitivity analyses were generally consistent with the main results.

Conclusions Increasing and short stable trajectories of sleep duration are associated with lower odds of successful aging relative to participants in the normal stable trajectory. The findings underscore the critical importance of monitoring dynamic changes in sleep duration in middle-aged and older Chinese adults.

Keywords Sleep duration trajectory, Successful aging, Cohort study, CHARLS

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Introduction

As a consequence of the prolonged life expectancy and declined fertility rates, the proportion of the global population aged 60 years or older is anticipated to surge from 12 to 22% between 2015 and 2050 [1]. China is one of the fastest aging countries in the world. The proportion of the population aged 60 years and above is expected to increase from 12.4% in 2010 to 28% in 2040, reaching approximately 397 million [2]. Despite the continued increase in life expectancy, the average life expectancy in China for 2019 was 77.6 years, whereas the healthy life expectancy was 68.4 years, indicating a nearly 9-year gap [3]. How to achieve successful aging, that is, living long while remaining free of major chronic diseases, with good physical function, cognitive function, mental health, and active social participation, is becoming an important public health issue [4]. A cross-national study of successful aging reveals that roughly 15.7% of Chinese older adults achieved successful aging, significantly lower than in developed nations like Japan and South Korea (29.2% and 25.5%) [5]. This suggests the necessity for increased focus on successful aging in China. Identifying modifiable factors for successful aging is essential in formulating strategies to promote it.

Insufficient or excessive sleep has been linked to adverse outcomes, such as co-morbidities [6], cognitive impairment [7], depression [8] and even mortality [9]. Although two studies examined the relationship between sleep duration and successful aging, the conclusions were mixed. A cross-sectional study from China found [10] that compared with those who slept 7 h per night, those who slept $\leq$6 h had a lower odds of successful aging, and those who slept $\geq$8 h had no statistically significant difference. In contrast, a prospective study conducted in the United States revealed [11] an "inverted J-shaped" relationship between total sleep duration and healthy aging. Participants with long sleep had a reduced odds of healthy aging, while those with insufficient sleep had a reduced but non-significant odds of healthy aging. However, the above studies have only taken a single measure of sleep duration, ignoring the fact that sleep duration changes with age [12]. Therefore, a single measurement may not provide an accurate picture of the relationship between sleep duration and successful aging.

Moreover, although some evidence suggests that persistently short sleep duration trajectories are associated with a variety of adverse health outcomes such as type 2 diabetes mellitus (T2DM) [13], cardiovascular disease (CVD) [14], dementia [15], multimorbidity [16], and mortality [14] when compared with those with normal total sleep duration trajectory, the relationship between sleep duration trajectories and successful aging has not yet been reported.

In view of this, we aim to prospectively explore the association between total sleep duration trajectories and successful aging in Chinese middle-aged and older adults to provide scientific evidence for promoting successful aging in older adults.

Materials and methods

Study population

We used the data from the China Health and Retirement Longitudinal Study (CHARLS) in 2011, 2013, 2015, 2018, and 2020. It is a nationally representative longitudinal survey, examining the health and economy of the population aged 45 and over from 28 provinces in China to tackle the rapidly aging population. Detailed methods of CHARLS have been previously documented [17]. This study was approved from the Biomedical Ethics Review Committee of Peking University (IRB00001052-11015), and all participants provided written informed consent. The study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline. For the sake of reproducibility, the list of variables extracted for this study is presented in Table S1.

There were a total of 17,708 participants at baseline 2011 (Wave 1). According to the design of previous studies on trajectory modeling [18, 19], 6,502 participants who were free of major chronic diseases such as diabetes, cancer, chronic lung disease, heart disease, and stroke at baseline and who had survived the age of 60 or older by 2020 (Wave 5) were potentially eligible. We then excluded 790 participants with missing nighttime sleep duration and nap time in Wave1, 2013 (Wave 2), and 2015 (Wave 3); 856 individuals who were lost to follow-up from Wave 1 to Wave 3; and 1,550 individuals with missing information on successful aging at Wave 5. The final analysis included 3,306 participants (Fig. 1). Participants excluded due to missing information on successful aging did not differ significantly from those included in terms of major confounders such as age, sex, lifestyle, and body type (Table S2).

Exposure assessment

We calculated total sleep duration over a 24 h period by summing nighttime sleep duration and daytime nap duration [20–22]. Nighttime sleep duration and daytime napping were assessed by asking, "*During the past month, how many hours of actual sleep did you get every night? (mean hours per night)*", and "*During the past month, how long did you take a nap after lunch?*". Nap duration refers to the total hours participants slept after lunch each day, while total sleep duration denotes the total hours of sleep participants achieved each day [21]. The reliability of self-reported nighttime sleep duration and daytime napping

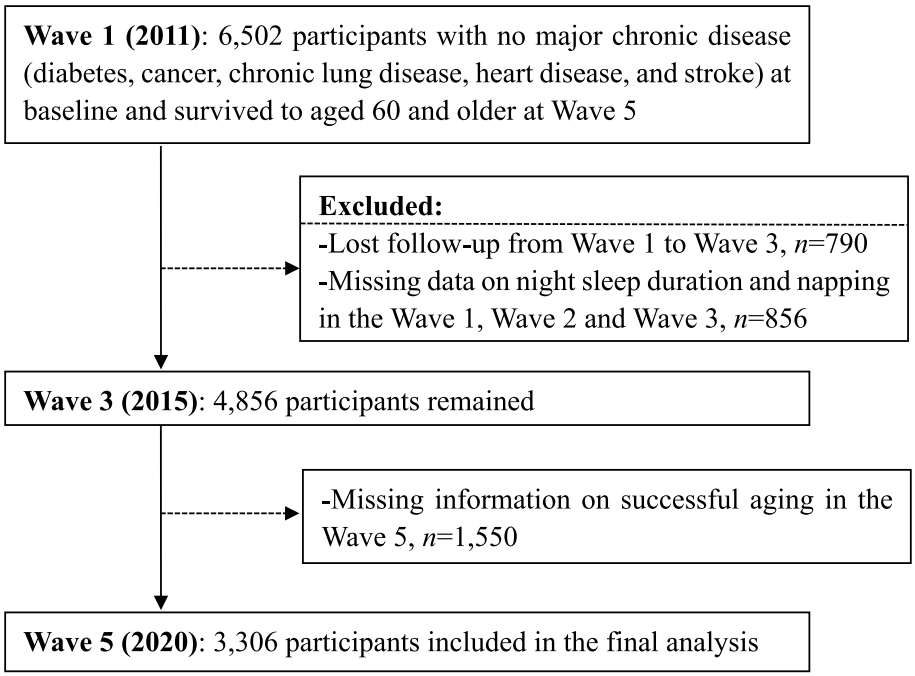

Fig. 1 Flow chart of participants selection

have been validated in the field of sleep epidemiology [23, 24]. This self-reported sleep duration exhibited a strong correlation with that recorded in sleep diaries (r_s=0.79, P<0.001) and moderately with objectively measured sleep via actigraphy [24]. Based on the sleep duration in 2011, 2013 and 2015, we identified sleep duration trajectories using a latent class mixed model [25, 26].

Assessment of successful aging

The concept of successful aging, as proposed by Rowe and Kahn, has been extensively employed to gauge the overall health of older adults [4]. Based on previous research [10, 27–29], we defined successful aging as the absence of major chronic diseases, no impairment in physical function, high cognitive function, good mental health, and active engagement with life in Wave 5. The evaluation methods and judgment criteria of the five dimensions are as follows:

Assessment of major chronic diseases

Based on main disease burden in China and previous studies [10, 29, 30], participants were asked if a doctor had told them that they have any of the following major chronic diseases including diabetes, cancer, chronic lung diseases, heart attack and stroke. The absence of any of the aforementioned diseases was considered as being free of major chronic diseases.

Assessment of physical function

Physical function was assessed using a physiologically-based activities of daily living (ADL) scale [31], widely adopted among the elderly in China [10, 29]. Respondents were queried about their need for assistance in six activities (dressing, bathing or showering, eating, getting into or out of bed, using the toilet, and controlling urination and defecation). Participants unable to independently perform any one of the six activities were considered to have physical function impairment [31].

Assessment of cognitive function

Cognitive function was assessed in a face-to-face interview using the Telephone Interview of Cognitive Status (TICS-10) [32], word recall and picture drawing, which was extensively evaluated for reliability and widely employed in the Chinese population [33]. TICS-10 consists of subtracting 7 consecutively from 100 (up to 5 times) and asking the respondent to name today's date (year, month, day), day of the week, and season, with a total score ranging from 0 to 10 points. Word recall requires the interviewer to randomly read out 10 Chinese nouns, prompting respondents to memorize as many as they can, both immediately (immediate recall) and a few minutes later (delayed recall). By calculating the average of the two recall scores, the final score of word recall ranges from 0 to 10. For drawing, the investigator presents a picture of two pentagrams overlapping each

other, assessing if the participant can draw a suitable pentagram. The total cognitive ability score ranges from 0 to 21, with higher scores indicating better cognitive function. Referring to previous studies [10, 27], participants were deemed to have high cognitive function when their total score was ≥ the median.

Assessment of mental health

We used a modified version of the Center for Epidemiologic Studies Depression Scale (CES-D) to assess depressive symptoms. This scale has been widely used and validated among elderly respondents in China [34]. The scale comprises 10 items with 4 response options:1) little or not at all (< 1 day); 2) not much (1–2 days); 3) sometimes or half the time (3–4 days); and 4) most of the time (5–7 days). Each of the 10 items is scored on a scale of 0 to 3, except for the 5th and 8th items which are reverse-scored. The total CES-D score ranges from 0 to 30, with higher scores indicating more severe depression. A score ≥ 10 was defined as having clinically significant depressive symptoms [35].

Assessment of social participation

Participants were classified as socially active if they engaged in any of the specified social activities within the past month, such as socializing with friends, playing games like Ma-Jong, chess, or cards, or attending community club events [5].

Assessment of covariates

The covariates in this study included age (continuous), sex (male/female), marital status (married/unmarried), place of residence (rural/urban), educational level (illiterate/elementary school or below/junior high school or above), annual per capita household expenditure level (tertiles), smoking behavior (never/former/current), alcohol consumption (0/< once a month/≥once a month) and physical activity (light/moderate/vigorous). The body mass index (BMI) was obtained by dividing weight (kg) by height (meters) squared. According to the Chinese standard [29], BMI was divided into four categories: underweight (< 18.5 kg/m^2), normal weight (18.5–23.9 kg/m^2), overweight (24.0–27.9 kg/m^2) and obese (≥ 28.0 kg/m^2).

Statistical analyses

We employed a latent class mixed model to identify distinct groups that exhibit similar trajectories of total sleep duration (R, lcmm package, version 2.0.0) [25]. Starting with the highest polynomial, models with different functional forms are compared by the level of significance of the cubic, quadratic and linear terms [36]. This method has been previously implemented [26]. As indicated in Table S3, Bayesian information criteria (BIC), Entropy, and the number of participants in each trajectory (> 5% of the total participants) were used to assess model fit. Ultimately, the model with five trajectories and a quadratic function demonstrated the best fit to the data.

The basic characteristics among participants with different sleep duration trajectories were compared using one-way ANOVA or the Kruskal-Wallis test for continuous variables and the Chi-square test for categorical variables. Logistic regression models were used to estimate the multivariable-adjusted odds ratio (*OR*) and 95% confidence intervals (*CIs*) for the associations between sleep duration trajectories groups and successful aging, as well as each of the 5 domains, with the normal stable trajectory as the reference. Model 1 adjusted for age, sex, marital status, place of residence, education level and annual per capita household expenditure level. Model 2 further adjusted for lifestyle factors, including smoking behavior, alcohol consumption, daytime nap and physical activity. Considering the potentially significant impact of body type on sleep duration trajectories and successful aging [11], body type was separately adjusted in model 3. An $OR < 1$ in these models indicates decreased odds of successful aging.

We performed subgroup analyses to explore whether the association between sleep duration trajectories and successful aging differed by age, sex, smoking behavior, alcohol consumption, physical activity, and body type. The *P*-values for the interaction effects were calculated using the likelihood ratio test. Additionally, we assessed the association between sleep duration at baseline, sleep duration variability (measured by the standard deviation of sleep duration from 2011 to 2015), and successful aging. Since the National Sleep Foundation recommends that older adults sleep 7–8 h per day [37] and based on previous studies based on CHARLS [20], we categorized sleep duration into three levels: <7, 7–8, and > 8 h; and sleep duration variability was classified into four categories: <0.5, 0.5-1.0, 1.1–1.5, and > 1.5 h.

In order to verify the robustness of our results, several sensitivity analyses were conducted. First, given that antidepressant and sleeping medications may affect sleep duration, we excluded participants who used antidepressants, tranquilizers, or sleeping medications. Second, to further control confounding of health status, we restricted participants to those without hypertension and physical disabilities and reassessed the relationship between sleep duration trajectories and successful aging. Third, we additionally adjusted for abdominal obesity to account for the confounding effect. Fourth, based on previous research, self-rated health may be an important dimension of successful aging [38], so we included it as one

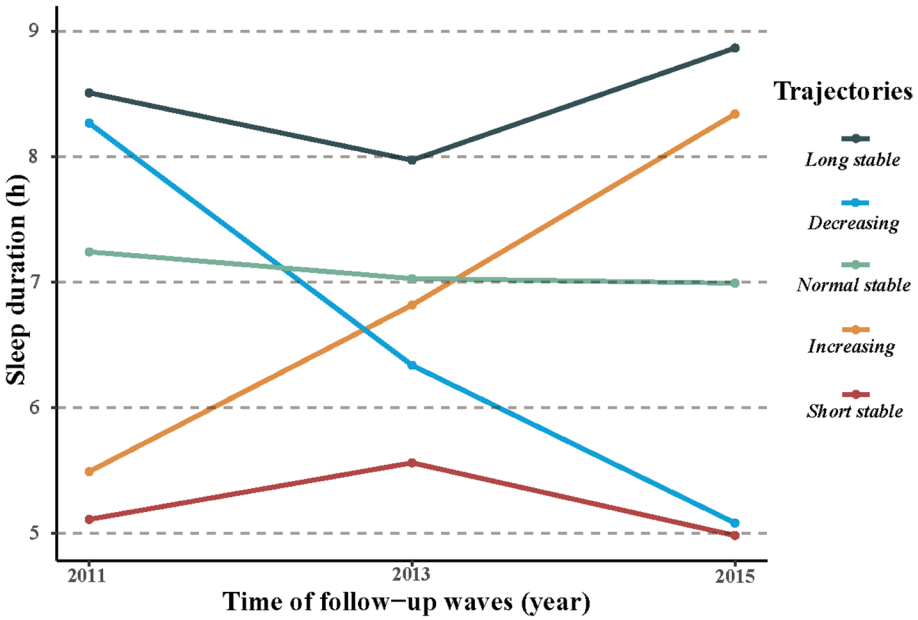

Fig. 2 Total sleep duration trajectories from 2011 to 2015 in the Chinese middle-aged and older adults. Long stable (26.7%, $n=882$); decreasing (7.3%, $n=242$); normal stable (26.1%, $n=862$); increasing (13.7%, $n=454$); and short stable trajectories (26.2%, $n=866$)

dimension of successful aging, and repeated the analyses. Fifth, to exclude the influence of daytime nap, we examined the association between nighttime sleep duration trajectories and successful aging. Finally, to further assess the stability of our finding, we calculated the *E*-value [39], which is defined as the minimum strength of association on the odds ratio scale that an unmeasured confounder must have with both sleep duration trajectories and the successful aging to fully suppress the observed association.

All data were analyzed using Empower® 4.0 (X & Y Solutions, Inc., Boston, MA), R 4.2.2 (R Development Core Team, Vienna, Austria), and STATA 17.0 (StataCorp LLC, College Station, Texas). A two-sided *P*-value of less than 0.05 was considered statistically significant.

Results

Of the 3,306 individuals included, the median age of the study population was 60y [Interquartile range (IQR): 56-64y], with 1,630 participants (49.3%) being female. During the 9-year follow-up, 455 individuals (13.8%) met the criteria for successful aging, 2,679 (81.0%) reported having "no major chronic diseases", 2,515 (76.4%) indicated "no physical dysfunction", 1,870 (56.6%) reported "high cognitive function", 1,990 (60.2%) exhibited "good mental health", and 1,458 (44.1%) demonstrated "active engagement with life".

Sleep duration trajectories and baseline characteristics

Based on total sleep durations from 2011 to 2015, we identified five optimal sleep duration trajectories: normal stable (26.1%, $n=862$), long stable (26.7%, $n=882$), decreasing (7.3%, $n=242$), increasing (13.7%, $n=454$), and short stable trajectories (26.2%, $n=866$) (Fig. 2). Table 1 outlines the basic characteristics of these participants based on sleep duration trajectories. In comparison with participants in decreasing, increasing, and short stable trajectories, those with a normal stable trajectory were more likely to be male, younger, married, urban residents, those with higher levels of education and per capita household expenditure, current smokers, and overweight or obese, all $P<0.05$.

Association of total sleep duration trajectories with successful aging

Table 2 illustrates the association between sleep duration trajectories and successful aging. Those with long stable, normal stable, decreasing, increasing, and short stable trajectories achieved successful aging at 17.1%, 18.1%, 9.9%, 10.6%, and 8.8% (Fig. 3), respectively. After adjusting for potential confounders, in comparison to the normal stable trajectory, the adjusted *ORs* (95% *CI*) for achieving successful aging for participants with long stable, decreasing, increasing, and short stable trajectories were 1.00 (0.77, 1.30), 0.64 (0.40, 1.03), 0.64 (0.45, 0.92), and 0.48 (0.35, 0.66), respectively. Moreover, the association between sleep duration trajectories and the

Table 1 Characteristics of participants according to total sleep duration trajectories

Characteristics [a]	Sleep duration trajectories					*P*
	Long stable (*n* = 882)	Normal stable (*n* = 862)	Decreasing (*n* = 242)	Increasing (*n* = 454)	Short stable (*n* = 866)	
Age [b], years	60.7 ± 5.9	59.9 ± 5.5	61.1 ± 6.8	60.7 ± 6.2	61.3 ± 6.3	**< 0.001**
Female [b], *n* (%)	371 (42.1)	397 (46.1)	132 (54.5)	235 (51.8)	496 (57.3)	**< 0.001**
Married [b], *n* (%)	803 (91.0)	798 (92.6)	215 (88.8)	398 (87.7)	756 (87.3)	**0.002**
Rural, *n* (%)	830 (94.1)	769 (89.2)	230 (95.0)	428 (94.3)	818 (94.5)	**< 0.001**
Education level, *n* (%)						**< 0.001**
Illiterate	234 (26.5)	196 (22.7)	85 (35.1)	158 (34.8)	278 (32.1)	
Elementary school or below	410 (46.5)	379 (44.0)	112 (46.3)	210 (46.3)	392 (45.3)	
Junior high school or above	238 (27.0)	287 (33.3)	45 (18.6)	86 (18.9)	196 (22.6)	
Per capita household expenditure level [b], *n* (%)						0.385
Tertile 1	286 (32.4)	270 (31.3)	84 (34.7)	149 (32.8)	313 (36.1)	
Tertile 2	289 (32.8)	287 (33.3)	87 (36.0)	155 (34.1)	285 (32.9)	
Tertile 3	307 (34.8)	305 (35.4)	71 (29.3)	150 (33.0)	268 (30.9)	
Smoking behavior, *n* (%)						**< 0.001**
Never	469 (53.2)	484 (56.1)	153 (63.2)	274 (60.4)	552 (63.7)	
Former	70 (7.9)	67 (7.8)	13 (5.4)	24 (5.3)	57 (6.6)	
Current	343 (38.9)	311 (36.1)	76 (31.4)	156 (34.4)	257 (29.7)	
Alcohol consumption, *n* (%)						0.189
Never	276 (31.3)	245 (28.4)	61 (25.2)	115 (25.3)	244 (28.2)	
Less than once a month	75 (8.5)	72 (8.4)	15 (6.2)	33 (7.3)	61 (7.0)	
More than once a month	531 (60.2)	545 (63.2)	166 (68.6)	306 (67.4)	561 (64.8)	
Physical activity, *n* (%)						0.720
Light	614 (69.6)	593 (68.8)	168 (69.4)	309 (68.1)	605 (69.9)	
Moderate	118 (13.4)	118 (13.7)	25 (10.3)	57 (12.6)	121 (14.0)	
Vigorous	150 (17.0)	151 (17.5)	49 (20.2)	88 (19.4)	140 (16.2)	
Body type [b], *n* (%)						**0.012**
Underweight	44 (5.0)	48 (5.6)	20 (8.3)	33 (7.3)	53 (6.1)	
Normal	500 (56.7)	499 (57.9)	150 (62.0)	271 (59.7)	551 (63.6)	
Overweight	261 (29.6)	239 (27.7)	61 (25.2)	123 (27.1)	212 (24.5)	
Obese	77 (8.7)	76 (8.8)	11 (4.5)	27 (5.9)	50 (5.8)	

[a] Continuous data is presented as the mean ± SD, and categorical data is presented as the number and percentage of participants

[b] Missing data: Age (*n* = 4, 0.001%); Sex (*n* = 2, 0.001%); Marital status (*n* = 1, 0.001%); Per capita household expenditure level (*n* = 21, 0.006%); Body type (*n* = 99, 0.030%)

five individual dimensions of successful aging was similar (Table S4).

Association of total sleep duration at baseline, sleep duration variability and successful aging

Table S5 shows the association between sleep duration at baseline and successful aging. Compared to those who slept 7–8 h per day, participants with < 7 h of sleep had reduced odds of attaining successful aging, with the adjusted *OR* (95%*CI*) of 0.54 (0.43, 0.69). The association between sleeping > 8 h and successful aging did not reach statistical significance, with an *OR* (95%*CI*) of 0.88 (0.67, 1.14). Furthermore, individuals with a standard deviation of sleep duration > 1.5 h exhibited the lowest odds of achieving successful aging, with an adjusted *OR* (95%*CI*) of 0.66 (0.46, 0.94).

Stratified and sensitivity analyses

In the stratified analyses, we observed consistent association between total sleep duration trajectories and successful aging across subgroups with different age, sex, daytime nap, smoking behavior, alcohol consumption, and overweight/obese (Table 3). Notably, sleep duration trajectories exhibited a weak interaction with physical activity (*P* for interaction = 0.050).

Table 2 Odds ratios (95% *CIs*) of successful aging by total and nighttime sleep duration trajectories

Outcome	No.	Successful aging, No. (%)	Base model [a]	Model 1 [b]	Model 2 [c]
Total sleep duration trajectories					
Long stable	882	151 (17.1)	1.06 (0.82, 1.37)	1.06 (0.82, 1.37)	1.00 (0.77, 1.30)
Normal stable	862	156 (18.1)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Decreasing	242	24 (9.9)	0.63 (0.40, 1.01)	0.64 (0.40, 1.02)	0.64 (0.40, 1.03)
Increasing	454	48 (10.6)	**0.66 (0.46, 0.94)**	**0.66 (0.46, 0.94)**	**0.64 (0.45, 0.92)**
Short stable	866	76 (8.8)	**0.53 (0.40, 0.72)**	**0.53 (0.39, 0.72)**	**0.48 (0.35, 0.66)**
Nighttime sleep duration trajectories					
Long stable	310	39 (12.6)	0.74 (0.51, 1.08)	0.74 (0.51, 1.07)	0.72 (0.49, 1.06)
Normal stable	1,319	252 (19.1)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Decreasing	332	34 (10.2)	**0.56 (0.38, 0.82)**	**0.56 (0.38, 0.82)**	**0.57 (0.39, 0.85)**
Increasing	299	23 (7.7)	**0.45 (0.29, 0.72)**	**0.46 (0.29, 0.73)**	**0.45 (0.28, 0.72)**
Short stable	1,046	107 (10.2)	**0.54 (0.42, 0.69)**	**0.53 (0.42, 0.69)**	**0.51 (0.40, 0.67)**

[a] Base model: Adjusted for age (continuous), sex (male/female), marital status (married/unmarried), place of residence (rural/urban), educational level (illiterate/elementary school or below/junior high school or above), and annual per capita household expenditure level (tertiles)

[b] Model 1 was additionally adjusted for smoking behavior (never/former/current), alcohol consumption (never/less than once a month/more than once a month) and physical activity (light/moderate/vigorous)

[c] Model 2 was additionally adjusted for body type (underweight/normal/overweight/obese)

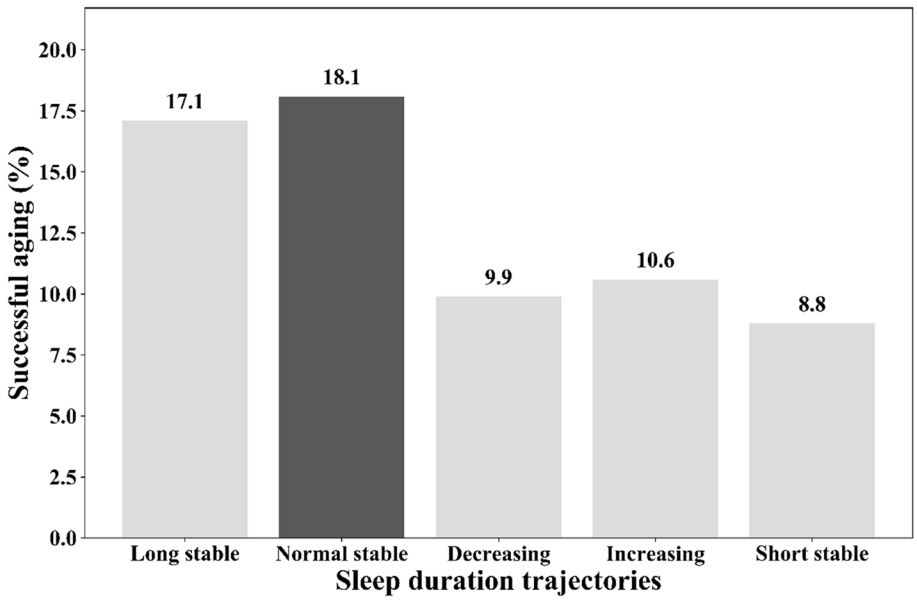

Fig. 3 Successful aging rates according to sleep duration trajectories

The results of sensitivity analyses are presented in Table 2, Table S6-S7, and Fig. S1-S2. Firstly, exclusion of individuals using antidepressants, sedatives, or sleeping medications did not change the association between sleep duration trajectories and successful aging. Secondly, restricting participants to those with non-hypertension and non-physical disabilities yielded generally consistent associations. Thirdly, additional adjustment for abdominal obesity yielded consistent results. Fourthly, inclusion of self-rated health as a component of successful aging aligned with the main findings. Fifthly, similar to the total sleep duration trajectory, we identified five nighttime sleep trajectories: normal stable, long stable, decreasing, increasing, and short stable (Table S7; Fig. S1). Compared to the normal stable trajectory, the adjusted *ORs* (95% *CI*) for achieving successful aging in the long stable, decreasing, increasing, and short stable trajectories were 0.72

Table 3 Stratified analysis for total sleep duration trajectories and successful aging

Subgroups	Total sleep duration trajectories, ORs (95%CI) *					*P* for interaction
	Long stable	Normal stable	Decreasing	Increasing	Short stable	
Age, years						0.920
< 60 (*n* = 1,640)	1.06 (0.75, 1.51)	1.00 (reference)	0.74 (0.40, 1.39)	0.68 (0.41, 1.10)	**0.52 (0.34, 0.81)**	
≥ 60 (*n* = 1,662)	0.91 (0.62, 1.35)	1.00 (reference)	0.53 (0.26, 1.09)	0.59 (0.34, 1.01)	**0.42 (0.26, 0.67)**	
Sex						0.471
Male (*n* = 1,674)	0.93 (0.67, 1.29)	1.00 (reference)	0.56 (0.29, 1.10)	0.74 (0.47, 1.17)	**0.42 (0.27, 0.66)**	
Female (*n* = 1,630)	1.21 (0.79, 1.85)	1.00 (reference)	0.75 (0.39, 1.48)	**0.52 (0.28, 0.95)**	**0.56 (0.35, 0.88)**	
Daytime nap, min						0.932
0 (*n* = 1,908)	1.10 (0.75, 1.62)	1.00 (reference)	0.48 (0.21, 1.08)	0.67 (0.43, 1.05)	**0.52 (0.35, 0.77)**	
1–60 (*n* = 958)	1.04 (0.67, 1.62)	1.00 (reference)	0.54 (0.24, 1.23)	0.75 (0.37, 1.52)	0.59 (0.34, 1.01)	
> 60 (*n* = 440)	0.93 (0.49, 1.76)	1.00 (reference)	1.05 (0.40, 2.72)	0.56 (0.14, 2.20)	0.63 (0.19, 2.13)	
Smoking behavior [a]						0.762
Never smoker (*n* = 1,932)	1.02 (0.71, 1.47)	1.00 (reference)	0.68 (0.37, 1.23)	**0.52 (0.31, 0.87)**	**0.49 (0.32, 0.74)**	
Smoker (*n* = 1,374)	0.99 (0.68, 1.44)	1.00 (reference)	0.61 (0.28, 1.30)	0.79 (0.47, 1.32)	**0.46 (0.28, 0.75)**	
Alcohol consumption [a]						0.216
No (*n* = 941)	0.91 (0.58, 1.44)	1.00 (reference)	0.20 (0.06, 0.68)	0.53 (0.27, 1.04)	**0.45 (0.26, 0.79)**	
Yes (*n* = 2,365)	1.04 (0.76, 1.44)	1.00 (reference)	0.86 (0.51, 1.44)	0.68 (0.44, 1.05)	**0.50 (0.34, 0.73)**	
Physical activity [a]						0.050
LPA (*n* = 2,289)	1.21 (0.88, 1.66)	1.00 (reference)	0.71 (0.40, 1.27)	0.89 (0.58, 1.35)	**0.47 (0.32, 0.70)**	
MVPA (*n* = 1,017)	0.69 (0.43, 1.10)	1.00 (reference)	0.48 (0.21, 1.09)	**0.27 (0.13, 0.59)**	**0.47 (0.28, 0.81)**	
Overweight/obese [b]						0.999
No (*n* = 2,107)	1.00 (0.70, 1.42)	1.00 (reference)	0.64 (0.35, 1.16)	0.65 (0.41, 1.05)	**0.47 (0.31, 0.71)**	
Yes (*n* = 1,100)	1.03 (0.69, 1.53)	1.00 (reference)	0.62 (0.28, 1.35)	0.63 (0.36, 1.12)	**0.50 (0.30, 0.82)**	

Abbreviations: LPA Light Physical Activity, *MVPA* Moderate-to-Vigorous Physical Activity

[*] Adjusted for age (continuous), sex (male/female), marital status (married/unmarried), place of residence (rural/urban), educational level (illiterate/elementary school or below/junior high school or above), annual per capita household expenditure level (tertiles), smoking behavior (never/former/current), alcohol consumption (never/less than once a month/more than once a month) and physical activity (light/moderate/vigorous) and body type (underweight/normal/overweight/obese)

[a] The current and past smoker groups were combined due to small sample size in the current smoker group; The moderate and vigorous activity groups were combined due to small sample size in the vigorous activity group; The "drink but less than once a month" and "drink more than once a month" groups were combined due to small sample size in the "drink but less than once a month" group

[b] Defined as a BMI of 24 kg/m^2 or greater

(0.49, 1.06), 0.57 (0.39, 0.85), 0.45 (0.28, 0.72), and 0.51 (0.40, 0.67), respectively. These results align with the association between the total sleep duration trajectory and successful aging (Table 2).

Finally, the *E*-value of 2.50 (upper confidence interval limit: 1.39) for the increasing trajectory of sleep duration, compared with the normal stable trajectory, indicates that residual confounding would significantly affect the observed associations only if the unmeasured covariates were associated with both the decreasing trajectory and successful aging with an odds ratio greater than 2.50. The larger the *E*-value, the more robust the current results. The *E*-values for short stable trajectories with successful aging is 3.59 (upper confidence interval limit: 2.40) (Fig. S2).

Discussion

Main findings

To the best of our knowledge, this is the first study to examine the association between sleep duration trajectories and successful aging. We identified five distinct sleep duration trajectories in this large longitudinal study among middle-aged and elderly Chinese adults residing in the community: normal stable, long stable, decreasing, increasing, and short stable. Relative to participants with the normal stable sleep duration trajectory, those with the low stable and increasing trajectory had 36% and 52% lower odds of successful aging, respectively. Participants with decreasing trajectories also exhibited lower odds, though this was not statistically significant, likely due to sample size limitations. Similarly, in nighttime sleep duration trajectories, decreasing, increasing, and short stable patterns were all associated with lower odds of successful aging compared to the normal stable trajectory.

These findings underscore that chronic sleep deprivation, as well as the patterns of increasing and decreasing sleep duration, are not mere age-related changes; rather, they emerge as pivotal indicators of obstacles in the pursuit of successful aging.

Comparison with other studies

Our finding was consistent with a cross-sectional study among 5,616 older adults in China through the CHARLS database. This study reported that individuals sleeping less than 6 h per night had a 48% lower odds of achieving successful aging compared to those who slept 7 h; additionally, individuals who slept 8 h and those who slept 9 h or more had lower, although not statistically significant, odds of achieving successful aging [10]. However, a 14-year follow-up study of 57 elderly Swiss adults found no association between 14 objectively and subjectively recorded sleep parameters and successful aging [40]. Furthermore, a study based on the American Nurses' Health Study reported that individuals sleeping 8 and ≥ 9 h per day were 17% and 40% less likely to achieve successful than women who slept 7 h per day; those with shorter sleep duration also showed a lower likelihood of achieving healthy aging, though not statistically significant [11]. Inconsistent results in these studies may be attributed to a single measurement of sleep duration. In contrast, our findings are firmly grounded in the analysis of repeated measures of sleep duration, underscoring the paramount importance of taking into account sleep duration trajectories.

Research on the association of sleep duration trajectories with different health outcomes provides further support, showing that consistently shorter, progressively increasing, and progressively decreasing sleep duration trajectories may be detrimental to successful aging. A study in 5,262 middle-aged and older Chinese adults found that participants with consistently short sleep duration trajectories had a 37% increased risk of co-morbidities than the group with sleep duration trajectories of 7–8 h [16]. Another study, involving 52,599 Chinese adults with nighttime sleep duration trajectories monitored over 7 years, found a 22% increase in the risk of CVD events in the low increasing group, and a 34% increase in the risk of death in the normal decreasing group, both compared with the normal-stable group, the highest risks of CVD and death occurred in the group with sleep duration < 5 h, which increased by 47% and 50%, respectively [14]. Additionally, a cohort study of 7,397 Chinese adults identified a 12% increased risk of hypertension in the trajectory of consistently declining sleep duration compared with the trajectory of consistently sleeping 8 h per day [41]. The study of 60,068 U.S. adults found a 43% increased risk of T2DM in those who slept consistently for 5 h compared to participants who slept consistently for 7 h in early to mid-adulthood; a 17% increase in the group who slept consistently for 6 h; a 33% increase in the group who slept progressively more; and a 32% increase in the group who slept progressively less, whereas those who slept consistently for 8 h were not statistically associated with T2DM [13].

Potential mechanisms

The biological mechanisms underlying the relationship between sleep duration trajectories and successful aging are complex. Chronic short sleep duration over a long time can result in the accumulation of sleep debt, which has been linked to the severity of age-related chronic diseases [6, 42]. Since the absence of chronic diseases is a major component of successful aging, the link between short sleep duration over time and successful aging was evident. Persistent insufficient sleep can activate the hypothalamus-pituitary-adrenal axis response pathway, which can release cortisol and can lead to adverse immunological and metabolic changes [43]. Long-term sleep deprivation is also associated with an increase in specific inflammatory biomarkers, including C-reactive protein and interleukin-6 [43, 44]. In addition, this deprivation was linked to reduced hippocampal volume [45] and increased β-amyloid levels in the thalamus [7]. These physiological changes could potentially lead to depression and cognitive impairments. Moreover, there was evidence suggesting that prolonged sleep insufficiency may also be associated with sarcopenia [46], a key underlying factor related to successful aging.

The gradually increasing trajectory group had a gradual increase in sleep duration, but they still had lower odds of successful aging. This suggests that the "sleep compensation behavior" may impair an individual's ability to fall asleep the next night, inadvertently encouraging a pattern of instability. In short, sleep deprivation can disrupt intracellular neuronal metabolism, and compensatory sleep may be inadequate to mitigate resultant damage, these effects may lead to long-term adverse health outcomes in older adults [14, 47]. Additionally, a gradual increase in sleep duration may be associated with obstructive sleep apnea, depression and fatigue [48], and excessive sleep duration does not indicate better sleep quality. Lastly, this trajectory may indicate an increased degree of variation (or irregularity) in an individual's sleep schedule over time, which could potentially result in depression [47] or poor overall health [49] by disrupting the circadian rhythms. Furthermore, chronic sleep deprivation and instability may lead to unhealthy dietary habits, nicotine and alcohol use, and reduced social participation, which prevent the elderly from achieving successful aging.

Strengths and limitations

Our study has several strengths, including a prospective design, repeated assessments of sleep duration, and a large representative sample of the national population. However, there are also limitations. Firstly, our sample only included Chinese middle-aged and elderly individuals, which limits the generalizability of our findings to other populations. Nevertheless, similar relationships between shorter sleep duration and lower odds of successful aging have been consistently observed in different ethnic groups [10, 11]. Secondly, our assessment of sleep duration relied on self-reported information, which can lead to measurement bias. However, objective methods like polysomnography to accurately measure sleep duration are often not feasible in large studies of the general population, which is a common limitation in real-world studies. And previous studies have demonstrated strong correlations between self-reported sleep duration and sleep diaries, although the diaries typically capture only bedtime and wake-up times [24]. Moreover, self-reported sleep duration shows moderate correlation with actigraphy-based measures [24]. In addition, actigraphy measurement is another validated, non-invasive and cost-effective method of objectively measuring sleep. Future research could employ this method to explore the association between objectively measured sleep trajectories and successful aging. Moreover, repeated measurements of sleep duration in our study may reduce misclassification. Thirdly, we cannot completely rule out the possibility of reverse causality since we did not assess impairments in physical, cognitive, and mental health at baseline of the study, which could have contributed to sustained short or increased sleep duration. Nevertheless, we excluded participants diagnosed with chronic diseases at baseline. While this study only identified an association between total sleep duration trajectory and successful aging; however, no causal relationship was established, and the findings should be interpreted with caution. Fourthly, sleep quality is an important confounder, but due to data limitations, we were unable to account for it in this study. Future studies could investigate the association between sleep quality or sleep pattern trajectories and successful aging using the Pittsburgh Sleep Quality Index, sleep diaries, or device monitoring. Fifthly, residual confounding is a potential problem in observational studies. However, we utilized *E*-values to show that those unmeasured confounders might not be sufficient to negate the observed relationships. Finally, the duration of follow-up in this research was relatively short, therefore, the longer-term effects of sleep duration trajectories on successful aging need to be verified.

Conclusions

Our study found that increasing and short stable total sleep duration trajectories were all associated with lower odds of successful aging compared to normal stable total sleep duration trajectories in middle-aged and older Chinese adults. This highlights that persistent sleep duration deficits and continuously increasing sleep duration trajectories impede successful aging. Additionally, the findings underscore the critical importance of monitoring dynamic changes in sleep duration.

Abbreviations

CHARLS	China Health and Retirement Longitudinal Study
T2DM	Type 2 diabetes mellitus
CVD	Cardiovascular disease
US	United States
ADL	Activities of daily living
TICS	Telephone Interview of Cognitive Status
CES-D	Center for Epidemiologic Studies Depression Scale
IQR	Interquartile range
WC	Waist circumference
BIC	Bayesian information criteria
OR	Odds ratio
CI	Confidence interval

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

TL, DP and SH conceived the study and designed the statistical analyses. TL and DP did the statistical analyses and prepared the draft of the manuscript. TL, DP, KX , AW and SH substantively revised the manuscript. All authors read and approved the final manuscript.

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Data availability

Data derived from a source in the public domain (https://charls.pku.edu.cn/). The datasets used are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved from the Biomedical Ethics Review Committee of Peking University (IRB00001052-11015). All participants provided written informed consent.

Consent for publication

Not applicable.

Competing interests
The authors declare no competing interests.

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