Sleep Health 8 (2022) 528–535

Contents lists available at ScienceDirect

Sleep Health

Journal of the National Sleep Foundation

journal homepage: sleephealthjournal.org

Multidimensional sleep health is associated with physical frailty in a national sample of Taiwanese community-dwelling older adults: Sex matters

Tuo-Yu Chen, PhD[a*], Soomi Lee, PhD[b], Orfeu M. Buxton, PhD[c]

[a] PhD Program in Global Health and Health Security, College of Public Health, Taipei Medical University, Taipei City, 110, Taiwan
[b] School of Aging Studies, University of South Florida, 4202 East Fowler Ave., MHC 1344 Tampa, Florida, USA
[c] Department of Biobehavioral Health, Pennsylvania State University, University Park, Pennsylvania, USA

ARTICLE INFO

Article History:
Received 18 December 2021
Revised 27 April 2022
Accepted 14 May 2022

Keywords:
Sleep health
Frailty
Sex
Older adults

ABSTRACT

Objectives: Although individual sleep characteristics are related to frailty, these characteristics do not occur separately. A multidimensional measure of sleep might provide a better estimation of frailty compared to isolated sleep characteristics. This study investigated the association of a multidimensional measure of sleep health with frailty both across and within sex groups.
Design: Data were from the Taiwan Longitudinal Study on Aging (2011), a survey with a nationally representative sample of Taiwanese older adults (N = 2,015). Frailty was defined using the Fried criteria. Self-reported sleep during the past month was used to conceptualize the five sleep health dimensions in the SATED model. Their relationship was estimated using logistic regression analysis adjusting for sociodemographic characteristics (age, sex, education), health status (comorbidity, cognitive function, pain, depressive symptoms [excluding items overlapping with frailty and sleep]), and health risk behaviors (drinking, smoking, lack of exercise).
Results: Having a better sleep health composite score was significantly related to lower odds of being frail in both sexes adjusting for sociodemographic characteristics. This association remained significant among women but not among men after adding health and risk behaviors to the models. Satisfaction and alertness in both sexes and duration among women were significantly associated with frailty adjusting for sociodemographic characteristics. Only alertness among men was significantly related to frailty in the model with all covariates.
Conclusions: Our findings show that having better sleep health across multiple dimensions is related to a lower risk of being frail, with differential risks for women and men.

Introduction

Frailty is a geriatric syndrome marked by a loss of reserve physiological capacity to maintain homeostasis[1] that affects about 12% of older adults worldwide.[2] Although frailty makes individuals vulnerable to adverse outcomes, such as falls, fracture, disability, hospitalization, and death,[1,3,4] the syndrome is preventable and reversible.[5] Hence, identifying factors that are associated with frailty is imperative for the development of health promotion strategies to delay frailty.

Problems with sleep may increase the odds of frailty. For instance, previous studies find that longer and/or shorter sleep duration,[6,7] poorer sleep quality,[7,8] and insomnia[7] are related to higher risks of frailty among older adults. Studies using objective measures also report that lower sleep efficiency[9,10] and longer sleep latency[9] are related to a higher likelihood of frailty.

One limitation in previous studies is that they examine the association of single sleep measures (eg, poor sleep quality) with frailty, though multiple sleep characteristics are likely to co-occur.[11-13] Operationalizing sleep as a multidimensional construct can give a broader understanding of sleep health and may provide a better estimation of frailty compared to isolated sleep characteristic. Second, evidence suggests that the relationship between sleep and frailty may depend on sex although the effects remain unclear.[14,15] For example, insomnia is related to frailty in both sexes among older

*Corresponding author: Tuo-Yu Chen, PhD Program in Global Health and Health Security, College of Public Health, Taipei Medical University, 250 Wuxing Street, Xinyi District, Taipei City, 110, Taiwan
E-mail address: otfish@gmail.com (T.-Y. Chen).

https://doi.org/10.1016/j.sleh.2022.05.003

Mexicans,[15] but in another study, sleep complaints were associated with frailty in older Mexican women, but not men.[14] In a separate study, longer sleep latency in men and longer sleep duration in women were related to frailty.[16] These studies do not provide a comprehensive picture because men and women may sleep differently and may experience different sleep problems,[17] which likely contributes to different results across studies using different sleep variables. Hence, whether the relationship between multidimensional (and comprehensive) sleep health and frailty differs within sex groups warrants further investigation. Sex-stratified analyses identify sex-specific risks of frailty associated with sleep health and yield more interpretable and generalizable findings specific to each sex group.[15] Third, previous studies have investigated the association of sleep with frailty by focusing on individuals with worse sleep (eg, using the clinical cut-off of ≥5 in the Pittsburgh Sleep Quality Index).[7,8] Recently, scholars have called for research on sleep health to promote healthy sleep and improve public health.[11,12]

This study investigated the association of a multidimensional sleep health measure with frailty among community-dwelling older adults. The multidimensional sleep health measure was constructed based on the 5 positive attributes of sleep health in the SATED model—satisfaction in sleep, alertness during daytime, timing, efficiency, and duration.[11] We hypothesized that better sleep health would be related to a lower likelihood of being frail among community-dwelling older adults. Additionally, we tested whether the relationship between sleep health and frailty in each sex stratum. Due to inconsistent findings in prior literature, we did not establish a specific hypothesis, but explored how older men and older women would exhibit different relationships between sleep health and frailty.

Methods

Data

Secondary data were obtained from the Taiwan Longitudinal Study on Aging (TLSA), a nationally representative sample aged 60 years and above. The TLSA was conducted by the Health Promotion Administration aiming to understand the impacts of population aging on the society in Taiwan.[18] The Institutional Review Board of the Bureau of Health Promotion Department of Health, R.O.C approved the protocol. All participants provided signed informed consent before participation. More information about the TLSA can be found in previous reports.[18-20] The present study used data from wave 2011 because items to operationalize the multidimensional sleep health measure were first available in this wave.

Sample

The sample size in wave 2011 was 3727. Based on the inclusion criteria of the current study, respondents who were younger than 65 years old (n = 1301) and living in long-term care facilities (n = 106) at the time of interview were excluded. Individuals had missing information on the multidimensional sleep health measure (n = 75) and other covariates were also excluded (n = 230). The final sample size was 2015. Compared to those who were excluded from the current analysis, the current sample was significantly older (χ^2 (5, N = 3,727) = 2472.77, $p < .001$) with a lower level of education (χ^2 (1, N = 3727) = 74.94, $p < .001$). Significant difference in sex was not found (χ^2 (1, N = 3727) = 2.49, $p = .114$).

Measures

Frailty

Following previous studies,[20-23] we used modified definitions to operationalize frailty under the Fried criteria (ie, weight loss, exhaustion, low physical activity, slowness, weakness).[1] These modified definitions were commonly used to conceptualize frailty.[21] Weight loss was assessed using *poor appetite (In the past week, were you not interested in eating or having a poor appetite?)* from the Center for Epidemiologic Studies Depression Scale (CESD).[21] Exhaustion was assessed by *everything is an effort* or *cannot get going* from the CESD.[21] Low physical activity was defined based on the frequency of engaging in the following activities: gardening, taking walks, riding bicycle, jogging, hiking, playing ball, and other outdoor physical exercise. Slowness was conceptualized by the difficulty with walking 200 to 300 meters, and weakness was conceptualized as the difficulty with carrying items >11-12 kg. Individuals were categorized as having "normal" or "frail" traits based on values used in published studies (Table 1).[20,22,23] A total number of frail traits (from 0 to 5) was calculated for each respondent. Individuals with 3 or more traits were considered as having frailty phenotype (coded as 1).

Sleep health

Self-reported sleep measures were used to conceptualize the 5 sleep health dimensions in the SATED model (ie, sleep satisfaction, daytime alertness, sleep timing, sleep efficiency, sleep duration).[11] Sleep satisfaction, daytime alertness, and sleep duration were assessed using relevant single item from the survey (Table 1). Sleep timing was assessed by mid-sleep time by calculating the middle time between the time when individuals went to bed and got up.[24,25] Sleep efficiency was assessed by time staying awake in bed through calculating the difference between total time in bed (ie, the time when individuals went to bed and got up) and time asleep. Individuals were categorized as having "good" or "poor" sleep health in each dimension based on the values used in the previous studies (Table 1).[11,25-28] Sleep health composite score was calculated by summing up "good" sleep health dimensions (from 0 to 5; higher scores representing better sleep health) and used in the analysis.

Covariates

Sociodemographic characteristics,[1,29,30] health status (comorbidity,[1,29,30] cognitive function,[1,25] pain,[29] depressive symptoms[1,30]), and health risk behaviors (drinking,[25,31] smoking,[25,31] and lack of exercise[22,25]) were included as covariates due to their known effects on sleep or frailty. Sociodemographic information included age (65-69 [reference], 70-74, ≥75), sex (female [reference], male), education (primary or below [reference], secondary or above). For comorbidity, individuals were asked whether a doctor had ever told them that they had the following health conditions: hypertension, diabetes, heart disease, stroke, cancer, lung disease, asthma, arthritis, liver disease, and renal disease. Individuals' total number of conditions were categorized into 0, 1, or 2 or more conditions. Global cognitive function was accessed by the Short Portable Mental Status Questionnaire,[32] which has been validated against the Mini-Mental State Examination.[33] The participants were asked about today's date, day of the week, the current home address, age in years, and to subtract 3 from 20 for 4 consecutive times. The total incorrect answer (0-5) was used in the analysis, a higher score indicating poorer cognitive function. Any pain was assessed by asking if individuals experienced pain in their body in the past month. Depressive symptoms were assessed by the 10-items CESD.[34] Individuals rated each item on a 0 (no) to 3 (often or most of the time) scale. We excluded reports of "poor appetite", "everything is an effort", "cannot get going", and

Table 1
Operationalization of frailty and sleep health

Frailty traits	Survey question	Reponses	Definition of normal traits	Definition of frail traits
Weight loss	In the past week, did you have poor appetite?	0-no 1-rarely 2-sometimes 3-often or chronically	0-no 1-rarely 2-sometimes	3-often or chronically
Exhaustion	In the past week, did you feel that everything was an effort? or In the past week, did you feel that you cannot get going?	0-no 1-rarely 2-sometimes 3-often or chronically	0-no 1-rarely 2-sometimes	3-often or chronically
Low physical activity	How often do you do gardening? or How often do you take a walk? or How often do you ride a bicycle? or How often do you jog, hike, play ball and other outdoor physical exercise?	1-less than once a month 2-2 to 3 times a month 3-1 to 2 times a week 4-just about every day	3-1 to 2 times a week 4-just about every day	1-less than once a month 2-2 to 3 times a month
Slowness	Do you have any difficulty walking for 200 to 300 meters?	0-no difficulty 1-some difficulty 2-great difficulty 3-cannot do it at all	0-no difficulty	1-some difficulty 2-great difficulty 3-cannot do it at all
Weakness	Do you have any difficulty lifting or carrying something weighing 11-12 kg?	0-no difficulty 1-some difficulty 2-great difficulty 3-cannot do it at all	0-no difficulty	1-some difficulty 2-great difficulty 3-cannot do it at all
Sleep health dimension	Survey question	Reponses	Definition of “good” sleep health	Definition of “poor” sleep health
SATED 1: Sleep satisfaction	How was your overall sleeping quality in the past month?	1-very good 2-good 3-not so good 4-very bad	1-very good 2-good	3-not so good 4-very bad
SATED 2: Daytime alertness	How often did you have difficulty staying awake when you drove, ate or engaged in the other social activities in the past month?	0-never 1-less than once a week 2-once or twice per week 3-more than 3 times a week	0-never 1-less than once a week	2-once or twice per week 3-more than 3 times a week
SATED 3: Sleep timing (sleep midpoint)	In the past month, when did you usually go to bed? In the past month, when did you usually get up?	Clock time	Between 2 am and 3:59 am	Earlier than 2:00 am Later than/equal to 4:00 am
SATED 4: Sleep efficiency	In the past month, when did you usually go to bed? In the past month, when did you usually get up? In the past month, approximately how many hours were you asleep every night? Do not count the time you lie in bed but were not asleep.	Clock time and Hours	Awake in bed $<$ 30 minutes	Awake in bed $\geq$ 30 minutes
SATED 5: Sleep duration	In the past month, approximately how many hours were you asleep every night? Do not count the time you lie in bed but were not asleep.	Hours	$\geq$ 7 hours $<$ 9 hours	$<$ 7 hours $\geq$ 9 hours

SATED, satisfaction, alertness, timing, efficiency, and duration scale.

“restless sleep” from the total score calculation to avoid circularity shared variance with frailty and sleep health. Hence, the possible total score ranged from 0 to 18. Drinking frequency was assessed by asking whether individuals drank alcohol in the past 12 months on a 0 (did not drink) to 5 (almost every day) scale. Smoking status was assessed by asking individuals’ smoking history. Their responses were categorized into never smoke (reference), ever smoked, and smoke now. Exercise frequency was recorded on a 0 (9 times or above per week) to 4 (no exercise) scale.

Statistical analysis

Descriptive analysis was used to examine the characteristics of all respondents and by sex. Correlational analysis was used to assess the relationship among the multidimensional sleep health measure and each sleep health dimension. To examine the effects of the multidimensional sleep health measure on frailty, multiple logistic regression analysis was first performed adjusting for sociodemographic information, and then adjusting for health and lifestyle characteristics. The same analysis stratified by sex was carried out to investigate whether the relationship between sleep health and frailty differed within sex groups. Sensitivity analysis was done to investigate which sleep health dimension was significantly related to frailty. We reported odds ratio (OR) with 95% confidence intervals (CI). The focal results were reported with the main text and the fully adjusted models can be found in Supplementary Tables 1-7. We applied sampling weights in all analyses and carried out all analyses with SPSS version 24 (IBM SPSS Statistics for Windows, Armonk, NY). The ethics board at the Taipei Medical University approved the secondary data analysis.

Results

Participant characteristics (Table 2) revealed 9% of the respondents were frail. The average sleep health composite score was 2.51. The most prevalent good sleep health dimension was daytime alertness (91%) and the least prevalent was sleep efficiency (11%). Compared to individuals who were not frail, those who were frail scored significantly lower on the multidimensional sleep health composite, and significantly fewer of them indicated satisfaction with sleep, being alert during daytime, and having adequate sleep duration. Significant differences in all covariates were also found when comparing frailty status. Table 3 shows the relationships among the sleep health composite score and each sleep health dimension. Overall, the

Table 2
Sample characteristics (applied sampling weights)

	Entire sample (N = 2,015)	Entire sample			Women			Men		
	M (SD) or %	Not frail(n = 1,835) *M (SD)* or %	Frail(n = 180) *M (SD)* or %	*p*	Not frail(n = 883) *M (SD)* or %	Frail(n = 124) *M (SD)* or %	*p*	Not frail(n = 952) *M (SD)* or %	Frail(n = 56) *M (SD)* or %	*p*
SATED composite score	2.51(1.10)	2.57 (1.08)	1.84 (1.08)	< .001	2.43 (1.11)	1.76 (1.05)	< .001	2.69 (1.03)	2.06 (1.15)	< .001
0	2.70%	2.20%	8.70%	< .001	3.30%	8.10%	< .001	1.10%	10.30%	< .001
1	15.70%	14.10%	33.60%		17.50%	39.10%		10.80%	18.80%	
2	31.50%	31.60%	30.20%		31.90%	27.70%		31.40%	37.20%	
3	30.50%	31.40%	19.80%		28.80%	19.00%		34.00%	21.90%	
4	17.40%	18.30%	7.70%		16.80%	6.20%		19.70%	11.70%	
5	2.20%	2.40%	0%		1.70%	0%		3.00%	0%	
SATED 1: Sleep satisfaction (yes)	69.90%	72.30%	42.90%	< .001	65.50%	34.10%	< .001	78.90%	66.70%	.046
SATED 2: Daytime alertness (yes)	90.90%	92.60%	70.80%	< .001	91.20%	73.30%	< .001	94.00%	63.70%	< .001
SATED 3: Sleep timing (yes)	41.60%	41.80%	39.40%	.537	41.90%	41.10%	.866	41.70%	34.50%	.340
SATED 4: Sleep efficiency (yes)	10.70%	11.00%	7.50%	.150	8.30%	5.30%	.282	13.60%	13.50%	.843
SATED 5: Sleep duration (yes)	37.70%	38.90%	23.60%	< .001	36.50%	22.10%	.003	41.20%	27.60%	.067
Age (years)				< .001			< .001			.001
65-69	29.10%	30.80%	9.80%		32.50%	10.50%		29.10%	7.80%	
70-74	29.50%	29.60%	28.10%		29.90%	29.80%		29.30%	23.40%	
≥75	41.40%	39.60%	62.10%		37.60%	59.70%		41.60%	68.80%	
Female (yes)	51.30%	49.40%	73.20%	< .001	-	-	-	-	-	-
Education				.018			.065			.480
Primary or below	73.60%	72.90%	81.80%		84.50%	91.50%		61.60%	55.20%	
Secondary or above	26.40%	27.10%	18.20%		15.50%	8.50%		38.40%	44.80%	
Comorbidity				< .001			< .001			.011
0	22.50%	23.90%	7.40%		21.00%	6.60%		26.70%	9.60%	
1	31.20%	32.10%	21.30%		32.30%	19.20%		31.80%	27.00%	
2+	46.20%	44.10%	71.30%		46.70%	74.20%		41.50%	63.40%	
Errors on cognitive test (0-5)	.69 (.95)	.64 (.91)	1.28 (1.22)	< .001	.85 (.99)	1.39 (1.25)	< .001	.44 (.77)	.98 (1.10)	< .001
Pain (yes)	48.10%	45.30%	80.30%	< .001	53.70%	84.90%	< .001	37.10%	67.50%	< .001
Depressive symptoms (0-18)[a]	2.88 (3.65)	2.45 (3.20)	7.87 (4.63)	< .001	2.88 (3.51)	7.95 (4.72)	< .001	2.02 (2.80)	7.67 (4.42)	< .001
Drinking (0-5)	.70 (1.45)	.74 (1.47)	.32 (1.12)	< .001	.22 (.79)	.28 (1.01)	.501	1.24 (1.77)	.45 (1.38)	.005
Smoking				.008			.172			.153
Never smoked	67.20%	66.40%	77.30%		97.10%	94.50%		36.40%	30.40%	
Ever smoked	21.10%	21.40%	17.30%		1.20%	3.40%		41.10%	55.60%	
Smoke now	11.70%	12.20%	5.30%		1.70%	2.20%		22.40%	14.00%	
Lack of exercise (0-4)	1.82 (1.40)	2.09 (1.37)	3.15 (1.29)	< .001	2.20 (1.36)	3.17 (1.29)	< .001	1.98 (1.37)	3.07 (1.31)	< .001

SATED, satisfaction, alertness, timing, efficiency and duration scale.
The score for depressive symptoms was calculated excluding poor appetite, everything is an effort, cannot get going, and restless sleep.

relationships among the 5 dimensions were relatively low, indicating that each sleep dimension provided relatively unique information about overall sleep health.

The associations of a multidimensional sleep health measure with frailty and stratified by sex

The results from the adjusted logistic regression analysis showed that the multidimensional sleep health composite was significantly associated with frailty adjusting for age, sex, and education (OR = 0.57, 95% CI = 0.49-0.68; Model 1A in Table 4). This effect remained significant after adding comorbidity, cognitive function, any pain, depressive symptoms, drinking, smoking, and exercise to the model (OR = 0.78, 95% CI = 0.64-0.94; Model 2A in Table 4). Specifically, individuals scored one point higher on the multidimensional sleep health measure were approximately 22% less likely to be frail.

The effect of the multidimensional sleep health composite on frailty was significant among female (OR = 0.59, 95% CI = 0.48-0.72; Model 3A in Table 4) and male (OR = 0.54, 95% CI = 0.39-0.75; Model 5A in Table 4) respondents adjusting for age and education. Significant effect was observed only among women (OR = 0.79, 95% CI = 0.63-0.98; Model 4A in Table 4) after further adjusting for comorbidity, cognitive function, any pain, depressive symptoms, drinking, smoking, and exercise, but not among men. The effects on women showed that those who scored one point higher on the multidimensional sleep health measure had lower odds of being frail by 21%.

Figure 1 depicts the adjusted probability of being frail based on the score of the multidimensional sleep health composite in the entire sample stratified by sex. The sleep health composite score exhibited a dose-relationship with the adjusted probability of being frail in the entire sample of older Taiwanese, such that each additional increase in the sleep health was associated with a decreased probability of being frail. Similar trends were observed among female and men although only the effects among women reached significant level.

The associations of individual sleep health dimensions with frailty and stratified by sex

The results from the adjusted logistic regression analyses (Table 4) revealed that sleep satisfaction (OR = 0.34, 95% CI = 0.24-0.48; Model 1B), daytime alertness (OR = 0.21, 95% CI = 0.14-0.31; Model 1c), and sleep duration (OR = 0.50, 95% CI = 0.34-0.74; Model 1F) were

Table 3
Correlation analysis among SATED total score and the 5 dimensions (applied sampling weights)

	(1)	(2)	(3)	(4)	(5)	(6)
Entire sample						
(1) SATED composite score	1					
(2) SATED 1: Sleep satisfaction (yes)	0.66**	1				
(3) SATED 2: Daytime alertness (yes)	0.34**	0.19**	1			
(4) SATED 3: Sleep timing (yes)	0.47**	0.02	−0.01	1		
(5) SATED 4: Sleep efficiency (yes)	0.43**	0.19**	0.03	0.01	1	
(6) SATED 5: Sleep duration (yes)	0.67**	0.31**	0.08**	0.04	0.16**	1
Women						
(1) SATED composite score	1					
(2) SATED 1: Sleep satisfaction (yes)	0.72**	1				
(3) SATED 2: Daytime alertness (yes)	0.38**	0.20**	1			
(4) SATED 3: Sleep timing (yes)	0.47**	0.04	0.01	1		
(5) SATED 4: Sleep efficiency (yes)	0.39**	0.21**	0.03	0.01	1	
(6) SATED 5: Sleep duration (yes)	0.67**	0.35**	0.11**	0.04	0.16**	1
Men						
(1) SATED composite score	1					
(2) SATED 1: Sleep satisfaction (yes)	0.58**	1				
(3) SATED 2: Daytime alertness (yes)	0.28**	0.15**	1			
(4) SATED 3: Sleep timing (yes)	0.48**	−0.01	−0.02	1		
(5) SATED 4: Sleep efficiency (yes)	0.45**	0.15**	0.02	0.00	1	
(6) SATED 5: Sleep duration (yes)	0.67**	0.25**	0.05**	0.04	0.16**	1

SATED, satisfaction, alertness, timing, efficiency and duration scale.
** $p < .01$.

significantly associated with frailty in the entire sample adjusting for age, sex, and education. After considering individuals' health and risk behaviors, only daytime alertness remained significant (OR = .46, 95%CI = 0.29-0.75; Model 2C).

For women, sleep satisfaction (OR = 0.29, 95% CI = 0.19-0.44; Model 3B), daytime alertness (OR = 0.29, 95%CI = 0.18-0.47; Model 3C), and sleep duration (OR = 0.48, 95%CI = .30-.78; Model 3F) were significantly related to frailty adjusting for age and education. However, these effects were no longer significant after adding health and risk behaviors to the model. For men, sleep satisfaction (OR = 0 .47, 95%CI = 0.24-0.94; Model 5B) and daytime alertness (OR = 0.10, 95%CI = 0.05-0.21; Model 5C) were significantly associated with frailty adjusting for age and education. Only daytime alertness (OR = 0.33, 95%CI = 0.13-0.82; Model 6C) remained significant after adding health and risk behaviors to the model. Figure 2 shows the adjusted probability of being frail according to the 5 sleep dimensions in the entire sample stratified by sex.

Discussion

The current study investigated the relationship between a multidimensional sleep health composite and frailty among community-dwelling older adults. Our findings revealed that better sleep health was significantly associated with lower odds of frailty above and beyond sociodemographic characteristics, health status, and health risk behaviors. We also found that the association of the multidimensional sleep health composite with frailty in each sex stratum, such that the relationship was only significant among older women, but not older men, in fully adjusted models. For individual sleep health dimensions, only daytime alertness was significantly related to frailty in the entire sample and among men adjusting for sociodemographic characteristics, health status, and health risk behaviors. Although sleep satisfaction, daytime alertness, and sleep duration were significantly related to frailty adjusting for sociodemographic information among women, none of these sleep health dimensions remained significant after taking health and risk behaviors into account.

To the authors' knowledge, this is the first study to examine the relationship between the multidimensional sleep health measure and frailty among community-dwelling older adults. Previous studies have shown that individual sleep characteristics are significantly related to frailty.[4,6,7] Our findings show that the probability of being frail is reduced with the increment in the sleep health composite score and that only daytime alertness among the 5 sleep health dimensions was significantly associated with frailty. This means that,

Table 4
Adjusted logistic regression analysis examining the associations between sleep health with frailty (applied sampling weights)

	Entire sample		Women		Men	
	Model 1[a]	Model 2[b]	Model 3[a]	Model 4[b]	Model 5[a]	Model 6[b]
	OR [95% CI]	OR [95% CI]	OR [95% CI]	OR [95% CI]	OR [95% CI]	OR [95% CI]
A SATED composite score	**0.57 [0.49-0.68]**	**0.78 [0.64-0.94]**	**0.59 [0.48-0.72]**	**0.79 [0.63-0.98]**	**0.54 [0.39-0.75]**	0.75 [0.52-10.09]
B SATED 1: Sleep satisfaction (yes)	**0.34 [0.24-0.48]**	0.74 [0.49-1.12]	**0.29 [0.19-0.44]**	0.62 [0.38-1.02]	**0.47 [0.24-0.94]**	1.21 [0.49-2.99]
C SATED 2: Daytime alertness (yes)	**0.21 [0.14-0.31]**	**0.46 [0.29-0.75]**	**0.29 [0.18-0.47]**	0.57 [0.32-1.03]	**0.10 [0.05-0.21]**	**0.33 [0.13-0.82]**
	1.00 [0.70-1.42]	0.79 [0.53-1.19]	1.06 [0.71-1.60]	0.84 [0.52-1.35]	0.86 [0.43-1.70]	0.69 [0.31-1.53]
D SATED 3: Sleep timing (yes)						
E SATED 4: Sleep efficiency (yes)	0.89 [0.47-1.68]	1.39 [0.65-2.95]	0.77 [0.32-1.86]	1.11 [0.39-3.15]	1.03 [0.41-2.60]	1.56 [0.50-4.86]
F SATED 5: Sleep duration (yes)	**0.50 [0.34-0.74]**	0.75 [0.47-1.18]	**0.48 [0.30-0.78]**	0.81 [0.46-1.40]	0.54 [0.27-1.10]	0.59 [0.26-1.37]

SATED, satisfaction, alertness, timing, efficiency and duration scale; Significant effects are bold.
[a] This model adjusted for age, sex (not in sex-stratified models), and education.
[b] This model adjusted for age, sex (not in sex-stratified models), education, comorbidity, global cognitive function, pain, depressive symptoms (excluding poor appetite, everything is an effort, cannot get going, and restless sleep), drinking, smoking, and lack of exercise.

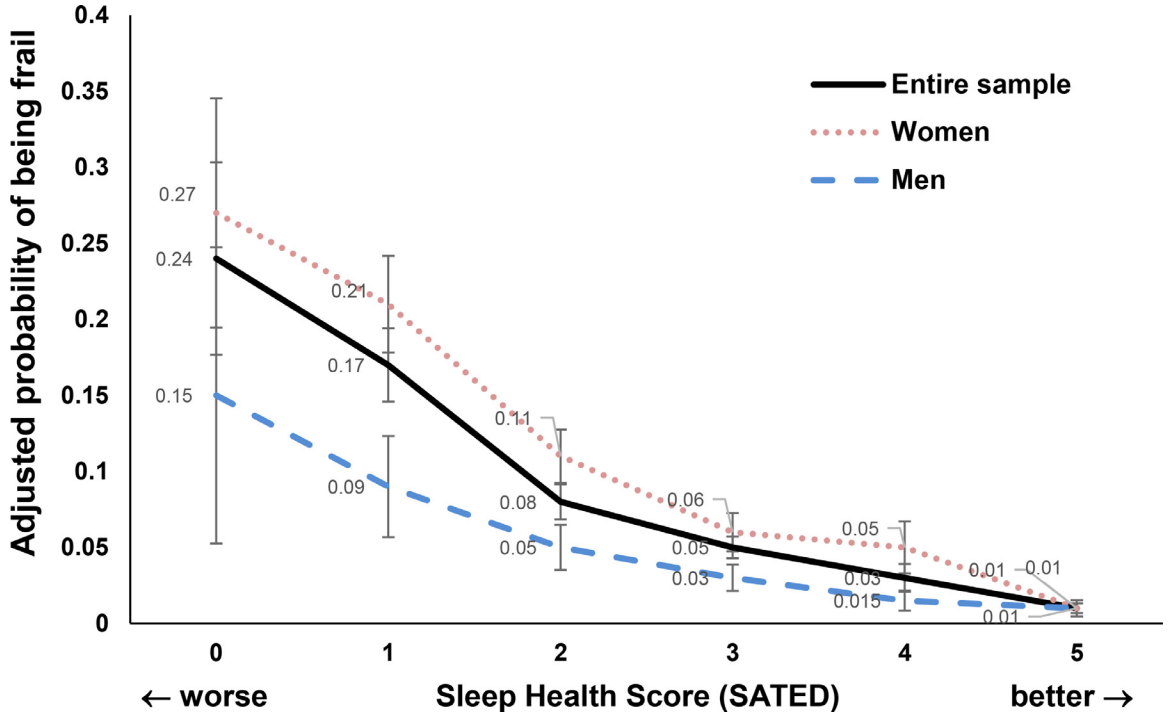

Figure 1. The association of multidimensional sleep health with adjusted probability of being frail. Overall, the results showed that a better sleep health (higher score) was associated with a lower probability of being frail. Significant effects of sleep health on frailty was found when analyzing data with the entire sample ($B = -0.26$, $p = .009$) and from women ($B = -0.24$, $p = .035$). Although the effects of sleep health on frailty among men revealed a similar trend as observed among the entire sample and women, the effect did not reach significance ($B = -0.13$, $p = .133$). Models adjusted for age, sex (not in sex-stratified models), education, comorbidity, global cognitive function, pain, depressive symptoms (excluding poor appetite, everything is an effort, cannot get going, and restless sleep), drinking, smoking, and lack of exercise. SATED, Satisfaction, Alertness, Timing, Efficiency and Duration Scale.

if we only consider single sleep measures (eg, sleep duration or quality as in most previous studies) when estimating the risk of frailty, we may underestimate the effect of sleep and miss opportunities to intervene early. Together, these findings reiterate the importance of understanding sleep in a multidimensional manner and suggest the potential additive effects of individual sleep characteristics.

We found that better sleep health was significantly associated with frailty only among women after controlling for sociodemographic characteristic, health status, and health risk behaviors. One possible explanation for our findings may be sex differences in shared pathways. For instance, previous evidence has shown that inflammatory biomarkers of frailty pathogenesis, such as C-reactive protein, are more likely to be elevated among women than men.[35] Poor sleep has also been linked to increased C-reactive proteins level among women, but not among men.[17,36] Having better sleep health might impact frailty through the reduction of inflammatory biomarkers among older women. Further investigations on the sex differences in the underlying mechanisms between sleep health and frailty are warranted.

Among the 5 sleep health dimensions, we found that daytime alertness was independently associated with frailty in the entire sample in the fully adjusted models (Model 2C in Table 4). Further analyses entering all 5 sleep health dimensions simultaneously in the model also showed similar results (Supplementary Table 7). Our results also showed sex differences in the relationship between daytime alertness and frailty, such that daytime alertness was significantly associated with frailty in men (Model 6C in Table 4), but not in women (Model 4C in Table 4). There were only a few studies investigated the relationship between daytime alertness and frailty among older adults, and the findings were mixed. For example, in a study focusing on community-dwelling older adults including both men and women, researchers found that an inability to maintain alertness during the daytime significantly increased the risks of being frail by 3 times.[37] In another study, daytime alertness was not significantly associated with frailty in the entire sample, and not in each sample of men and women.[15] One other study that focused only on older men also did not find the relationship between daytime alertness and frailty.[9] Although a recent meta-analysis showed that daytime drowsiness was significantly correlated with frailty,[6] the pooled effects included social frailty (ie, reduced social interactions), which made it difficult to discern the effects of daytime alertness on physical frailty. Because these studies looked at the individual effects of daytime alertness on frailty, more studies investigating the impact of daytime alertness on frailty simultaneously with other sleep dimensions are recommended.

Our study contributes to the literature on sleep and aging by demonstrating that better sleep health is associated with a lower likelihood of being frail among community-dwelling older adults. Recent studies have shown that behavioral changes are effective in improving sleep health among older adults with insomnia[38] or even among individuals without sleep disorders.[39] At the population level, public health education targeting sleep myths and increasing knowledge on sleep hygiene may have the potential to change sleep practices.[40] Because the existing interventions on frailty are mainly focused on nutrition and exercise training,[5] more studies are needed to investigate the impacts of sleep-focused interventions on frailty risk. Our study also reveals that the effects of sleep health on frailty may be stronger among older women than older men. This is not to negate the benefits of sleep health on preventing frailty among men, but to emphasize the sex differences in this relationship and effective strategies specific for each sex might be needed.

Using a representative national sample of older adults in a relatively understudied Asian context is a unique strength of this study. We include extensive covariates of sociodemographic characteristics,

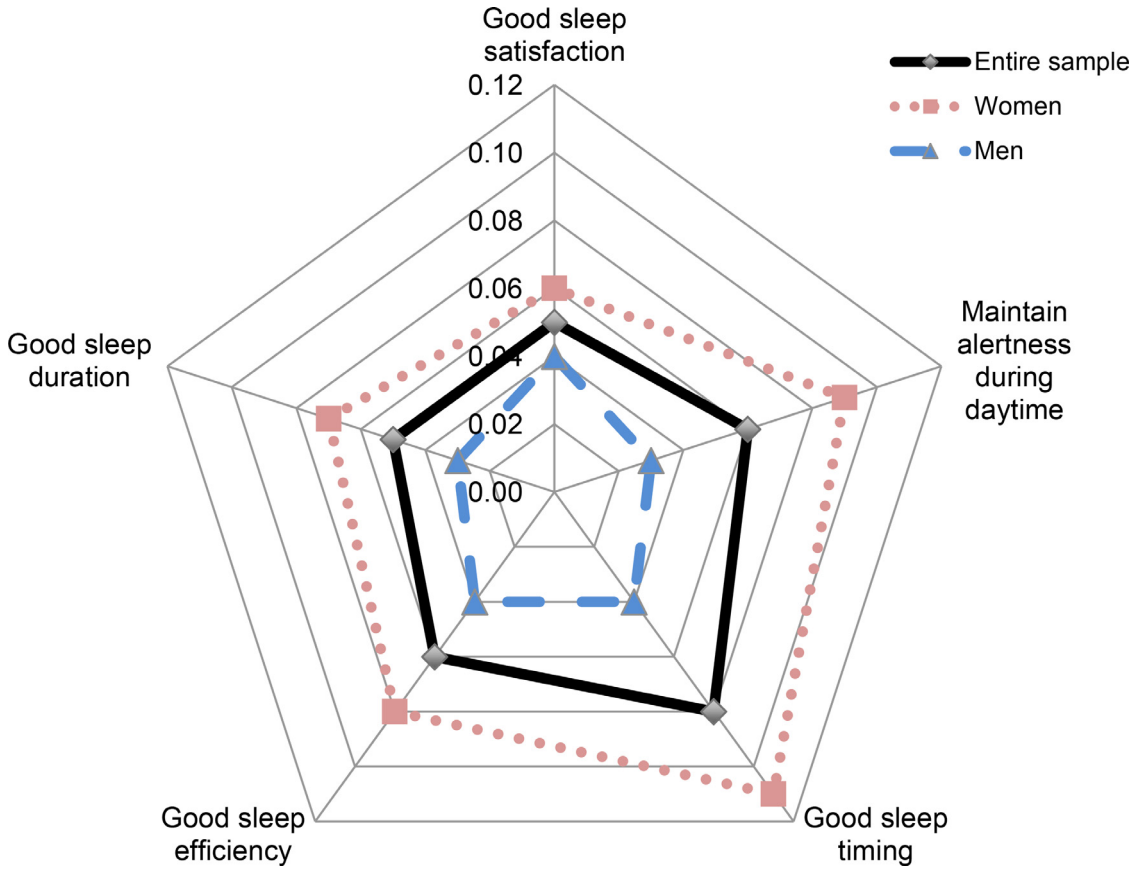

Figure 2. Radar plot of the association of each sleep health dimension with adjusted probability (beta) of being frail. The probability of being frail is zero at the center point of the plot and increases from inner to outer grids. Daytime alertness and frailty were significantly associated among all respondents ($B = -0.77$, $p = .002^{**}$) and men ($B = -1.11$, $p = .017^{*}$). No other significant effects of other sleep health facets on frailty were found. Variables adjusted in analysis included age, sex (not in sex-stratified models), education, comorbidity, global cognitive function, pain, depressive symptoms (excluding poor appetite, everything is an effort, cannot get going, and restless sleep), drinking, smoking, and lack of exercise.

health, and risk behaviors in analyses, increasing the validity of our findings. There are, however, limitations in this study. First, the cross-sectional design is susceptible to reverse causality. Previous study suggested that there might be bi-directional relationship between sleep and frailty.[37] Further longitudinal investigations on this relationship are warranted. Second, due to the constraints of archival data, we used self-report items to create an adopted frailty index and the multidimensional measure of sleep health according to the SATED model. Future studies may benefit from the utilization of a validated tool to assess frailty[21] and sleep health.[11] Third, although napping is associated with frailty and mortality[10] and sleep medications can affect sleep,[28] they are not available in the TLSA dataset, precluding investigation of their moderation effects on the relationship between sleep health and frailty. Last, sleep disorders can increase the risks of frailty[15] which may help explain our findings. For instance, obstructive sleep apnea is associated with higher odds of frailty among older adults[15] and the significant relationship between obstructive sleep apnea and frailty has been observed among older women.[15] However, variables on sleep disorders are not available in the TLSA. We are, therefore, unable to further investigate whether the impacts of sleep health on frailty are independent of sleep disorders, whether sleep disorder modify the relationship between sleep health and frailty, and whether sleep disorders account for the differences in the relationship between sleep health and frailty within each sex. Our models may have captured some of the effects of sleep disorders on frailty because many symptoms of sleep disorders overlap with SATED dimensions.[11] Nevertheless, concerns may remain regarding uncaptured, respiratory-specific characteristics (eg, sleep-disordered breathing) that may not overlap with the sleep health dimensions. We recommend future research to delve into these relationships among older adults.

This study shows the first empirical evidence that sleep health may be an early risk factor for frailty by investigating the association of a multidimensional measure of sleep health with frailty among community-dwelling older adults in Taiwan. Our findings show that better sleep health is related to lower odds of frailty independent of sociodemographic, health status, and health risk behaviors. We also report that the associations of individual sleep health facets with frailty within each sex, with a stronger relationship between overall sleep health and frailty among older women. Improving sleep health among older adults may help delay and prevent frailty.

Declaration of conflict of interest

The authors have declared no conflicts of interest.

Disclosures

The first author received support from the Intramural Grant for Newly Appointed Faculty at Taipei Medical University (TMU109-AE1-B12) during the time conducting this research. The conception of the study and the analysis of the results were independent of the sponsor. Outside of the current work, Dr. Orfeu M. Buxton discloses that he received subcontract grants to Penn State from Proactive Life (formerly Mobile Sleep Technologies), doing business as SleepSpace (National Science Foundation grant #1622766 and NIH/National

Institute on Aging Small Business Innovation Research Program R43AG056250, R44 AG056250), received honoraria/travel support for lectures from Boston University, Boston College, Tufts School of Dental Medicine, New York University, University of Miami, Harvard Chan School of Public Health, Eric H. Angle Society of Orthodontists, and Allstate, consulting fees for SleepNumber, and receives an honorarium for his role as the Editor in Chief of the journal Sleep Health. Other authors have nothing to disclose.

Funding

The first author received support from the Intramural Grant for Newly Appointed Faculty at Taipei Medical University (TMU109-AE1-B12) during the time conducting this research.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.sleh.2022.05.003.

Reference

1. Fried LP, Tangen CM, Walston J, et al. Frailty in older adults: Evidence for a phenotype. J Gerontol Series A Biol Sci Med Sci. 2001;56:M146–M157.
2. O'Caoimh R, Sezgin D, O'Donovan MR, et al. Prevalence of frailty in 62 countries across the world: a systematic review and meta-analysis of population-level studies. Age Ageing. 2021;50:96–104. https://doi.org/10.1093/ageing/afaa219.
3. Ensrud KE, Ewing SK, Taylor BC, et al. Comparison of 2 frailty indexes for prediction of falls, disability, fractures, and death in older women. Arch Intern Med. 2008;168:382–389.
4. Ensrud KE, Ewing SK, Cawthon PM, et al. A comparison of frailty indexes for the prediction of falls, disability, fractures, and mortality in older men. J Am Geriatr Soc. 2009;57:492–498.
5. Marcucci M, Damanti S, Germini F, et al. Interventions to prevent, delay or reverse frailty in older people: a journey towards clinical guidelines. *BMC medicine*. 2019;17:1–11.
6. Pourmotabbed A, Boozari B, Babaei A, et al. Sleep and frailty risk: a systematic review and meta-analysis. *Sleep and Breathing*. 2020;24:1187–1197. https://doi.org/10.1007/s11325-020-02061-w. 2020/09/01.
7. Moreno-Tamayo K, Manrique-Espinoza B, Ortiz-Barrios LB, Cárdenas-Bahena Á, Ramírez-García E, Sánchez-García S. Insomnia, low sleep quality, and sleeping little are associated with frailty in Mexican women. Maturitas. 2020;136:7–12. https://doi.org/10.1016/j.maturitas.2020.03.005.
8. Shih A-C, Chen L-H, Tsai C-C, Chen J-Y. Correlation between sleep quality and frailty status among middle-aged and older Taiwanese people: a community-based, cross-sectional study. Int J Environ Res Public Health. 2020;17:9457.
9. Ensrud KE, Blackwell TL, Redline S, et al. Sleep disturbances and frailty status in older community-dwelling men. J Am Geriatr Soc. 2009;57:2085–2093. https://doi.org/10.1111/j.1532-5415.2009.02490.x.
10. Guida JL, Alfini AJ, Gallicchio L, Spira AP, Caporaso NE, Green PA. Association of objectively measured sleep with frailty and 5-year mortality in community-dwelling older adults. Sleep. 2021;44:zsab003. https://doi.org/10.1093/sleep/zsab003.
11. Buysse DJ. Sleep health: can we define it? Does it matter? Sleep. 2014;37:9–17. https://doi.org/10.5665/sleep.3298.
12. Wallace ML, Stone K, Smagula SF, et al. Which sleep health characteristics predict all-cause mortality in older men? An application of flexible multivariable approaches. Sleep. 2017;41:zsx189. https://doi.org/10.1093/sleep/zsx189.
13. Huang T, Redline S, Gordon CM, Schernhammer E, Curhan GC, Paik JM. Self-reported sleep characteristics and risk for incident vertebral and hip fracture in women. *Sleep Health*. 2022. https://doi.org/10.1016/j.sleh.2021.11.011. 2022/02/28/.
14. Moreno-Tamayo K, Manrique-Espinoza B, Rosas-Carrasco O, Pérez-Moreno A, Salinas-Rodríguez A. Sleep complaints are associated with frailty in Mexican older adults in a rural setting. Geriatr Gerontol Int. 2017;17:2573–2578. https://doi.org/10.1111/ggi.13111.
15. Moreno-Tamayo K, Manrique-Espinoza B, Guerrero-Zúñiga S, Ramírez-García E SS-G. Sex differences in the association between risk of obstructive sleep apnea, insomnia, and frailty in older adults. *Nat Sci Sleep*. 2021;13:1461–1472.
16. Kang I, Kim S, Kim BS, Yoo J, Kim M, Won CW. Sleep latency in men and sleep duration in women can be frailty markers in community-dwelling older adults: the Korean Frailty and Aging Cohort Study (KFACS). J Nutr Health Aging. 2019;23:63–67. https://doi.org/10.1007/s12603-018-1109-2.
17. Suarez EC. Self-reported symptoms of sleep disturbance and inflammation, coagulation, insulin resistance and psychosocial distress: evidence for gender disparity. Brain Behav Immun. 2008;22:960–968.
18. Hermalin A, Liang J, Chang M-C. 1989 survey of the health and living status of the elderly in Taiwan: questionnaire and survey design. *Elderly Asia Rep*. 1989;12:89–91.
19. Zimmer Z, Martin LG, Chang M-C. Changes in functional limitation and survival among older Taiwanese, 1993, 1996, and 1999. Popul Stud (Camb). 2002;56:265–276.
20. Chu W-M, Ho H-E, Yeh C-J, et al. Self-rated health trajectory and frailty among community-dwelling older adults: evidence from the Taiwan Longitudinal Study on Aging (TLSA). *BMJ Open*. 2021;11: e049795. https://doi.org/10.1136/bmjopen-2021-049795.
21. de Vries NM, Staal JB, van Ravensberg CD, Hobbelen JSM. Olde Rikkert MGM, Nijhuis-van der Sanden MWG. Outcome instruments to measure frailty: a systematic review. Ageing Res Rev. 2011;10:104–114. https://doi.org/10.1016/j.arr.2010.09.001. 2011/01/01/.
22. Ho H-E, Yeh C-J, Chu W-M, Lee M-C. Midlife body mass index trajectory and risk of frailty 8 years later in Taiwan. *J Nutr Health Aging*. 2019;23:849–855.
23. Hsu H-C, Chang W-C. Trajectories of frailty and related factors of the older people in Taiwan. Exp Aging Res. 2015;41:104–114.
24. Roenneberg T, Wirz-Justice A, Merrow M. Life between clocks: Daily temporal patterns of human chronotypes. J Biol Rhythms. 2003;18:80–90.
25. Furihata R, Hall MH, Stone KL, et al. An aggregate measure of sleep health is associated with prevalent and incident clinically significant depression symptoms among community-dwelling older women. Sleep. 2016;40:zsw075. https://doi.org/10.1093/sleep/zsw075.
26. Maglione JE, Ancoli-Israel S, Peters KW, et al. Depressive symptoms and subjective and objective sleep in community-dwelling older women. J Am Geriatr Soc. 2012;60:635–643.
27. Sukegawa T, Itoga M, Seno H, et al. Sleep disturbances and depression in the elderly in Japan. Psychiatry Clin Neurosci. 2003;57:265–270.
28. Watson N, Badr M, Belenky G, Consensus Conference Panel. Joint consensus statement of the American Academy of Sleep Medicine and Sleep Research Society on the recommended amount of sleep for a healthy adult: methodology and discussion. Sleep. 2015;38:1161–1183.
29. Chen T-Y, Lee S, Schade MM, Saito Y, Chan A, Buxton OM. Longitudinal relationship between sleep deficiency and pain symptoms among community-dwelling older adults in Japan and Singapore. Sleep. 2019;42:zsy219.
30. Chen T-Y, Saito Y. Longitudinal effects of nocturnal insomnia symptom subtypes and nonrestorative sleep on the incidence of depression among community-dwelling older adults: results from the health and retirement study. Sleep Med. 2021;79:155–163. https://doi.org/10.1016/j.sleep.2021.01.003.
31. Hoogendijk EO, van Hout HPJ, Heymans MW, et al. Explaining the association between educational level and frailty in older adults: results from a 13-year longitudinal study in the Netherlands. Ann Epidemiol. 2014;24:538–544. https://doi.org/10.1016/j.annepidem.2014.05.002. e2.
32. Glei DA, Landau DA, Goldman N, Chuang YL, Rodríguez G, Weinstein M. Participating in social activities helps preserve cognitive function: An analysis of a longitudinal, population-based study of the elderly. Int J Epidemiol. 2005;34:864–871. https://doi.org/10.1093/ije/dyi049.
33. Katzman R, Zhang MY, Ouang Ya Q, et al. A Chinese version of the Mini-Mental State Examination; impact of illiteracy in a Shanghai dementia survey. J Clin Epidemiol. 1988;41:971–978. https://doi.org/10.1016/0895-4356(88)90034-0.
34. Lee K, Ou Y, Chen S, Weng L. The psychometric properties of a short form of the CES-D used in the Taiwan Longitudinal Study on Aging. *Formosa J Mental Health*. 2009;22:383–410.
35. Valentine RJ, McAuley E, Vieira VJ, et al. Sex differences in the relationship between obesity, C-reactive protein, physical activity, depression, sleep quality and fatigue in older adults. Brain Behav Immun. 2009;23:643–648. https://doi.org/10.1016/j.bbi.2008.12.003.
36. Irwin MR, Olmstead R, Carroll JE. Sleep disturbance, sleep duration, and inflammation: a systematic review and meta-analysis of cohort studies and experimental sleep deprivation. Biol Psychiatry. 2016;80:40–52. https://doi.org/10.1016/j.biopsych.2015.05.014.
37. Vaz Fragoso CA, Gahbauer EA, Van Ness PH, Gill TM. Sleep–wake disturbances and frailty in community–living older persons. J Am Geriatr Soc. 2009;57:2094–2100. https://doi.org/10.1111/j.1532-5415.2009.02522.x.
38. Irwin MR, Olmstead R, Carrillo C, et al. Cognitive behavioral therapy vs. Tai Chi for late life insomnia and inflammatory risk: a randomized controlled comparative efficacy trial. Sleep. 2014;37:1543–1552.
39. Murawski B, Wade L, Plotnikoff RC, Lubans DR, Duncan MJ. A systematic review and meta-analysis of cognitive and behavioral interventions to improve sleep health in adults without sleep disorders. Sleep Med Rev. 2018;40:160–169. https://doi.org/10.1016/j.smrv.2017.12.003.
40. Robbins R, Grandner MA, Buxton OM, et al. Sleep myths: an expert-led study to identify false beliefs about sleep that impinge upon population sleep health practices. *Sleep Health*. 2019;5:409–417. https://doi.org/10.1016/j.sleh.2019.02.002.