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Association between sleep quality, sleep duration, and physical frailty among adults aged 50 years and older in India

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Abstract

Background Considering the significant growth in India's aging population, it is imperative to identify factors associated with frailty among older Indians. This study examined the association between sleep quality, sleep duration, and physical frailty among older adults in India. Moreover, we examined whether the associations between sleep quality, sleep duration, and physical frailty varied by gender.

Methods In this secondary analysis, we used data from the 2015 wave 2 of the Study on Global Aging and Adult Health (WHO-SAGE) in India, comprising a sample of 6,512 older adults aged 50 years and above. Pre-frailty and frailty were assessed using the modified version of the frailty phenotype developed by Fried and colleagues. Sleep was assessed by self-reported quality and duration. Multinomial and multivariable logistic regression models were used to examine the associations between sleep quality, sleep duration, and physical frailty (including its components), as well as to explore the moderating effect of gender.

Results 66.8% of older Indians were pre-frail, while 25.2% were frail. Relative to those with good sleep quality, older adults with poor sleep quality had significantly higher odds of frailty [AOR: 2.79; CI: 1.37–5.66]. Compared to those receiving the recommended age-appropriate 7–8 h of sleep, older adults sleeping ≥ 9 h reported a significantly lower likelihood of both pre-frailty [AOR: 0.73; CI: 0.57–0.93] and frailty [AOR: 0.68; CI: 0.51–0.91]. Analysis of specific components of frailty showed that older adults with long sleep had lower odds of exhaustion [AOR: 0.86; CI: 0.73–1.00] compared to those with age-appropriate sleep duration. Moreover, frailty was more pronounced in older men with poor sleep quality and short sleep duration (< 7 h/night) than in older women with similar sleep patterns. Poor sleep quality was not linked to any of the frailty components in older women; however, in older men, it was associated with exhaustion [AOR: 4.28; CI: 2.28–8.06], weak grip strength [AOR: 2.31; CI: 1.46–3.67], and low physical activity [AOR: 2.81; CI: 1.10–7.21].

Conclusion The findings indicate potential associations between sleep quality, sleep quantity, and physical frailty among older Indians. Poor sleep quality was associated with frailty, yet long sleep duration was associated with a lower prevalence of frailty, independent of sleep quality. Moreover, the prevalence of frailty associated with poor sleep quality and shorter sleep duration was more pronounced among older Indian men than women, underscoring the need for targeted interventions to address sleep-related concerns in this demographic.

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Keywords Sleep quality, Sleep duration, Physical frailty, Older adults, India

Background

The global population is experiencing a significant shift towards aging due to increased longevity and decreased fertility rates. However, low- and middle-income countries (LMICs), like India, are experiencing a rate of aging three times faster than their wealthier counterparts [1, 2]. As a result, LMICs have limited time to brace for the rapid aging of their populations [1, 2]. According to the 2011 Indian Census, approximately 9% (104 million) of India's population was aged 60 and over, and this is expected to double to 19.6% (330 million) by 2050 [3–5]. Population aging comes with enormous challenges for policy making, planning, and the delivery of health, human, and social services [6]. Among the many challenges brought on by population aging, physical frailty remains particularly daunting [7].

Frailty, characterized by symptoms of weakness or poor handgrip strength, slow walking speed, reduced physical activity, unintentional weight loss, and fatigue [1], represents a clinical syndrome reflecting a "*loss of physiologic reserve and resistance to stressors due to cumulative declines across multiple physiologic systems*" [8–10]. Physically frail individuals endure an increased risk of early death and other unfavorable health outcomes, including falls, fractures, injuries, disability, dependence, and cognitive impairment, including dementia [11]. These issues undermine the quality of life [12] and increase the use and costs associated with the care and maintenance of health [13–15].

Although a significant public health problem, frailty is preventable, treatable, and, as such, reversible [16]. Therefore, identifying older adults most susceptible to frailty is a public health priority. Recently, sleep problems have garnered attention as a potential contributor to physical frailty [17, 18]. Aging often alters sleep patterns, including decreased sleep time, disruptions of deep sleep, and more frequent nighttime awakenings [19, 20]. Sleep disturbances are common among older adults [21, 22], with about 50% reporting some sleep problems [21]. This is concerning, as sleep plays a vital role in maintaining optimal health and facilitating various biological functions, including hormone regulation, muscle repair, tissue growth, protein synthesis, energy conservation, glucose management, cognitive function, and cardiovascular health [8, 23, 24].

Among various sleep characteristics, sleep duration and quality have been extensively studied and consistently linked to frailty [25]. Adverse health effects have been linked to short and lengthy sleep durations that deviate from the recommended 7–8 h of sleep per night in older persons [26, 27]. Recent empirical studies have linked various sleep problems to physical frailty, including disturbed sleep [28], inadequate sleep duration [29, 30], excessive sleep [10, 17, 30–32], insomnia [29], and poor sleep quality [10, 29]. Some studies have observed a U-shaped relationship between sleep duration and frailty, implying that insufficient and excessive sleep may contribute to physical frailty [33].

As far as we know, however, only one previous study has explored the association between sleep and physical frailty among older adults in India, and it is focused on a sleep disorder, specifically insomnia-related symptoms [34]. To better understand the role of sleep in frailty among older Indians, it is important to examine additional sleep dimensions and consider potential modifiers. Focusing solely on sleep disorders may overlook older adults experiencing poor sleep quality or insufficient sleep duration who do not meet diagnostic criteria for specific sleep disorders. Examining sleep quality and duration can help capture a broader range of sleep-related factors that may contribute to physical frailty in later life. By understanding the relative contributions of sleep quality and duration to frailty, care providers and practitioners can develop targeted interventions to improve sleep health in older adults.

As such, this study investigates the association of sleep quality, sleep duration, and physical frailty among older Indians. Additionally, we explore potential variations in these associations by gender. Biological variances, such as hormonal fluctuations, may influence how sleep affects physiological processes [35, 36] related to frailty differently in men and women. Social and cultural factors, including caregiving responsibilities and healthcare utilization patterns, which often differ by gender [37, 38], may also play a role. Additionally, gender differences in physical and leisure activity levels [39, 40], psychosocial factors [41], and genetic or epigenetic predispositions may interact with sleep patterns, uniquely affecting frailty outcomes in men and women [29, 42, 43]. Understanding how sleep correlates with frailty differently for men and women improves our knowledge of gender-specific health disparities and provides valuable guidance for crafting individualized interventions to promote healthy aging and reduce frailty burdens across diverse populations.

We evaluate frailty as a whole and examine its individual components. Assessing physical frailty as a composite measure offers a holistic understanding of an older adult's physical vulnerability, while examining its individual components allows for a more nuanced exploration of the specific risk factors contributing to frailty. For instance, poor sleep quality may co-occur with symptoms

of exhaustion [44], while shorter sleep durations could potentially exacerbate muscle weakness and impact physical activity levels [45]. By delineating these relationships, our study is likely to yield valuable insights into the interplay between sleep patterns and physical frailty, informing potential strategies to improve aging and health among older Indians. Figure 1 presents our conceptual framework.

Methods

Data

This secondary analysis utilizes data from the 2015 wave 2 of the Study on Global Aging and Adult Health (WHO-SAGE) in India, conducted across six selected states representing different regions of the country: Assam (Northeast), Karnataka (South), Maharashtra (West), Rajasthan (North), Uttar Pradesh (Central) and West Bengal (East). The survey covers a diverse and representative sample of 9,116 respondents aged 18 years and above. SAGE wave 2 India was a follow-up study of SAGE wave 1 and covered the same states with the same primary sampling units (PSU) and sample households initially covered in the WHO-World Health Survey (WHS) of 2003. Sampling was based on a stratified multistage cluster sample design. In rural areas, a two-stage sampling approach was employed, with villages serving as primary sampling units (PSUs) and households as secondary stage units (SSUs). Urban areas followed a three-stage sampling process, sequentially selecting wards, census enumeration blocks, and households. The number of households chosen was proportional to the population of each respective state and was evenly distributed across urban and rural regions. Household enumerations were conducted for the final sampling units. One household questionnaire was completed per household, where the household informant and individual respondent did not have to be the same person. One individual was selected from households with members aged 18–49, while all individuals aged 50+in the households were invited to complete the individual interview. Face-to-face interviews were used to collect both household and individual level data. For further details on sampling and other procedures, refer to Kowal et al. (2012) [46].

The SAGE study received human subjects testing and ethics council approval from the WHO Ethical Review Committee and the research review boards local to each participating site (International Institute for Population Sciences, India). Written informed consent was obtained from each respondent before the interview and examination. A standard consent form, approved by the WHO Ethics Review Committee, was read to the respondent in their language. The current study is a secondary analysis of the de-identified, publicly available SAGE data

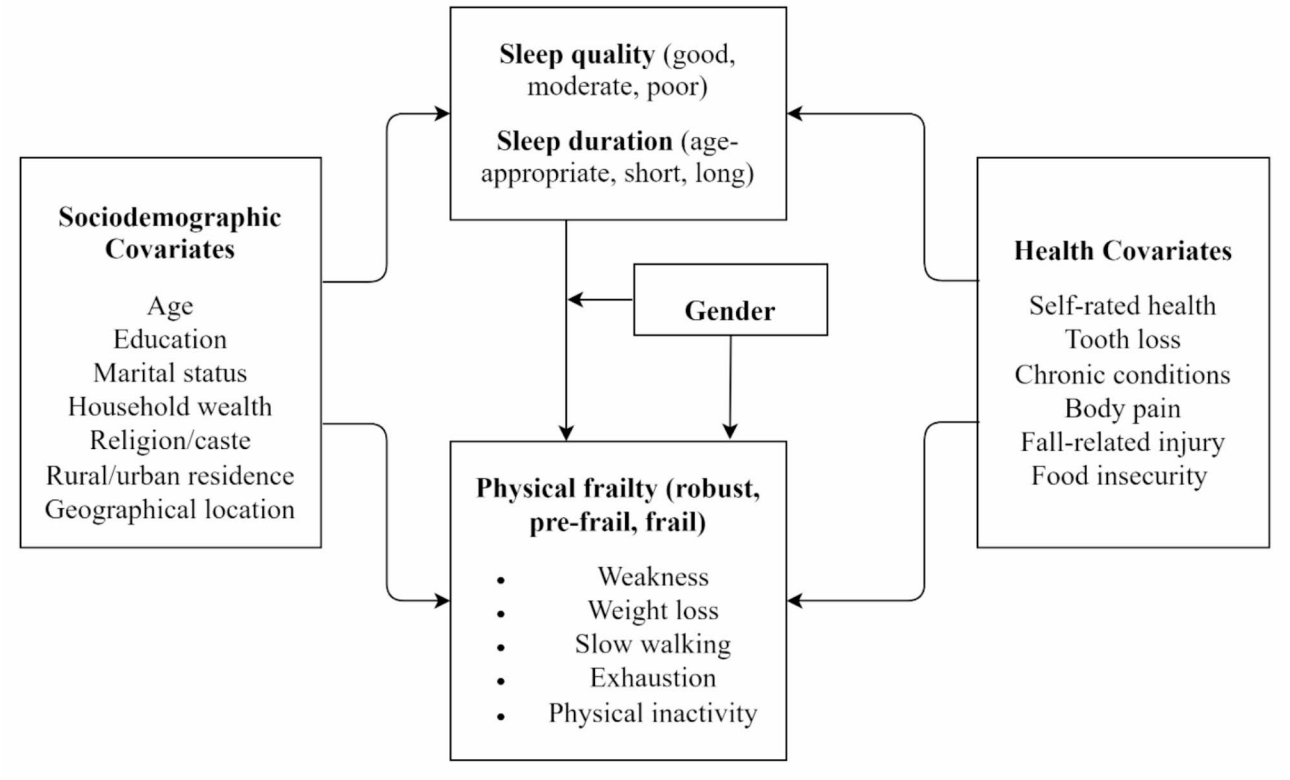

Fig. 1 Conceptual framework of the study

and, and does not require additional ethics committee approval.

Study sample

The number of respondents in WHO-SAGE wave 2 includes 1,998 individuals aged 18–49 years and 7,118 individuals aged 50 and above. The present study only included respondents aged 50 years and over. After excluding those with cognitive limitations that prevented them from being interviewed (n=4), those with missing information on frailty components and/or other study variables (n=610), our analytical sample was reduced to 6,512 adults age 50 years and over. The final analytic sample (n=6,512) of adults aged 50 and over did not exhibit any significant differences in sociodemographic characteristics compared to the full sample (n=7,118).

Measurements

Outcome

Frailty: Physical frailty was measured using a modified version of the frailty phenotype developed by Fried and colleagues [47]. Weakness, weight loss, slow walking, exhaustion, and physical inactivity were dichotomized as described below and used as individual components to create a frailty score of 0–5.

Weakness was assessed using the measure of hand grip strength. The grip strength test was performed on both hands with a hand dynamometer. Measurement was taken in a sitting position, and the respondents were asked to keep their upper arm against their body and bend their elbow to 90 ° with palms facing in. Four grip strength measurements were taken in the WHO-SAGE survey, and the mean value of the maximum grip strength for both hands was available in continuous form. Grip strength measurement was adjusted for sex and body mass index (BMI) [48]. In older men, weak grip strength was defined as 29 kg or less, 30 kg or less, and 32 kg or less for those with a BMI of 24 or less, 24.1 to 28, and more than 28, respectively. Similarly, older women were classified as having weak grip strength if their grip strength was 17 kg or less, 17.3 kg or less, 18 kg or less, and 21 kg or less for those with a BMI of 23 or less, 23.1 to 26, 26.1 to 29, and more than 29, respectively [49].

Because of the unavailability of data, instead of weight loss, we used the measure of lower weight as a frailty component. Low BMI is a widely accepted gold-standard indicator of malnutrition in the population and in clinical studies [50, 51]. Various studies have shown it to be a good, alternative indicator of the weight loss dimension [52–54]. Respondents were classified as having lower weight if their BMI measurement fell within the underweight category, defined as a BMI < 18.5 kg/m2 [55, 56].

To assess walking speed, respondents were asked to walk a 4 m distance twice, and slowness was assessed by averaging the time (in seconds) taken to complete four meters (stratified by sex and height). Older men were categorized as having a "slow walking speed" if it took seven or more seconds for those with a height of 173 cm or less and six or more seconds for those with a height of more than 173 cm. Similarly, older women were classified as having a slow walking speed if it took seven or more seconds for those with a height of 159 cm or less and six or more seconds for those with a height of more than 159 cm [49].

Exhaustion was assessed using the survey question, "Overall in the last 30 days, how much of a problem did you have due to not feeling rested and refreshed during the day (for example, feeling tired, not having energy)?" with responses of "none," "mild," recoded as 0, and "moderate," "severe," and "extreme," recoded as 1. SAGE collected information on the time individuals spent on light, moderate, and vigorous activities in a week using a validated scale of the Global Physical Activity Questionnaire (GPAQ) [57, 58]. Due to data availability issues, we chose to use the GPAQ instead of the Minnesota Leisure Time Activity Questionnaire proposed by Fried and colleagues, as utilized in other studies [59, 60]. The total time spent on these activities was added, and individuals who spent more than 300 min a week were coded as 0, while those spending less than that were coded as 1 [61].

Dichotomous variables were created for each of the five components, and a frailty variable was created by summing all the scores. Respondents with a score of 0 were classified as "robust," those with a score of 1–2 were classified as "pre-frail," and individuals scoring three or higher were labelled as "frail."

Key predictor variables

The predictor variables in this study were sleep quality and sleep duration. Sleep quality for the night before the survey date was assessed using the question, "Please rate the quality of your sleep last night. Was it very good, good, moderate, poor or very poor?" Responses of very good or good were coded as good sleep, moderate as moderate sleep, and poor and very poor were coded as poor sleep. Sleep duration was assessed using the question, "How many hours did you sleep last night?" The responses in the format of minutes were converted into hours and the duration was classified based on the total number of hours the respondent slept in the last night. Less than seven hours was classified as short sleep, 7–8 h was considered age-appropriate sleep, and 9 or more hours was considered long sleep in this study, as recommended by the National Sleep Foundation [62]. Although a single night may not fully capture typical sleep patterns, this approach is often used in studies on older adults [63–65], as it reduces recall bias, which can occur when participants are asked to recall their sleep for more extended

periods. Additionally, any potential errors are likely minimal, given that factors like weekday versus weekend nights are randomly distributed among participants.

Covariates

We considered various sociodemographic and health characteristics potentially associated with both sleep and frailty. Sociodemographic covariates included age (grouped as 50–59, 60–69, 70–79, 80+years), sex (male and female), educational level (no education, up to primary, secondary, and higher), current marital status (married, widowed, and others, which include never married, separated, and divorced), work status (never worked, currently not working, and working), and household wealth index. The wealth index was computed based on a detailed list of household assets and divided into five quintiles, ranging from lowest (poorest households) to highest (richest households). Given the Indian context, we also considered religious affiliation, including Hindu, Muslim, and others, and social status, including scheduled castes and scheduled tribes (both socioeconomically most disadvantaged) [66] and others. Additionally, residential areas were classified as urban or rural, and states included Assam, Karnataka, Maharashtra, Rajasthan, Uttar Pradesh and West Bengal.

Health-related covariates included self-rated health, chronic conditions, body pain, tooth loss, fall-related injury, and food insecurity. Self-rated health was assessed using a single question from the SAGE survey: "In general, how would you rate your health today?" with responses ranging from very good to very bad on a five-point scale. Respondents who rated their health as bad or very bad were classified as having poor self-rated health. Chronic conditions in this study included having been diagnosed with any of the following conditions: hypertension, diabetes, stroke, arthritis, angina, asthma, and chronic lung disease. The question was, "Have you ever been diagnosed with the condition?" for each health condition. Body pain was assessed using the question, "Overall in the last 30 days, how much of bodily aches or pains did you have?" The responses were none, mild, moderate, severe, extreme/ cannot do. The severe and extreme categories were combined due to the small sample size in the extreme category. Tooth loss was evaluated with the question, "Have you lost all of your natural teeth?" Participants responded with yes or no. The fall-related injury was assessed using the questions, "In the last 12 months, have you had any other event where you suffered from bodily injury?" and "What was the cause of this injury?." Those who reported injury due to a fall were classified as yes and otherwise no. Food insecurity was measured using the survey questions "In the last 12 months, how often did you ever eat less than you wanted because there wasn't enough food?" and "In the last 12 months, were you ever hungry, but didn't eat because you couldn't afford enough food?" Individuals who answered affirmatively to either item were categorized as "food insecure, " while those who did not were classified as "food secure."

Statistical analysis

We first used descriptive statistics to examine the characteristics of the study sample. To test our hypothesis, we employed both unadjusted and adjusted multinomial logistic regression models to examine the associations between sleep quality, sleep duration, and physical frailty among older adults. Additionally, we utilized multivariable logistic regression models to examine the associations between sleep quality, sleep duration and frailty sub-components, stratified by gender, and to evaluate the moderating effect of gender on the association between sleep quality, sleep duration and frailty. We present results from unadjusted and adjusted multinomial logistic regression models, as well as adjusted multivariable logistic regression models. The adjusted models account for socio-demographic characteristics such as age, sex, level of education, current marital status, work status, wealth quintiles, religion, social group, place of residence, and states, and for health-related covariates such as self-rated health, tooth loss, chronic conditions, body pain, fall-related injury, and food security. Estimates are reported for pre-frailty and/or frailty compared to the robust (no-frailty) base category.

Survey weights were meticulously applied to account for the complex survey design, ensuring the accuracy and reliability of population-level estimates. Regression diagnostics, including variance inflation factor for multicollinearity and tests for linearity and normality of residuals, were conducted to check for any violations of regression assumptions. Results are reported as weighted percentages, p-values and adjusted odd ratios (AOR) with 95% confidence intervals (CI). All analyses were performed using Stata version 15.1 [67].

Results

Table 1 displays the socioeconomic profile of the study participants. Most participants (77.9%) were in their 50s and 60s, and only about 4.6% of the older adults were aged 80 or above. About 48.4% were without any formal education. The proportion of respondents widowed was 23.4%, and the proportion never worked was around 25%. Nearly 17% of the respondents reported poor health, while 12.3% reported tooth loss. Chronic conditions affected 41.6% of the respondents, and 1.9% experienced severe/extreme pain. Approximately 5% of the older adults reported fall-related injuries. Food insecurity was reported by 18.8% of the participants. Around 20% of the older adults belonged to the poorest wealth quintile.

Table 1 Sample characteristics, WHO-SAGE 2015 ($n = 6,512$)

	Variables	*n* (w%)
Age (in years)		
	50–59	2676 (41.19)
	60–69	2401 (36.75)
	70–79	1155 (17.44)
	80+	280 (4.62)
Sex		
	Male	3051 (47.55)
	Female	3461 (52.45)
Level of education		
	No formal education	3260 (48.42)
	Up to primary	1767 (26.88)
	Secondary	625 (9.8)
	Higher	860 (14.91)
Current marital status		
	Married	4878 (75.13)
	Widowed	1531 (23.35)
	Others	103 (1.51)
Work status		
	Never worked	1726 (24.96)
	Currently not working	2737 (42.60)
	Currently working	2049 (32.44)
Sleep quality		
	Good	4566 (71.37)
	Moderate	1674 (24.61)
	Poor	260 (4.01)
Sleep duration		
	Age-appropriate (7–8 h)	3314 (52.58)
	Short (< 7 h)	2352 (35.02)
	Long (9 and more hours)	814 (12.40)
Poor self-rated health		
	No	5453 (83.13)
	Yes	1058 (16.87)
Tooth loss		
	No	5741 (87.69)
	Yes	766 (12.31)
Chronic conditions		
	No	3560 (58.42)
	Yes	2952 (41.58)
Body pain		
	None	1771 (27.89)
	Mild	2509 (36.7)
	Moderate	1583 (24.52)
	Severe/ extreme	649 (10.89)
Fall-related injury		
	No	6144 (95)
	Yes	361 (5)
Food insecurity		
	No	5220 (81.16)
	Yes	1292 (18.84)
Wealth quintile		
	Poorest	1256 (19.9)
	Poor	1203 (18.3)
	Middle	1196 (17.86)

Table 1 (continued)

	Variables	*n* (w%)
	Rich	1348 (21.13)
	Richest	1509 (22.8)
Religion		
	Hindu	5449 (84.68)
	Muslim	811 (12.29)
	Others	252 (3.03)
Social group		
	Scheduled castes	488 (6.47)
	Scheduled tribes	1068 (14.81)
	Other backward classes	3003 (49.5)
	Others	1953 (29.22)
Place of residence		
	Urban	1325 (27.3)
	Rural	5187 (72.7)
States		
	Assam	690 (5.33)
	Karnataka	729 (10.17)
	Maharashtra	1095 (21.96)
	Rajasthan	1329 (12.24)
	Uttar Pradesh	1397 (31.79)
	West Bengal	1272 (18.52)

Notes n: Un-weighted counts; w % Weighted column percentage to account for population estimates

More than two-thirds of those in our study were rural dwellers.

Table 2 presents the percentages of respondents as non-frail, pre-frail, and frail based on their background characteristics. The overall prevalence of pre-frailty was 66.8%, while the prevalence of frailty was 25.2%. Approximately 8% of the respondents were categorized as non-frail or robust. Among the older adults who reported poor sleep quality, 44.8% were frail. Conversely, most respondents (68.6%) who reported good sleep quality were classified in the pre-frail stage. Of those with short sleep duration, 61.5% were pre-frail, and 32.2% were frail. Additionally, 25.62% of frail older adults and 65.1% of pre-frail individuals reported sleeping longer than the recommended 7–8 h.

Table 3 displays the outcomes of multinomial logistic regression, predicting the increased prevalence of pre-frailty and frailty through three separate models. Model 1 was unadjusted for covariates, Model 2 accounted for socio-demographic covariates, and Model 3 included health-related covariates. Starting with the association between sleep quality and pre-frailty, older adults with poor quality sleep had 95% higher odds of pre-frailty relative to those with good sleep quality [AOR: 1.95; CI: 1.00–3.78]; however, this association became non-significant in the fully adjusted model [AOR: 1.58; CI: 0.80–3.14]. The likelihood of experiencing frailty increased among older adults with moderate [AOR: 1.72; CI: 1.27–2.32] and poor [AOR: 4.94; CI: 2.49–9.81] quality sleep, relative to those with good sleep quality. The fully adjusted model revealed that respondents with poor sleep quality endured a 2.79 times higher likelihood of experiencing frailty than peers who enjoyed good sleep quality [AOR: 2.79; CI: 1.37–5.66].

Turning to the association between sleep duration and pre-frailty, both the socio-demographic and fully adjusted models showed that older adults with long sleep duration had 23% lower odds of experiencing pre-frailty and frailty compared to those with age-appropriate sleep [AOR: 0.77; CI: 0.60–0.98 and AOR: 0.73; CI: 0.57–0.93, respectively]. There was no significant association between short sleep duration and pre-frailty. Next, a sociodemographic adjusted model predicting frailty showed that older adults with short sleep duration had a 1.71 times higher likelihood of experiencing frailty than older adults with the recommended sleep duration [UOR: 1.71; CI: 1.06–2.77], although the fully adjusted model showed the same direction of association, it was not statistically significant [AOR: 1.50; CI: 0.92–2.45]. The probability of experiencing frailty was lower in older adults with long sleep duration [AOR: 0.68; CI: 0.51–0.91] than counterparts who reported age-recommended duration of sleep.

There was a significant moderation by gender in the association between sleep quality and frailty ($p=0.009$). Figure 2 presents the margins plots of interactions between sleep quality and gender on frailty after adjusting for all the socio-demographic and health-related variables. Frailty was more pronounced in older men

Table 2 Prevalence of frailty among older adults by their background characteristics, WHO-SAGE 2015 ($n=6,512$)

Variables	Robust		Pre-frail		Frail	
	w%	95% Confidence intervals	w%	95% Confidence intervals	w%	95% Confidence intervals
Sleep quality						
Good	8.66	7.65, 9.80	68.62	66.78, 70.41	22.71	21.10, 24.41
Moderate	6.73	5.50, 8.22	63.8	60.79, 66.71	29.46	26.70, 32.38
Poor	3.85	2.12, 6.87	51.32	43.44, 59.14	44.83	37.31, 52.60
Sleep duration						
Age-appropriate	7.56	6.44, 8.86	69.09	66.91, 71.19	23.34	21.46, 25.35
Short	6.31	4.42, 8.93	61.5	57.03, 65.78	32.2	28.07, 36.63
Long	9.29	7.99, 10.77	65.09	62.63, 67.48	25.62	23.43, 27.94
Age (in years)						
50–59	12.58	10.97, 14.38	73.36	71.08, 75.52	14.06	12.47, 15.83
60–69	6.29	5.31, 7.44	67.69	65.21, 70.07	26.02	23.76, 28.41
70–79	2.67	1.76, 4.03	56.55	52.76, 60.26	40.79	37.11, 44.57
80+	0.69	0.17, 2.76	39.59	32.46, 47.18	59.73	52.11, 66.90
Sex						
Male	7.5	6.30, 8.92	68.85	66.67, 70.94	23.65	21.81, 25.60
Female	8.43	7.41, 9.58	64.91	62.74, 67.03	26.66	24.67, 28.75
Level of education						
No formal education	6.86	5.92, 7.93	61.6	59.40, 63.76	31.54	29.44, 33.72
Up to primary	7.65	6.14, 9.49	69.52	66.61, 72.28	22.83	20.40, 25.45
Secondary	9.64	6.65, 13.78	72.66	67.66, 77.15	17.7	14.35, 21.63
Higher	11.2	8.85, 14.08	74.81	70.95, 78.32	13.99	11.32, 17.16
Current marital status						
Married	8.9	7.93, 9.97	69.8	68.12, 71.44	21.3	19.87, 22.80
Widowed	4.88	3.67, 6.46	56.83	53.36, 60.23	38.29	34.93, 41.77
Others	10.9	5.12, 21.72	70.47	58.62, 80.08	18.63	11.53, 28.69
Work status						
Never worked	8.52	6.93, 10.43	62.57	60.18, 64.91	28.91	26.40, 31.56
Currently not working	5.55	4.64, 6.63	65.58	63.43, 67.67	28.86	26.91, 30.90
Currently working	11.91	10.20, 13.86	72.91	70.98, 74.77	15.18	13.43, 17.11
Poor self-rated health						
No	8.98	8.04, 10.01	70.13	68.47, 71.73	20.89	19.48, 22.38
Yes	3.13	2.20, 4.43	50.34	46.62, 54.05	46.54	42.83, 50.28
Tooth loss						
No	8.53	7.65, 9.51	68.36	66.75, 69.92	23.11	21.71, 24.58
Yes	4.21	2.84, 6.20	55.34	50.63, 59.96	40.45	35.87, 45.20
Chronic conditions						
No	7.86	6.84, 9.03	68.3	66.28, 70.25	23.84	22.06, 25.71
Yes	8.17	6.95, 9.58	64.65	62.27, 66.97	27.18	25.04, 29.43
Body pain						
None	10.58	8.86, 12.58	74.73	72.00, 77.27	14.7	12.70, 16.95
Mild	8.94	7.75, 10.30	67.32	64.86, 69.69	23.74	21.53, 26.09
Moderate	5.59	4.06, 7.64	65.09	61.84, 68.21	29.32	26.49, 32.32
Severe/ extreme	3.57	2.31, 5.49	48.43	43.60, 53.29	48	43.12, 52.91
Fall-related injury						
No	8.07	7.24, 8.99	66.86	65.27, 68.42	25.06	23.64, 26.54
Yes	6.28	4.14, 9.42	64.72	58.96, 70.08	28.99	23.98, 34.58
Food insecurity						
No	8.68	7.74, 9.73	67.21	65.47, 68.90	24.11	22.58, 25.72
Yes	5.02	3.93, 6.39	64.96	61.74, 68.04	30.02	27.03, 33.19
Wealth quintile						
Poorest	4.19	3.21, 5.45	62.2	58.84, 65.45	33.61	30.41, 36.96
Poor	7.47	5.64, 9.84	65.54	61.96, 68.96	26.98	23.87, 30.34

Table 2 (continued)

Variables	Robust		Pre-frail		Frail	
	w%	95% Confidence intervals	w%	95% Confidence intervals	w%	95% Confidence intervals
Middle	9.85	8.03, 12.03	63.99	60.42, 67.42	26.16	23.02, 29.55
Rich	9.79	7.73, 12.32	67.99	64.38, 71.39	22.22	19.29, 25.46
Richest	8.6	7.05, 10.45	72.84	69.71, 75.76	18.56	16.02, 21.39
Religion						
Hindu	8.13	7.24, 9.12	67.04	65.35, 68.69	24.83	23.33, 26.40
Muslim	6.35	4.65, 8.61	64.23	60.01, 68.25	29.42	25.59, 33.56
Others	10.82	7.23, 15.89	69.97	63.02, 76.11	19.21	14.05, 25.69
Social group						
Scheduled castes	7.11	4.90, 10.21	70.09	65.09, 74.66	22.8	18.63, 27.58
Scheduled tribes	8.19	6.52, 10.24	64.77	61.46, 67.95	27.04	24.12, 30.17
Other backward classes	8.59	7.31, 10.06	66.29	63.88, 68.63	25.12	23.01, 27.36
Others	7.07	5.88, 8.49	67.9	65.21, 70.48	25.03	22.62, 27.59
Place of residence						
Urban	9.07	6.97, 11.73	69.6	65.27, 73.61	21.33	17.75, 25.39
Rural	7.58	6.87, 8.36	65.73	64.34, 67.09	26.69	25.42, 28.00
States						
Assam	5.82	4.26, 7.90	70.62	66.93, 74.06	23.56	20.39, 27.06
Karnataka	9.67	7.38, 12.57	68.63	64.55, 72.44	21.7	18.42, 25.37
Maharashtra	8.09	5.99, 10.85	73.39	69.19, 77.21	18.52	15.26, 22.29
Rajasthan	8.87	7.38, 10.63	66.38	63.57, 69.07	24.75	22.32, 27.36
Uttar Pradesh	4.45	3.40, 5.79	63.75	60.79, 66.62	31.8	29.02, 34.73
West Bengal	13.08	11.08, 15.37	62.3	59.29, 65.23	24.62	22.11, 27.32
Total	7.99	7.19, 8.87	66.78	65.25, 68.28	25.23	23.85, 26.66

Notes w %: Weighted row percentage to account for population estimates

who reported poor sleep quality than older women who reported poor quality of sleep. There was also a significant interaction between sleep duration and gender on frailty ($p=0.045$). As shown in Fig. 3, frailty was lower among older men who were long sleepers compared to their peers with age-appropriate sleep. In contrast, frailty was higher in older women who were long sleepers than their peers with age-appropriate sleep.

Table 4 presents the prevalence of each component of frailty by sleep quality and sleep duration in older adults, stratified by gender. Results from the total sample showed that, compared to older adults with age-appropriate sleep, short sleepers had a higher prevalence of slow walking (12.26% vs. 9.80%) and low physical activity (53.97% vs. 44.12%). Compared to those with age-appropriate sleep duration, long sleepers had a lower prevalence of low physical activity (41.70% vs. 44.12%). Compared to those with a good quality of sleep, older adults who reported a poor sleep quality had a higher prevalence of exhaustion (64.23% vs. 26.62%), slow walking (19.76% vs. 10.13%), and unintentional weight loss (33.85% vs. 25.37%). Gender-stratified analysis showed higher rates of exhaustion (69.17% vs. 60.00%) and unintentional weight loss (35.00% vs. 32.86%) among men compared to women, whereas slow walking was more common among women than men (23.53% vs. 15.18%). The adjusted results from the multivariable logistic regression analysis of each component of frailty by sleep quality and sleep duration stratified by gender is presented in Table 5. The odds of exhaustion were lower among older adults with long sleep [AOR: 0.86; CI: 0.73–1.00] relative to those with age-appropriate sleep duration. Conversely, the odds of slow walking [AOR: 1.52; CI: 1.06–2.17] and low physical activity [AOR: 1.61; CI: 1.29–2.01] were higher among older adults with short sleep than those with age-appropriate sleep duration. In older women, poor sleep quality was not associated with any of the frailty components. However, among older men, poor sleep quality was associated with exhaustion (AOR: 4.28; CI: 2.28–8.06), weak grip strength (AOR: 2.31; CI: 1.46–3.67), and low physical activity (AOR: 2.81; CI: 1.10–7.21).

Discussion

The purpose of this study was to examine the associations of sleep quality and sleep duration with the increased prevalence of frailty among older Indians. Consistent with prior studies, poor sleep quality is associated with frailty, independent of sleep duration and other potential confounders. This finding is concerning because a large proportion of older adults who reported poor sleep quality (45%) were in the frail group. This means that if their sleep worsens, the prevalence of frailty may increase. Yet, our results additionally show that long sleep duration is associated with a lower prevalence of pre-frailty and

Table 3 Multinomial logistic regression estimates for pre-frailty and frailty versus robust by background variables among older adults, WHO-SAGE 2015 ($n=6,512$)

Variables	Unadjusted model (Model 1)		Adjusted for socio-demographics (Model 2)		Fully adjusted model (Model 3)	
	Pre-frail versus robust	Frail versus robust	Pre-frail versus robust	Frail versus robust	Pre-frail versus robust	Frail versus robust
	UOR 95% CI	UOR 95% CI	AOR 95% CI	AOR 95% CI	AOR 95% CI	AOR 95% CI
Sleep quality						
Good	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Moderate	1.26 (0.97–1.64)	1.76*** (1.33–2.34)	1.27 (0.97–1.67)	1.72*** (1.27–2.32)	1.16 (0.87–1.54)	1.33 (0.98–1.82)
Poor	1.91 (0.98–3.71)	5.02*** (2.62–9.61)	1.95* (1.00–3.78)	4.94*** (2.49–9.81)	1.58 (0.80–3.14)	2.79** (1.37–5.66)
Sleep duration						
Age-appropriate	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Short	1.06 (0.70–1.61)	1.62* (1.03–2.53)	1.09 (0.70–1.71)	1.71* (1.06–2.77)	1.05 (0.66–1.65)	1.50 (0.92–2.45)
Long	0.73* (0.57–0.93)	0.76* (0.58–1.00)	0.77* (0.60–0.98)	0.78 (0.59–1.03)	0.73* (0.57–0.93)	0.68** (0.51–0.91)
Age (in years)						
50–59			Ref.	Ref.	Ref.	Ref.
60–69			1.77*** (1.36–2.29)	3.24*** (2.41–4.37)	1.73*** (1.33–2.26)	2.98*** (2.19–4.05)
70–79			3.45*** (2.11–5.65)	11.7*** (6.97–19.5)	3.20*** (1.92–5.32)	9.41*** (5.52–16.0)
80+			9.19** (2.18–38.8)	61.2*** (14.3–261)	8.44** (1.98–35.9)	43.3*** (9.97–188)
Sex						
Male			Ref.	Ref.	Ref.	Ref.
Female			0.87 (0.65–1.16)	0.85 (0.62–1.16)	0.86 (0.64–1.16)	0.78 (0.57–1.08)
Level of education						
No formal education			Ref.	Ref.	Ref.	Ref.
Up to primary			1.20 (0.90–1.61)	1.00 (0.73–1.39)	1.22 (0.91–1.65)	1.01 (0.72–1.40)
Secondary			0.95 (0.60–1.52)	0.58* (0.35–0.97)	1.00 (0.62–1.60)	0.61 (0.36–1.04)
Higher			0.81 (0.54–1.21)	0.38*** (0.23–0.61)	0.87 (0.58–1.30)	0.44*** (0.27–0.71)
Current marital status						
Married			Ref.	Ref.	Ref.	Ref.
Widowed			1.18 (0.82–1.70)	1.72** (1.16–2.55)	1.14 (0.79–1.65)	1.58* (1.06–2.35)
Others			0.92 (0.40–2.11)	0.75 (0.28–2.01)	0.93 (0.41–2.14)	0.74 (0.27–2.06)
Work status						
Never worked			Ref.	Ref.	Ref.	Ref.
Currently not working			1.04 (0.75–1.44)	0.98 (0.69–1.40)	1.04 (0.75–1.43)	0.98 (0.68–1.40)
Currently working			0.58** (0.41–0.81)	0.30*** (0.21–0.45)	0.57** (0.40–0.80)	0.31*** (0.21–0.46)
Poor self-rated health						
No					Ref.	Ref.
Yes					1.58* (1.04–2.40)	2.70*** (1.74–4.21)
Tooth loss						
No					Ref.	Ref.
Yes					1.20 (0.77–1.87)	1.70* (1.06–2.74)
Chronic conditions						
No					Ref.	Ref.
Yes					0.90 (0.70–1.16)	0.95 (0.72–1.27)
Body pain						
None					Ref.	Ref.
Mild					0.99 (0.76–1.28)	1.42* (1.03–1.95)
Moderate					1.41 (0.92–2.15)	2.39*** (1.51–3.80)
Severe/ extreme					1.44 (0.85–2.44)	3.88*** (2.19–6.86)
Fall-related injury						
No					Ref.	Ref.
Yes					1.21 (0.76–1.92)	1.14 (0.67–1.95)
Food insecurity						
No					Ref.	Ref.
Yes					1.49** (1.10–2.00)	1.65** (1.18–2.30)

Table 3 (continued)

Variables	Unadjusted model (Model 1)		Adjusted for socio-demographics (Model 2)		Fully adjusted model (Model 3)	
	Pre-frail versus robust	Frail versus robust	Pre-frail versus robust	Frail versus robust	Pre-frail versus robust	Frail versus robust
	UOR 95% CI	UOR 95% CI	AOR 95% CI	AOR 95% CI	AOR 95% CI	AOR 95% CI
Wealth quintile						
Poorest			Ref.	Ref.	Ref.	Ref.
Poor			0.67 (0.44–1.01)	0.60* (0.38–0.93)	0.69 (0.46–1.04)	0.63* (0.40–0.99)
Middle			0.58** (0.39–0.85)	0.55** (0.36–0.85)	0.61* (0.42–0.90)	0.63* (0.40–0.97)
Rich			0.54** (0.36–0.81)	0.41*** (0.26–0.64)	0.58** (0.39–0.88)	0.46** (0.29–0.73)
Richest			0.68 (0.46–1.01)	0.46*** (0.29–0.73)	0.74 (0.49–1.11)	0.54** (0.33–0.86)
Religion						
Hindu			Ref.	Ref.	Ref.	Ref.
Muslim			1.24 (0.85–1.81)	1.26 (0.83–1.92)	1.21 (0.83–1.77)	1.21 (0.79–1.85)
Others			0.68 (0.41–1.12)	0.54* (0.29–0.99)	0.68 (0.41–1.14)	0.52* (0.28–0.95)
Social group						
Scheduled castes			Ref.	Ref.	Ref.	Ref.
Scheduled tribes			0.82 (0.51–1.32)	0.91 (0.53–1.55)	0.82 (0.51–1.33)	0.88 (0.51–1.52)
Other backward classes			0.72 (0.45–1.15)	0.87 (0.52–1.47)	0.73 (0.46–1.17)	0.84 (0.49–1.42)
Others			0.87 (0.53–1.40)	1.07 (0.63–1.84)	0.85 (0.52–1.39)	0.97 (0.56–1.68)
Place of residence						
Urban			Ref.	Ref.	Ref.	Ref.
Rural			0.93 (0.66–1.30)	0.98 (0.66–1.47)	0.89 (0.64–1.25)	0.91 (0.60–1.37)
States						
Assam			Ref.	Ref.	Ref.	Ref.
Karnataka			0.70 (0.43–1.14)	0.65 (0.37–1.13)	0.70 (0.43–1.15)	0.63 (0.36–1.11)
Maharashtra			0.86 (0.54–1.38)	0.65 (0.38–1.10)	0.86 (0.53–1.39)	0.64 (0.37–1.10)
Rajasthan			0.73 (0.48–1.12)	0.83 (0.52–1.34)	0.82 (0.53–1.26)	1.07 (0.65–1.75)
Uttar Pradesh			1.33 (0.84–2.12)	2.17** (1.30–3.61)	1.34 (0.83–2.18)	2.18** (1.28–3.72)
West Bengal			0.45*** (0.30–0.66)	0.54** (0.34–0.84)	0.47*** (0.31–0.71)	0.52** (0.33–0.82)
Constant	8.72*** (7.26–10.5)	2.68*** (2.19–3.28)	16.1*** (7.83–33.0)	2.46* (1.09–5.56)	13.6*** (6.25–29.6)	1.48 (0.61–3.60)

Notes *** $p<0.001$, ** $p<0.01$, * $p<0.05$; UOR: Unadjusted odds ratio; AOR: Adjusted odds ratio; Model 2 is adjusted for socio-demographic characteristics such as age, sex, level of education, current marital status, work status, wealth quintiles, religion, social group, place of residence and states; Model 3 is further adjusted for health-related covariates such as self-rated health, tooth loss, chronic conditions, body pain, fall-related injury and food security

frailty (independent of sleep quality). Below, we discuss several important findings from this study.

Poor sleep quality was associated with frailty, in particular, adjusting for sociodemographic differences and well-known health-related factors. Poor sleep may be symptomatic of the existence of multiple health conditions, which increase the odds of becoming frail [33, 68]. Although, our study adjusted for chronic conditions and body pain, future research should further explore the relevance of chronic illnesses in frailty, with a particular focus on the nature, duration, and severity of chronicity. Poor sleep can cause bodily changes, including inflammatory alterations, kidney, endocrine, and metabolic malfunctions all of which can increase the risk of frailty [68–70]. Moreover, poor sleep and sleep disorders can induce muscle proteolysis, leading to sarcopenia and frailty by tempering the release of sex hormones, such as testosterone, insulin-like growth factor-1, and growth hormone [8, 71]. Future studies may want to consider potential pathways connecting poor sleep quality with the development of frailty among older Indians.

Inconsistent with our hypothesis, we found that sleeping 9 or more hours a night was protective for both pre-frailty and frailty in our sample of older Indians. Relative to their peers who slept the recommended duration (7–8 h), older adults who slept 9 or more hours were 27% and 32% less likely to develop pre-frailty and frailty, respectively. This finding contradicts previous research linking long sleep duration, defined 9 or more hours of sleep, to poor health outcomes [72, 73]. Notably, the prevalence of short sleep duration in our sample was relatively high at 35%, contrasting with the 31% observed among US older adults [74, 75]. Several factors, including diet and nutrition [76], high and humid temperatures [77], caregiving responsibilities within multigenerational families, and cultural norms valuing early rising and

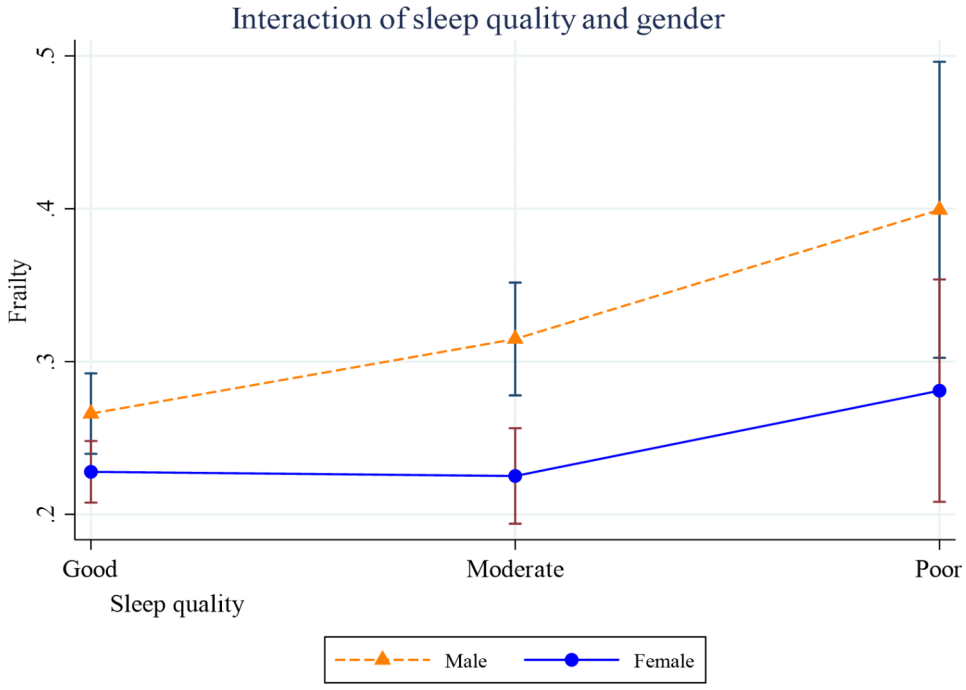

Fig. 2 Margins plot of the interaction between sleep quality and gender on frailty, adjusted for all socio-demographic and health-related variables

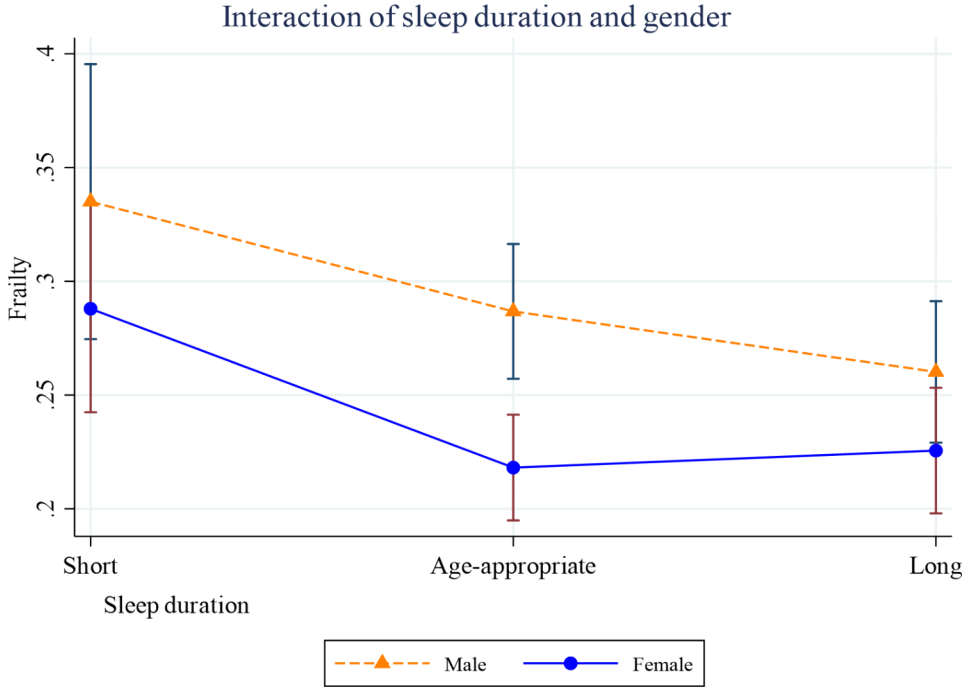

Fig. 3 Margins plot of the interaction between sleep duration and gender on frailty, adjusted for all socio-demographic and health-related variables

productivity [78], may contribute to shorter sleep duration among older Indians. Consequently, the observed association between extended sleep duration and lower prevalence of frailty found in this study may relate to selection bias. In other words, older Indians with longer sleep durations may possess greater socioeconomic resources, such as higher education and income levels, a trend supported by our data (results are not shown). That said, the fact that the associations between long sleep and pre-frailty and frailty were independent of sleep quality is encouraging, as sleep quality typically declines with

Table 4 Percentage prevalence of components of frailty by sleep quality (good, moderate, poor) and sleep duration (age-appropriate, short, long) among older adults, stratified by gender, WHO-SAGE 2015 ($n=6,512$)

Components of frailty	Sleep quality			*p*-value	Sleep duration			*p*-value	Total
	Good	Moderate	Poor		Age-appropriate	Short	Long		
	w %	w %	w %		w %	w %	w %		w %
Total									
Exhaustion	26.62	42.59	64.23	< 0.001	31.25	33.78	33.12	0.366	32.23
Weak grip strength	74.08	71.59	75.72	0.233	73.18	74.60	73.61	0.788	73.50
Slow walking	10.13	11.29	19.76	< 0.001	9.80	12.26	11.77	0.040	10.79
Unintentional weight loss	25.37	28.34	33.85	0.007	26.27	29.40	25.72	0.167	26.46
Low physical activity	43.64	46.51	48.84	0.063	44.12	53.97	41.70	< 0.001	44.61
Male									
Exhaustion	22.93	40.47	69.17	< 0.001	27.67	32.79	29.07	0.195	28.85
Weak grip strength	81.72	80.27	82.05	0.701	81.92	83.67	80.04	0.331	81.36
Slow walking	5.85	7.49	15.18	< 0.001	5.59	8.66	7.35	0.059	6.57
Unintentional weight loss	25.89	27.99	35.00	0.035	26.84	30.98	24.96	0.093	26.71
Low physical activity	40.95	45.73	43.33	0.081	41.23	53.30	39.57	0.001	42.21
Female									
Exhaustion	30.08	44.19	60.00	< 0.001	34.39	34.61	36.79	0.441	35.20
Weak grip strength	66.71	65.00	69.84	0.539	65.34	66.91	67.60	0.443	66.38
Slow walking	14.20	14.13	23.53	0.014	13.53	15.24	15.78	0.255	14.52
Unintentional weight loss	24.88	28.60	32.86	0.022	25.77	28.09	26.41	0.567	26.23
Low physical activity	46.16	47.10	53.62	0.248	46.67	54.52	43.64	0.004	46.73

Notes w %: Weighted row percentage to account for population estimates

Table 5 Multivariable logistic regression estimates for each component of frailty by sleep quality and sleep duration among older adults, stratified by gender, WHO-SAGE 2015 ($n=6,512$)

Components of frailty	Sleep quality		Sleep duration	
	Moderate vs. good	Poor vs. good	Short vs. age-appropriate	Long vs. age-appropriate
	AOR (95% CI)	AOR (95% CI)	AOR (95% CI)	AOR (95% CI)
Total				
Exhaustion	1.80*** (1.54–2.10)	3.04*** (2.08–4.44)	1.26 (0.98–1.61)	0.86* (0.73–1.00)
Weak grip strength	1.01 (0.85–1.21)	1.30 (0.89–1.91)	1.02 (0.79–1.33)	0.93 (0.78–1.10)
Slow walking	0.91 (0.71–1.16)	1.82* (1.00–3.28)	1.52* (1.06–2.17)	1.20 (0.94–1.53)
Unintentional weight loss	1.03 (0.88–1.22)	1.12 (0.80–1.57)	1.23 (0.98–1.54)	1.03 (0.88–1.21)
Low physical activity	1.02 (0.87–1.19)	1.09 (0.75–1.58)	1.61*** (1.29–2.01)	0.99 (0.85–1.16)
Male				
Exhaustion	1.96*** (1.57–2.45)	4.28*** (2.28–8.06)	1.48* (1.01–2.19)	0.86 (0.68–1.07)
Weak grip strength	1.73*** (1.40–2.13)	2.31*** (1.46–3.67)	1.11 (0.81–1.52)	0.86 (0.70–1.06)
Slow walking	1.01 (0.75–1.36)	0.95 (0.53–1.70)	0.95 (0.60–1.51)	0.86 (0.66–1.11)
Unintentional weight loss	1.01 (0.80–1.26)	1.53 (0.94–2.50)	1.08 (0.78–1.48)	0.99 (0.79–1.25)
Low physical activity	0.99 (0.67–1.48)	2.81* (1.10–7.21)	1.84* (1.06–3.20)	1.38 (0.91–2.10)
Female				
Exhaustion	0.88 (0.65–1.19)	1.27 (0.72–2.27)	1.35 (0.86–2.12)	1.15 (0.86–1.54)
Weak grip strength	1.06 (0.84–1.35)	1.09 (0.66–1.81)	1.43* (1.04–1.97)	0.94 (0.75–1.17)
Slow walking	1.04 (0.82–1.31)	1.08 (0.69–1.68)	1.04 (0.76–1.42)	1.15 (0.91–1.44)
Unintentional weight loss	1.03 (0.81–1.30)	0.73 (0.41–1.30)	1.82*** (1.32–2.52)	0.90 (0.72–1.12)
Low physical activity	0.99 (0.80–1.22)	1.46 (0.93–2.30)	1.45* (1.07–1.96)	1.08 (0.88–1.33)

Notes *** $p<0.001$, ** $p<0.01$, * $p<0.05$; AOR: Adjusted odds ratio; All models are adjusted for socio-demographic characteristics such as age, sex, level of education, current marital status, work status, wealth quintiles, religion, social group, place of residence and states, and health-related covariates such as self-rated health, tooth loss, chronic conditions, body pain, fall-related injury and food security

age and may be less amenable to modification than sleep duration.

Interestingly, the prevalence of frailty associated with short sleep duration was reduced after considering other health-related factors, rendering it statistically inconsequential. Findings on sleep duration and later life frailty have been mixed [79]. According to one cross-sectional study, sleeping for less than 6 h and for 9 or more hours

was associated with an increased prevalence of frailty [30], whereas others have observed that only short [29, 80] or only long sleepers run the risk of developing frailty [10, 17, 31, 32]. Further, a longitudinal study discovered that while nighttime hypoxemia and compromised sleep quality negatively affected frailty, sleep duration did not exert a significant effect [33]. A recent prospective study found a link between both, too much and too little sleep and physical frailty [79]. Most of these studies used samples of older adults in the US and other LMICs, not India. Worth noting is that some studies have found the association between sleep duration and physical frailty to vary across social groups [10, 29, 31].

In addition to examining associations of sleep quality and duration with frailty, we also assessed whether the association between sleep and frailty varied by gender. We found that frailty was more pronounced among older men reporting poor sleep quality than older women with poor sleep quality. Among older men, long sleepers reported lower frailty than peers with age-appropriate sleep duration. Conversely, among older women, long sleepers exhibited higher frailty than counterparts who slept the recommended hours of sleep. This suggests that the association between sleep duration and physical frailty varies by gender, with long sleep potentially being more beneficial for men and less so for women in frailty prevalence. These gender differences in the relationship between sleep and frailty may be influenced by factors such as biological dissimilarities, including hormonal profiles and musculoskeletal differences, as well as psychosocial factors like coping mechanisms, social support networks, and disparities in access to health care and other socioeconomic resources [36, 37, 41, 42, 81–84]. Additionally, variations in age-related comorbidities, medication use, and lifestyle behaviors between men and women [43, 85–89] may contribute to the observed differences in how sleep patterns affect frailty. Cultural pressures, expectations, paid and unpaid work transitions, and conditions may also matter for the association between sleep and frailty among older men and women in India. Overall, understanding these gender-specific nuances is crucial for developing targeted interventions aimed at addressing frailty among older adults, taking into account the complex interplay between sleep, gender, and frailty.

Our findings shed light on the nuanced relationships between sleep quality, sleep duration, and frailty components among older adults, with variations observed between older Indian women and men. Poor sleep quality was linked to a higher prevalence of exhaustion, slow walking, and unintentional weight loss. Among older Indian women, poor sleep quality was not significantly associated with frailty components. However, older Indian men with poor sleep quality reported exhaustion, weak grip strength, and low physical activity. Gender differences in frailty sub-components were evident, with men exhibiting higher rates of exhaustion and unintentional weight loss, while women showed a higher prevalence of slow walking. A previous study also found similar patterns: Men had a higher prevalence of weakness, while women reported higher odds of slow walking [60].

Short sleep duration was associated with a higher prevalence of slow walking and low physical activity, suggesting a link between mobility constraints and reduced activity levels. Conversely, long sleep duration may be associated with lower physical activity. We also found that long sleep duration was associated with lower odds of exhaustion, suggesting that longer sleep may help reduce feelings of exhaustion among older adults. Alternatively, older adults with short sleep duration reported higher odds of slow walking and low physical activity, implying that insufficient sleep may contribute to physical sluggishness by adversely affecting mobility and activity levels.

Taken together, these findings highlight the complex relationship between sleep quality, sleep duration, and the different components of frailty in older adults. Poor sleep quality is significantly associated with frailty in both men and women. While the increased prevalence of frailty associated with short sleep is largely explained by other health risks, long sleep is associated with a lower prevalence of pre-frailty and frailty, particularly for men. Further research is needed to identify the biological and sociocultural mechanisms driving the differences in sleep patterns and susceptibility to frailty between women and men.

Limitations and future directions

Our study, while providing valuable insights, does have several important limitations. *First*, the cross-sectional nature of our study constrains our capacity to draw any causal or even temporal conclusions on sleep and frailty. *Second*, our data lacked information on specific sleep disturbances or disorders, such as sleep apnea, insomnia, parasomnias, narcolepsy, and/or restless leg syndrome. Relatedly, data regarding the usage of sleep medications, including sleeping pills or non-pharmacological interventions, were not available. *Third*, both sleep quality and duration were subjectively assessed using a single night's measure, potentially leading to under- or over-reporting by respondents influenced by perceived social expectations or the context of the prior night. Although we partially addressed this potential concern of self-report bias by controlling for self-rated health, actigraphic assessment over multiple days would help validate the associations between objective sleep characteristics and frailty. Moreover, the current study was retrospective, and thus the limitation of recall bias lingers.

Fourth, while we adjusted for several conceptually relevant covariates, the potential for omitted variable bias persists. For example, we did not consider the relevance of work conditions to the association of sleep and frailty. Individuals in physically strenuous jobs or facing unfavorable work conditions – such as irregular work hours, excessive workloads, workplace discrimination, job insecurity, limited access to health care, and unsafe environments – may be more susceptible to both sleep problems and physical frailty. As such, future investigations replicating our work should consider work-related contexts when evaluating the nexus between sleep and frailty in aging adults. *Lastly*, similar to many studies in this domain, our research was constrained to community-dwelling older adults. Future work on sleep quality, quantity, and physical frailty should include older Indians in formal care institutions. This is important because physical frailty is a key indicator of mortality among older persons receiving formal care, with its prevalence significantly higher among residents of assisted living facilities and nursing homes compared to those aging in their own homes [90, 91]. Strengths of the study include a larger sample size representative of the older Indian population. However, given the physical, financial, sociocultural, and environmental factors unique to India, caution is warranted when applying these results to older adults in other countries. Future research should explore whether these associations hold in diverse populations, including in other LMICs.

Conclusion

Our study found that poor sleep quality was related to an increased prevalence of frailty, independent of other risk factors. Conversely, short-duration sleep was not associated with frailty in this study when adjusted for other health risks, suggesting a need for further investigation. Further, we observed that older adults who slept longer than the recommended amount had a lower prevalence of both pre-frailty and frailty than counterparts with age-appropriate sleep duration. Gender differences were also evident, with older Indian men with poor sleep quality reporting exhaustion, weak grip strength, and low physical activity, whereas poor sleep quality was statistically inconsequential for frailty components among older women. Understanding the gender-specific nuances in the relationship between sleep and frailty is crucial for developing targeted interventions to assist older adults at the highest risk of frailty. However, because the associations found in this study are based on cross-sectional data, future studies utilizing longitudinal data are needed to verify our findings.

Author contributions

T. Muhammad conceived and designed the research paper and analyzed the data; T. Muhammad, Soomi Lee, Manacy Pai, and Bittu Mandal wrote the manuscript; All authors made critical revisions of the manuscript for key intellectual content. All authors read and approved the final version of the manuscript and have agreed to the authorship and order of authorship for this manuscript.

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Data availability

The dataset analyzed for this study is available at International Institute for Population Sciences, data repository and accessible on reasonable request at, https://iipsindia.ac.in/content/SAGE-data.

Declarations

Ethics approval and consent to participate

The procedures undertaken in this study and the data collection processes were conducted ethically per the World Medical Association's Declaration of Helsinki. Ethical approvals were obtained for SAGE study from the Ethics Review Committee of the World Health Organization, the Ethics and Protocol Review Committee of the Ghana Medical School, Accra, Ghana, the Ethics Committee of the School of Preventive and Social Medicine, and the Russian Academy of Medical Sciences, Moscow, Russia. Approval was also obtained for the SAGE 1 study from the Ethics Committee of the Shanghai Municipal Centre for Disease Control and Prevention, Shanghai, China, Institutional Review Board of the International Institute of Population Sciences, Mumbai, India, and finally from the Research Ethics Committee of the Human Sciences Research Council, Pretoria, South Africa. These approvals also covered all procedures through which written informed consent was obtained from each participant. Confidential records of participants' consent were maintained by SAGE. Further, written informed consents for participating in the SAGE study were obtained from each participant.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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