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Associations between sleep duration and quality and physical frailty in community-dwelling older adults: a cross-sectional study

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The effects of sleep duration and quality on physical frailty may differ. We examined the association between sleep duration/quality and frailty phenotype according to frailty components. This cross-sectional study analyzed 848 community-dwelling Japanese adults aged 65–75 years (mean age 70.8 yrs, 50.1% women) without long-term care needs. We classified the participants by their sleep duration: short-, middle-, and long-sleep groups. Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI) and divided into PSQI ≤ 5, 6–8, and ≥ 9 groups. Physical frailty was operationalized with the Fried phenotype. A logistic regression model was used to compute the odds ratios (ORs) and 95% confidence interval (CIs) for frailty status outcomes. The prevalence of frailty was 4.7%. The ORs for the presence of frailty in the long-sleep group was 8.50 (95%CI: 2.82–25.62) compared to the middle-sleep group, and the PSQI ≥ 9 group was 2.81 (95%CI: 1.08–7.33) compared to the PSQI ≤ 5 group. Short sleep and poor sleep quality were associated with exhaustion; long sleep was associated with low physical activity. The duration and quality of sleep may thus have different effects on frailty components. The possible causal relationship between sleep duration/quality and frailty merits further investigation.

Keywords Sleep duration, Sleep quality, Physical frailty, Frailty component, Community-dwelling, Older adult

The average life expectancy continues to increase in Japan (a 'super-aging' society), and there is great interest in extending healthy life expectancy[1]. In older adults, frailty is considered one of the factors in the reduction of healthy life expectancy[2,3]. Fried et al. defined the phenotype of frailty based on five components: unintentional weight loss, self-reported exhaustion, low handgrip strength, slow gait speed, and low physical activity[4], and this 'Fried phenotype' has been used in many studies to assess physical frailty. Many older adults transition from a healthy state to frailty and further to a state that requires nursing care; however, frailty is reversible, and appropriate interventions can help an individual with frailty recover to a healthy state[3].

Among older adults, changes in both the duration and quality of sleep become apparent with aging. These changes include a reduced duration of nocturnal sleep, difficulty in maintaining sleep, and decreased deep sleep (i.e., non-rapid eye movement [REM] sleep)[5]. Sleep duration and sleep quality are both important indicators of sleep but may have different effects on health[6]. Early research by Hammond focusing on sleep duration suggested a relationship between both short and long sleep durations and increased mortality, thus indicating an impact of the duration of sleep on physical health[7]. An investigation of sleep quality by Ford and Kamerow detected a relationship between sleep disturbances and an increased risk of depression[8], suggesting an impact of sleep quality on psychiatric health. The duration of sleep may therefore have a greater impact on physical health and the quality of sleep may have a greater impact on psychological health, but evidence regarding these possibilities is still scarce[6].

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Several investigations have identified an association in older adults between sleep disorders and physical frailty. A cross-sectional study described a positive association between both short (≤ 6 h) and long (≥ 9 h) sleep durations and physical frailty[9], and a prospective cohort study showed that short (≤ 5 h) and long (≥ 9 h) sleep durations are associated with the incidence of physical frailty[10]. However, the findings of other cross-sectional studies have indicated a positive association between the incidence of physical frailty and long sleep duration (≥ 10 or ≥ 9 or > 8 h), but no association with short sleep[11–13], and thus the evidence is conflicting. However, there is consistent and accumulating evidence regarding the relationship between sleep quality and physical frailty, indicating a positive association between poor sleep quality and physical frailty[12–14].

Based on the components of physical frailty proposed by Fried et al.[4], Stenholm et al. conducted a trajectory study of each frailty component prior to the onset of frailty[15]. They observed that the individual components of frailty do not appear at the same time; rather, they occur at different times. This suggests that studies of not only frailty as a phenotype but also studies of the relationship between sleep and each frailty components may provide extremely important information for the design of interventions and measures to stop or delay the onset of frailty.

Several research groups have examined the association between sleep and the components of frailty[9,16], and their results suggest that different exposure factors affect different frailty components. Although their useful evidence has been obtained regarding sleep duration and frailty components[9], the research examining the relationship between sleep quality and frailty components is very limited. We speculated that a clarification of the relationships between sleep duration and sleep quality and each component of frailty could contribute to the development of optimal sleep management strategies to prevent physical frailty among older adults.

We thus examined the association between sleep duration/quality and the physical frailty phenotype according to the components of frailty in community-dwelling older adults. Considering the impact of sleep duration on physical health and the impact of sleep quality on psychological health, we hypothesized that irregular sleep duration, i.e., short and long sleep durations, is associated with physical components of frailty and poor sleep quality is associated with psychological components of frailty.

Participants and methods

Study population

This was a cross-sectional study using data obtained from the baseline survey of the Itoshima Felix Study, a prospective cohort study that has been ongoing since 2017 in Itoshima City, Fukuoka Prefecture, Japan. The aim of the Itoshima Felix Study is to explore modifiable lifestyle factors causing and protecting against frailty. We randomly chose participants in the Itoshima Felix Study from among approx. 10,000 older adults who responded to the Community Needs Survey in 2016. The participants were aged 65–75 years, residing in Itoshima, and not in need of support or care certified by the Japanese public long-term care insurance system. To improve participation rates, the Itoshima Felix study was advertised to citizens through Itoshima City's public relations magazine, and multiple explanatory sessions were held at community centers in various regions; a research information sheet, consent form, and questionnaire were mailed to 5,000 randomly selected older adults, and participation in measurement sessions was encouraged for a more detailed assessment.

As a result, 1,589 participants submitted consent forms and questionnaires, and 930 participants participated in measurement sessions for objective assessments of physical function. In the present study, we excluded 25 participants who did not provide valid data on sleep, as they did not complete the sleep questionnaire, thus preventing the assessment of scores. Another 47 participants were excluded due to invalid data on physical frailty: handgrip strength data ($n = 9$), walking test data ($n = 5$), accelerometer data ($n = 32$), and basic information (height, weight) ($n = 1$) preventing the completion of the stratified assessment of physical frailty. An additional 10 participants were excluded for not providing responses to other analysis items: five did not answer the question about subjective economic status, one did not answer about current tobacco consumption, one did not answer about current alcohol consumption, and three did not have cognitive function assessments conducted. This resulted in a final analytical sample of 848 participants. This study was approved by the Institutional Review Board of Kyushu University (approval no. 201708). The residents participated in this study based on their own volition. None of the participants received compensation for their participation, and they each provided written informed consent to have their data used and published. All methods used in this study were performed in accord with the principles outlined in the Declaration of Helsinki.

Assessment of physical frailty status

We defined physical frailty based on the five components of the frailty phenotype described by Fried et al.[4]: unintentional weight loss, self-reported exhaustion, low handgrip strength, slow gait speed, and low physical activity. Participants with three or more affected components are classified as having frailty; those with one or two affected components are classified as being pre-frailty, and those with no affected components are classified as non-frail (or robust). In the present participants, each component was assessed as described[15–19]. Briefly, unintentional weight loss was assessed by asking whether the participant had experienced "unintentional loss of > 2–3 kg in the previous 6 months." Handgrip strength was measured using a handheld dynamometer (GRIP-D, TKK 5401; Takei Scientific Instruments Co., Niigata, Japan). For this assessment, the participant maintained a standing position and two measurements were taken on each hand, with the maximum value used. We defined low handgrip strength as scoring in the lowest 20% of the present population's handgrip strength results and was stratified by sex and body mass index (BMI).

Self-reported exhaustion was assessed by the question "Do you ever feel that everything you do is an effort?" and "Do you ever feel exhausted for no reason?"[20]. As these two questions were extracted from the six-item Kessler Psychological Distress Questionnaire (K6), exhaustion was considered comprehensively as a psychological factor in this study. Gait speed was measured with a 5-meter walking test at the participant's maximum gait speed, timed over an 11-m course, with measurements taken at the 3-m and 8-m marks. Slow gait speed was defined as scoring in the slowest 20% of the study population's gait speed results, stratified by sex and standing height. The participants' physical activity was objectively measured using a tri-axial accelerometer (Active Style Pro, HJA350-IT, Omron Healthcare, Kyoto, Japan) for > 1 week for the assessment of physical activity energy expenditure[21]. The participants were instructed to wear the accelerometer on the right or left side of their waist and remove it only before going to bed or participating in water activities. Low physical activity was defined as scoring in the lowest 20% of physical activity stratified by sex.

Assessment of sleep duration

We asked the participants, "During the past month, how many hours of actual sleep, including naps, did you get at night?" and we calculated their sleep duration. Sleep duration categories have been divided in previous studies as short sleep (< 5–6 h) and long sleep (> 9–10 h)[9–12]. In the present study, while referencing the criteria from prior research and considering that the median sleep duration of our population was 7 h (interquartile range: 6–8 h), we divided the participants into the following three groups based on their sleep durations: the short-sleep group (≤ 5 h), the middle-sleep group (5.1–8.9 h), and the long-sleep group (≥ 9 h).

Assessment of sleep quality

We evaluated the quality of the participants' sleep using the Japanese version of the Pittsburgh Sleep Quality Index (PSQI-J)[22,23]. The PSQI is a questionnaire consisting of nine questions and 18 items, assessing an individual's subjective evaluations of his or her sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction over the prior month. Each item is scored from 0 to 3 points, with a total score ranging from 0 to 21 points. The reliability and validity of the PSQI-J have been confirmed[20]. According to Buysse et al., a PSQI score of ≤ 5 points is defined as good sleep quality[22,23]. We followed an earlier study[24] and used the mean PSQI score (approx. 9 points or above) for sleep disorders such as primary insomnia and major depression as described by Doi et al.[22]. We divided our participants based on the PSQI scores ≤ 5 points, 6–8 points, and ≥ 9 points.

Potential confounding factors

We investigated the following items as potential confounding factors: education level, employment status, subjective economic status, BMI, comorbidities, cognitive function, current tobacco consumption, and current alcohol consumption. Education level was categorized into two groups based on the number of years of education completed by the participants (< 9 vs. ≥9 years). The employment status was determined by those who answered "yes" to the question "Do you currently have a job with income?" Subjective economic status was classified into two categories, "difficult, somewhat difficult" and "somewhat affluent, affluent," based on responses to the question "How would you describe your current economic situation?"

The participants' weight (kg) and height (m) were measured according to standard protocols while they were wearing light clothing and no shoes. BMI was calculated as weight (kg) divided by the square of height (m^2). Comorbidities included osteoporosis, hypertension, hyperlipidemia, diabetes, stroke, and heart disease; we classified the participants as having a comorbidity if they had more than one disease currently under treatment. Cognitive function was assessed using the Japanese version of the Montreal Cognitive Assessment (MoCA-J)[25]. To prevent interference from external factors, a separate evaluation space was provided for the participants, and the cognitive assessments were conducted by trained professionals. Current tobacco consumption was defined as the responses "almost every day" or "sometimes" to the question "Do you smoke cigarettes?" Current alcohol consumption was defined as the responses "almost every day" or "sometimes" to the question "Do you drink alcohol?"

Statistical analyses

Continuous variables are presented as the mean ± standard deviation (SD), and categorical variables are presented as the percentage of participants. We used a one-way analysis of variance (ANOVA) and Dunnett's test to compare characteristics among the groups of sleep duration and sleep quality. For sleep duration, the middle-sleep group was used as the reference group, and for sleep quality, the PSQI ≤ 5 was used as the reference group to test for significant differences. We used a direct method to calculate the age- and sex-adjusted prevalences of pre-frailty and frailty according to the groups of sleep duration and sleep quality. The trends in age- and sex-adjusted frequencies across sleep-quality groups were tested by a logistic regression analysis.

The association between sleep duration and physical frailty was examined by a multinomial logistic regression analysis. Odds ratios (ORs) and 95% confidence intervals (CIs) for pre-frailty and frailty were calculated for the short and long sleep-duration groups compared to the middle sleep-duration group. Similarly, a multinomial logistic regression analysis was used to investigate the association between sleep quality and physical frailty. Odds ratios and 95%CIs for pre-frailty and frailty were calculated for the PSQI scores 6–8 and PSQI ≥ 9 compared to the PSQI scores ≤ 5 as reference. We also conducted trend tests for the sleep-quality groups with a linear regression analysis for continuous variables and a logistic regression analysis for categorical variables. In a multivariable-adjusted model, we adjusted for age, sex, education, employment status, subjective economic status, BMI, comorbidities, MoCA-J score, current tobacco consumption, and current alcohol consumption.

We performed a binomial logistic regression analysis to explore the relationship between sleep duration/sleep quality and individual components. The P for trend was assessed with a logistic regression analysis across sleep-quality groups. For sleep duration, we calculated the ORs and 95%CIs for unintentional weight loss, self-reported exhaustion, low handgrip strength, slow gait speed, and low physical activity for the short and long sleep-duration groups compared to the middle-duration group. For sleep quality, we performed similar calculations comparing the PSQI 6–8 and PSQI ≥ 9 groups with the PSQI ≤ 5 group as the reference. In a multivariable-adjusted model, we adjusted for age, sex, education, employment status, subjective economic status, BMI, comorbidities, MoCA-J score, current tobacco consumption, and current alcohol consumption.

The statistical analyses were carried out at the computer facilities at the Research Institute for Information Technology, Kyushu University.

Results

The participants' characteristics

Table 1 summarizes the study participants' characteristics ($n = 848$). The average age of the participants was 70.8 years (SD 3.0 years), with 425 women (50.1%). Sleep duration was categorized as follows: the short-duration group ($n = 73$, 8.6%), the middle-duration group ($n = 727$, 85.7%), and the long-duration group ($n = 48$, 5.7%). Compared to the middle-duration group, the long-duration group had significantly fewer women and significantly lower MoCA-J scores, but the short-duration group had significantly fewer individuals with PSQI ≤ 5 and significantly more individuals with PSQI 6–8 or PSQI ≥ 9 scores ($p < 0.05$). The categorization of the participants by their PSQI scores was follows: PSQI ≤ 5 ($n = 652$, 76.9%), PSQI 6–8 ($n = 116$, 13.7%), and PSQI ≥ 9 ($n = 80$, 9.4%). Compared to the PSQI ≤ 5 group, the PSQI ≥ 9 group had a significantly higher average age, a significantly higher proportion of individuals with lower education, and significantly fewer employed individuals. Compared to the PSQI ≤ 5 group, the PSQI 6–8 and PSQI ≥ 9 groups had significantly more individuals with short sleep durations but significantly fewer individuals with middle sleep durations ($p < 0.05$).

The relationships between physical frailty and sleep duration and quality

As shown in Fig. 1, the age- and sex-adjusted prevalence of frailty was significantly greater among the participants in the long sleep-duration group compared to the middle duration group ($p < 0.001$). As depicted in Fig. 2, the age- and sex-adjusted prevalence of frailty was significantly increased in the PSQI ≥ 9 group compared to the PSQI ≤ 5 group ($p < 0.05$). There was no evidence of a significant association between sleep duration or sleep quality and the prevalence of pre-frailty.

Table 2 provides the ORs and 95%CI values for the presence of pre-frailty and frailty according to the status of sleep duration and sleep quality. Regarding the association between sleep duration and physical frailty, the multivariate-adjusted ORs for frailty in the short- and long-sleep groups were 2.50 (95%CI: 0.89–7.02, $p = 0.06$) and 8.50 (95%CI: 2.82–25.62, $p < 0.001$), respectively, indicating a marginal association in the short-sleep group and a significant association in the long-sleep group. Conversely, no significant association was found between sleep duration and pre-frailty.

We also investigated the association between sleep quality and physical frailty. The multivariate-adjusted ORs for frailty in the PSQI 6–8 and PSQI ≥ 9 groups were 1.71 (95%CI: 0.68–4.30, $p = 0.25$) and 2.81 (95%CI: 1.08–7.33, $p = 0.03$), respectively, with only the PSQI ≥ 9 status remaining significantly associated with frailty. Additionally, the multivariate-adjusted ORs for frailty showed an increasing trend across the PSQI 6–8 and PSQI ≥ 9 groups compared to the PSQI ≤ 5 group ($p = 0.02$). Similarly, there was an increasing trend in the

	Sleep duration			Sleep quality		
	Short	Middle	Long	PSQI ≤ 5	PSQI 6–8	PSQI ≥ 9
	$n = 73$	$n = 727$	$n = 48$	$n = 652$	$n = 116$	$n = 80$
Age, yrs, mean (SD)	70.6 (3.1)	70.8 (3.0)	71.5 (3.1)	70.6 (3.0)	71.3 (2.9)	71.5 (3.1)†
Women, %	54.8	50.9	31.3*	48.5	56.0	55.0
Education, ≤ 9 yrs, %	15.1	10.0	8.3	9.1	12.1	18.8†
Employment status, employed, %	30.1	35.5	31.3	36.4	35.3	21.3†
Subjective economic status, low, %	48.0	52.3	43.8	49.9	56.9	56.3
BMI, kg/m², mean (SD)	23.2 (3.4)	22.8 (3.1)	23.2 (3.4)	22.9 (3.1)	22.9 (3.6)	22.7 (3.1)
Overweight, %	28.8	23.0	25.0	23.5	26.7	20.0
Comorbidities, %	61.6	67.3	58.3	65.0	72.4	67.5
MoCA-J, points, mean (SD)	24.3 (2.9)	24.4 (2.9)	23.4 (3.6)*	24.4 (2.9)	23.9 (3.0)	24.1 (2.9)
Current tobacco consumption, %	2.7	8.9	10.4	9.2	7.8	3.8
Current alcohol consumption, %	48.0	51.4	60.4	53.1	48.3	45.0
Sleep quality:						
PSQI ≤ 5, %	15.1*	82.1	91.7	–		
PSQI 6–8, %	30.1*	12.4	8.3	–		
PSQI ≥ 9, %	54.8*	5.5	0.0	–		
Sleep duration						
Short, %	–			1.7	19.0†	50.0†
Middle, %	–			91.6	77.6†	50.0†
Long, %	–			6.7	3.4	0.0

Table 1. Characteristics of the 848 community-dwelling older Japanese participants according to their sleep duration and sleep quality. *$p < 0.05$ vs. Middle, †$p < 0.05$ vs. PSQI ≤ 5. BMI: body mass index, MoCA-J: Montreal Cognitive Assessment-Japanese version, PSQI: Pittsburgh Sleep Quality Index.

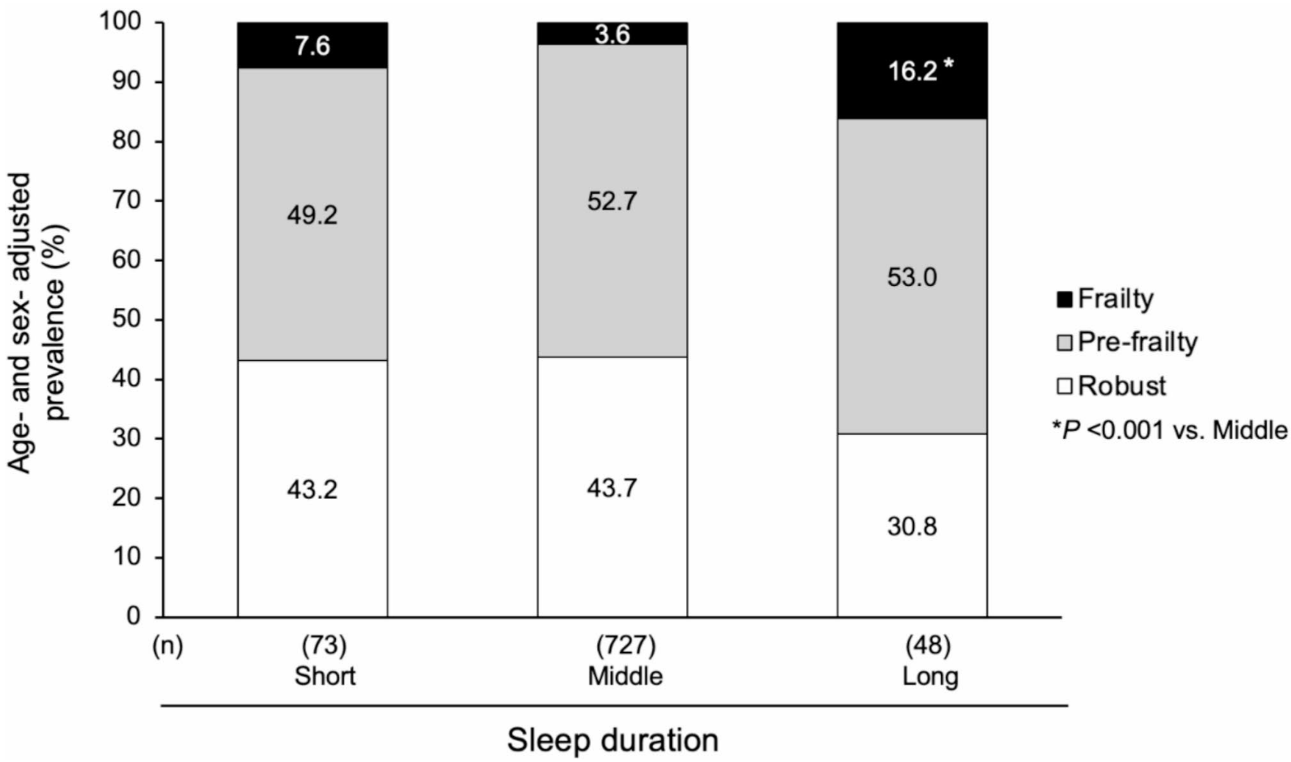

Fig. 1. The age- and sex- adjusted prevalence of robust status, pre-frailty, and frailty according to the participants' sleep duration: short (≤ 5 h, $n = 73$), middle (5.1–8.9 h, $n = 727$), and long (≥ 9 h, $n = 48$).

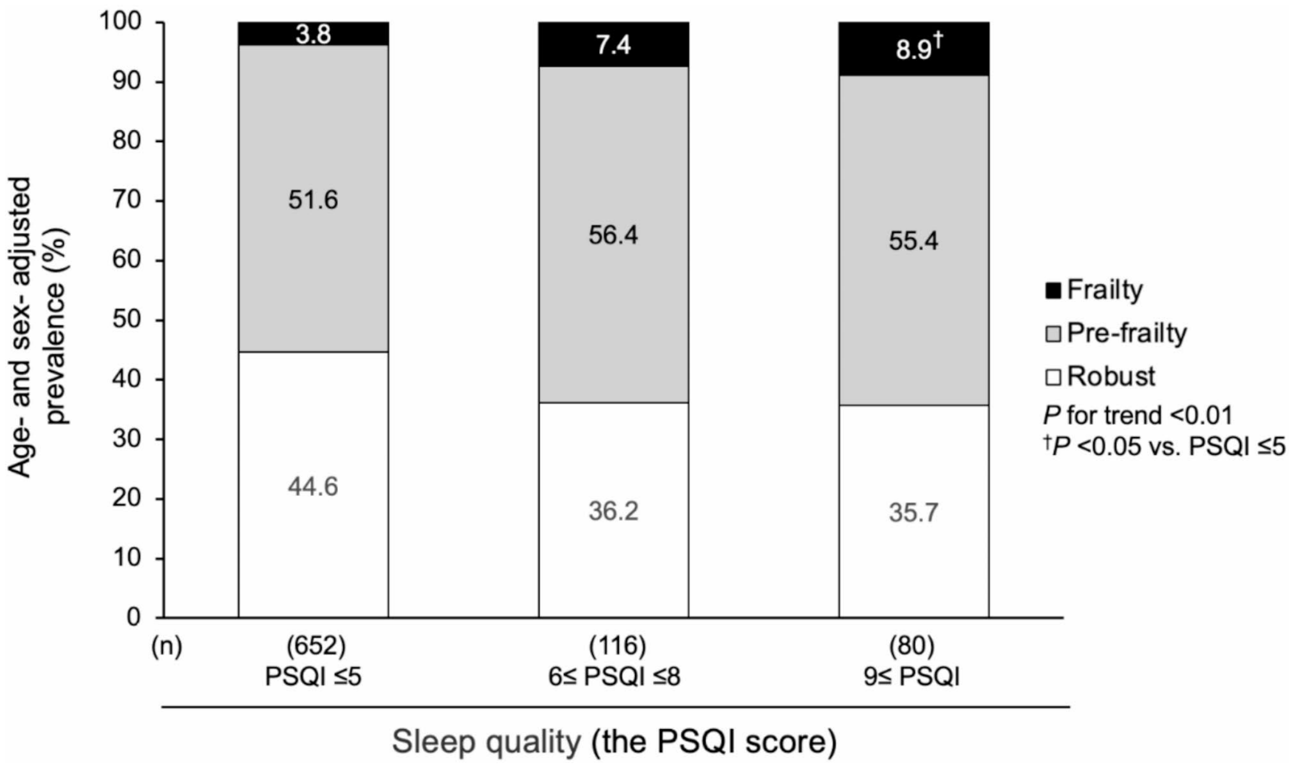

Fig. 2. The age- and sex- adjusted prevalence of robust status, pre-frailty, and frailty according to the participants' sleep quality, i.e., based on the PSQI score: ≤5 points ($n = 652$), 6–8 points ($n = 116$), and ≥ 9 points ($n = 80$).

	Participants, *n*	Participants with sub-items, *n*		Multivariable-adjusted OR (95%CI)			
		Pre-frailty	Frailty	Pre-frailty	*p*-value	Frailty	*p*-value
Sleep duration:							
Short	73	35	6	0.92 (0.54–1.55)	0.94	2.50 (0.89–7.02)	0.06
Middle	727	383	26	1.00 (ref.)		1.00 (ref.)	
Long	48	26	8	1.56 (0.77–3.15)	0.19	8.50 (2.82–25.62)	< 0.001
Sleep quality:							
PSQI ≤ 5	652	334	24	1.00 (ref.)		1.00 (ref.)	
PSQI 6–8	116	66	8	1.21 (0.78–1.87)	0.39	1.71 (0.68–4.30)	0.25
PSQI ≥ 9	80	44	8	1.29 (0.76–2.17)	0.35	2.81 (1.08–7.33)	0.03
P for trend[a]					0.24		0.02
PSQI score[b]					0.22		0.04

Table 2. The ORs and 95%cis for pre-frailty and frailty according to the participants' sleep duration and sleep quality. [a]Per one status increment; [b]Per 1-point increase. The multivariable model was adjusted for age, sex, education, employment status, subjective economic status, BMI, comorbidities, MoCA-J, current tobacco consumption, and current alcohol consumption. CI: confidence interval, OR: odds ratio.

	Participants, *n*	Participants applicable to each component, *n*	Multivariable-adjusted	
			OR (95%CI)	*p*-value
Unintentional weight loss:				
Short	73	11	1.90 (0.91–3.87)	0.08
Middle	727	64	1.00 (ref.)	
Long	48	7	1.90 (0.79–4.55)	0.15
Low handgrip strength:				
Short	73	13	0.89 (0.47–1.69)	0.71
Middle	727	147	1.00 (ref.)	
Long	48	16	1.75 (0.91–3.38)	0.10
Exhaustion:				
Short	73	15	2.10 (1.12–3.92)	0.02
Middle	727	81	1.00 (ref.)	
Long	48	7	1.42 (0.60–3.36)	0.43
Slow gait speed:				
Short	73	12	0.85 (0.44–1.67)	0.65
Middle	727	143	1.00 (ref.)	
Long	48	15	1.73 (0.87–3.46)	0.12
Low physical activity:				
Short	73	15	1.19 (0.63–2.27)	0.59
Middle	727	135	1.00 (ref.)	
Long	48	18	2.98 (1.49–5.98)	< 0.01

Table 3. The ORs and 95%cis for frailty components according to the sleep duration status. The multivariable model was adjusted for age, sex, education, employment status, subjective economic status, BMI, comorbidities, MoCA-J, current tobacco consumption, and current alcohol consumption.

association between frailty per 1-point increase in the PSQI score ($p = 0.04$). No significant association between sleep quality and pre-frailty was observed.

Associations between sleep duration and the physical frailty components

Table 3 presents the ORs and 95%CIs values for the five physical frailty components according to the sleep-duration groups. The results of the binomial logistic regression analysis demonstrated that compared to the middle sleep-duration group, there were significant positive associations between the short-sleep duration status and exhaustion (multivariate-adjusted OR 2.10, 95%CI: 1.12–3.92, $p = 0.02$) and between the long-sleep status and low physical activity (multivariate-adjusted OR 2.98, 95%CI: 1.49–5.98, $p < 0.01$).

Associations between sleep quality and the physical frailty components

Table 4 presents the ORs and 95%CIs for physical frailty components according to the participants' sleep quality. The results of the binomial logistic regression analysis revealed that compared to the PSQI ≤ 5 status, the PSQI

	Participants, *n*	Participants applicable to each component, *n*	Multivariable-adjusted OR (95%CI)	*p*-value
Unintentional weight loss:				
PSQI ≤ 5	652	62	1.00 (ref.)	
PSQI 6–8	116	11	0.92 (0.46–1.83)	0.81
PSQI ≥ 9	80	9	1.11 (0.52–2.37)	0.80
P for trend				0.91
Low handgrip strength:				
PSQI ≤ 5	652	129	1.00 (ref.)	
PSQI 6–8	116	24	0.94 (0.57–1.55)	0.80
PSQI ≥ 9	80	23	1.47 (0.86–2.53)	0.16
P for trend				0.25
Exhaustion:				
PSQI ≤ 5	652	54	1.00 (ref.)	
PSQI 6–8	116	27	3.10 (1.84–5.23)	< 0.001
PSQI ≥ 9	80	22	3.89 (2.17–6.97)	< 0.001
P for trend				< 0.001
Slow gait speed:				
PSQI ≤ 5	652	128	1.00 (ref.)	
PSQI 6–8	116	27	1.04 (0.63–1.70)	0.89
PSQI ≥ 9	80	15	0.82 (0.44–1.53)	0.53
P for trend				0.67
Low physical activity:				
PSQI ≤ 5	652	127	1.00 (ref.)	
PSQI 6–8	116	22	0.81 (0.47–1.40)	0.45
PSQI ≥ 9	80	19	1.19 (0.65–2.16)	0.57
P for trend				0.95

Table 4. The ORs and 95%cis for frailty components according to the participants' sleep quality. The multivariable model was adjusted for age, sex, education, employment status, subjective economic status, BMI, comorbidities, MoCA-J, current tobacco consumption, and current alcohol consumption.

6–8 (multivariate-adjusted OR 3.10, 95% CI: 1.84–5.23, $p < 0.001$) and PSQI ≥ 9 status (multivariate-adjusted OR 3.89, 95%CI: 2.17–6.97, $p < 0.001$) were significantly positively associated with exhaustion, and the P for trend indicated a significant increasing trend across PSQI 6–8 and PSQI ≥ 9 ($p < 0.001$). No significant associations were observed for the other components.

Discussion

The results of this study demonstrated that (*i*) long sleep duration and poor sleep quality were positively associated with physical frailty in community-dwelling Japanese adults aged 65–75 years, and (*ii*) short sleep duration and poor sleep quality were associated with exhaustion, while long sleep duration was associated with low physical activity.

The prevalence of physical frailty in this study was 4.7%, which is slightly lower than the prevalence that has been observed among community-dwelling older Japanese adults (7.4%)[26]. This difference could potentially be attributed to variations in the age of the study population, demographic characteristics, and/or the methods used to assess physical frailty[26,27].

The association that we observed between long sleep duration and physical frailty in community-dwelling older adults is similar to findings reported by Baniak et al.[11] and Sun et al.[12], who investigated older populations in other regions and observed that a long sleep duration (> 10 h or > 9 h) was associated with physical frailty. However, the models before the adjustment for depressive symptoms in the Baniak et al. study and for sleep quality in the Sun et al. study revealed an association between shorter sleep duration and physical frailty. Given that the PSQI questionnaire includes sleep duration and that the physical frailty component also includes a questionnaire on depressive symptoms, we considered the possibility that sleep quality and depressive symptoms may have been over-adjusted in those two studies.

An investigation conducted by Nakakubo et al. of older Japanese community-dwellers indicated that both short sleep duration (< 6 h) and long sleep duration (> 9 h) were associated with physical frailty[9]. Similarly, Moreno-Tamayo et al.'s prospective cohort study of community-dwelling older adults revealed that both short sleep duration (< 5 h) and long sleep duration (> 9 h) were associated with the incidence of physical frailty[10]. In our present cohort, short sleep duration was marginally associated with physical frailty after adjustment for confounding factors ($p = 0.06$). Our comparison of the present and prior studies revealed that the prevalence of physical frailty among the present participants with short sleep durations (8.2%) was lower than those reported by Nakakubo et al. (10.5%)[9] and Moreno-Tamayo et al. (19.1%)[10]. We suspect that this discrepancy in the results might be due to insufficient statistical power, which prevented the detection of true effects. A longitudinal study with an increased sample size and optimized study design is needed to test these associations.

Other investigations of the relationship between sleep quality and physical frailty have reported an association with PSQI ≥ 6[12–14]. In the present study, we observed a tendency for the ORs of physical frailty to increase in the PSQI 6–8 and PSQI ≥ 9 groups, with a significant increase in OR observed in the PSQI ≥ 9 group compared to the PSQI ≤ 5 group. Mizuno et al.'s study of older Japanese adults residing in the community detected no significant association between sleep quality and physical frailty at age 70 (75–78 yrs), but a significant association was observed at age 80 (85–87 yrs)[13]. Our present findings thus provide new insights into the association between poor sleep quality and physical frailty among community-dwelling Japanese adults aged 65–75 years.

Our comparison by the five components of physical frailty revealed different associations for sleep duration and sleep quality. Regarding sleep duration, short sleep duration was associated with exhaustion, while long sleep duration was associated with low physical activity. Regarding sleep quality, significant associations with exhaustion were observed in the PSQI 6–8 and PSQI ≥ 9 groups. These findings are consistent with the study of older Japanese by Nakakubo et al.[9]. The associations between objectively measured sleep and fatigue symptoms were also investigated by Alfini et al., and their findings revealed that short sleep duration was associated with increased physical fatigability and mental fatigability, and greater sleep fragmentation was associated with increased mental fatigability[28]. Notably, 84.9% of the present participants with short sleep duration had a PSQI score ≥ 6 points. This suggests that short sleep duration and poor sleep quality may be associated with physical frailty through similar mechanisms.

Another research group indicated that long sleep duration may be associated with physical frailty through a mechanism involving low physical activity[9]. Our present analyses also revealed an association between long sleep duration and low physical activity. Individuals with long sleep duration tend to be relatively less physically active during the day[29] and may also be in a low energy expenditure state[30]. Moreover, individuals with long sleep durations may have reduced sunlight exposure, which can affect the synthesis of melatonin by the pineal gland[31], thereby affecting sleep quality. However, as our present investigation is a cross-sectional study, future research based on our findings is necessary to determine the directionality of these effects.

Neither sleep duration nor sleep quality showed associations with slow gait speed or low handgrip strength in our study. An association between short[9,32] or long[9] sleep duration and slow gait speed has been described, but longitudinal studies have identified no association between sleep duration and gait speed. Similarly, short[33,34] or long[9,35] sleep duration has been reported to be associated with low handgrip strength, but no association with low handgrip strength has been detected in a longitudinal study. These contradictory results regarding slow gait speed and low handgrip strength emphasize the need for further research.

There are several potential biological mechanisms relating sleep duration and quality to physical frailty, as follows. (*1*) Phosphorylated sleep-need-index-phosphoproteins (SNIPPs) are normally resolved through sleep, but persistent short sleep duration or poor sleep quality may lead to an accumulation of SNIPPs. Consequently, synaptic function throughout the brain may become inefficient, affecting neurotransmitters such as norepinephrine, dopamine, and serotonin, which transmit signals between these synapses, potentially influencing exhaustion[36–38]. (*2*) Peripheral interleukin (IL)-6 concentrations may increase due to short sleep duration and/or poor sleep quality, impacting central nervous system and immune functions, potentially contributing to the onset of physical frailty[39–41]. (*3*) Sleep promotes the secretion of anabolic hormones such as growth hormone, testosterone, and insulin, which stimulate protein and muscle synthesis as well as tissue growth and repair. Reduced secretions of anabolic hormones due to short sleep duration and/or poor sleep quality may lead to decreased muscle mass in older adults, contributing to physical frailty[42]. (*4*) Long sleep duration may provide mitochondria with an energy supply adjusted to low activity levels, leading to a decreased oxidative capacity and efficiency of mitochondria, which are associated with low muscle mass and may contribute to the onset of physical frailty[43,44].

The strength of our study is its nature as an exploration of the association between physical frailty and both sleep duration and sleep quality among older community-dwelling adults. By examining the components of physical frailty separately, we observed that long sleep duration was associated with low physical activity (a physical component), while short sleep duration and poor sleep quality were associated with exhaustion (a psychological component). This indicates that sleep duration and sleep quality may have different effects on physical frailty.

However, there are several limitations to this study. Although this was an observational study of community-dwelling older adults, the participants attended the study and measurement sessions by themselves, indicating relatively better physical and mental health. The lower prevalence of poor sleep quality and physical frailty may lead to low statistical power and a limited ability to detect true effects. In addition, we excluded some participants from the analyses due to missing values, but the excluded participants had only minor differences compared to the included participants, such as a slightly higher proportion of low education (≤ 9 yrs) (15.9% vs. 10.4%), higher BMIs (23.6 kg/m^2 vs. 22.9 kg/m^2), and a lower proportion of current tobacco smokers (3.8% vs. 8.5%). Nevertheless, the study was of a limited number of older adults in a single region of Japan, which would limit the generalizability of our findings to other populations with different ages, cultures, and lifestyles.

Although we investigated the participants' medication use, we did not collect the specific names of each medication, and we thus could not determine whether the medications had side effects that affected the participants' sleep. However, the PSQI includes the impact of participants' medication use on sleep, and we thus believe that we have controlled for this factor as much as possible. Additionally, the subjective evaluations of sleep could lead to recall bias. Research using devices capable of objectively measuring sleep duration and quality is necessary. We analyzed exhaustion as a psychological factor because we defined it by using two questions in the K6, but we cannot state whether exhaustion was caused by psychological stress. Finally, as the study's design was cross-sectional, causality cannot be established, and since there may be bidirectional associations between sleep and physical frailty, longitudinal studies are necessary. Understanding the connection between sleep and physical frailty components will enable healthcare professionals to design more precise prevention and treatment strategies, ultimately improving the healthy life expectancy of older adults. Future studies should explore the mechanisms that underlie these associations and focus on developing effective intervention strategies.

Conclusion
The results of our analyses demonstrated that both long sleep duration and poor sleep quality were associated with physical frailty in community-dwelling Japanese adults aged 65–75 years. Short sleep duration and poor sleep quality were shown to be associated with exhaustion, whereas long sleep duration was associated with low physical activity. Longitudinal studies are needed to elucidate the impacts of sleep duration and sleep quality on the components of physical frailty. Assessments of sleep disturbances from the perspective of both sleep duration and sleep quality in older populations may contribute to the optimal prevention and management of physical frailty.

Data availability
The data used in this study are available from the corresponding author on reasonable request.

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Author contributions
LW, TS, TY, CC, HY, XL, and HK contributed to the conceptualization of the study. LW and TS wrote the manuscript, conducted statistical calculations, and interpreted the data. HY and XL collected the data. LW, TS, CC, HY, and XL participated in data organization. The manuscript was reviewed and edited by LW, TS, TY, CC, HY, XL, and HK. HK provided research direction, managed the study project, and acquired funding. All of the authors approved the final version of the manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

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