Increased Steps in Japanese Older Adults Associated with Improved Winter Sleep Quality

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Abstract

Objective: We aimed to assess seasonal and age-related variations in sleep quality using Fitbit data and offer lifestyle recommendations for enhancing winter sleep quality. **Methods:** Fitbit sleep and activity data of 51 participants randomly recruited from members of the Association for Research in Supporting System of Chronic Disease, a nonprofit organization in the Yamanashi Prefecture of Japan, were collected and retrospectively analyzed from July to December 2022. Sleep stage targets were set at 10% to 25% for deep sleep, 50% to 60% for shallow sleep, and 20% to 25% for REM sleep. Participants were categorized into improved, unchanged, and worsened groups based on sleep stage unit changes between August and December. **Results:** The median (interquartile range) age was 71 (68–74) years old. There were eight participants in the improved group, 23 in the unchanged group, and nine in the worsened group. The improved group showed significantly more steps (990 ± 1,102 steps/day, $p = .039$) in December than in August, while the worsened group showed fewer steps (−507 ± 1,638 steps/day, $p = .38$). **Conclusion:** Increasing step count in winter may improve sleep quality, as assessed by sleep stage. Further research considering potential confounders and factors affecting winter sleep is needed to support and extend these findings.

Keywords

sleep quality, Fitbit, deep sleep, REM sleep, step count

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Introduction

Approximately 30% of the Japanese population over 60 years of age experience sleep disorders (Tsutsumi, 2008). Aging-related sleep quality decline is associated with decreased melatonin secretion, reduced core body temperature amplitude, and brain atrophy (Romanella et al., 2021; Suzuki et al., 2017; Tuft et al., 2023). Despite the challenges posed by age-related brain changes, addressing sleep disorders in older adults remains a crucial social issue.

Additionally, seasonal variations impact sleep quality, with conflicting reports on whether sleep quality improves or worsens from summer to winter (Johnsen et al., 2012; Pallesen et al., 2001; Sivertsen et al., 2011). Yamanashi Prefecture, with its significant seasonal temperature and sunlight fluctuations, provides an ideal setting for objectively studying the relationship between sleep and seasonal variations.

Polysomnography, while being the gold standard for sleep quality assessment, is often impractical for older adults due to its invasive nature and artificial sleep environment (Schyvens et al., 2024). Fitbit offers a non-invasive alternative, capable of monitoring sleep stages, activity levels, and resting heart rate (RHR) in a free-living environment. This technology could potentially enable timely feedback between healthcare professionals and patients, improving health management for older adults.

This study aims to evaluate the relationships between sleep, seasonal changes, and aging using Fitbit-derived data and to identify practical strategies to enhance sleep quality for older adults from summer to winter. By

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leveraging wearable technology, we seek to provide insights that can contribute to better sleep management in this population.

Methods and Methodology

Study Design and Patients

This study used a retrospective cohort design. This study is part of a project titled "Establishment of a System for Watching Over the Elderly Using Digital Technology" led by the Association for Research in Supporting System of Chronic Disease, a nonprofit organization in the Yamanashi Prefecture of Japan. The corporation aims to develop effective medical support systems for chronically ill patients and their reserve forces, promote medical care and welfare, and contribute to the development of an information society. Participants were recruited from the patients' associations, civil welfare committees, and social welfare councils in this corporation on the condition that they would wear Fitbit on a daily basis between July and December 2022.

Fitbit is a popular commercially available wearable device. Fitbit uses microelectronic 3-axis accelerometers to capture body movements in 3-dimensional space and analyzes these movement data using proprietary algorithms to identify movement patterns, thereby measuring daily steps, energy consumption, and distance. It also collects RHR data, which is combined with accelerometer data to assess sleep-wake states and sleep stages. The study used the Fitbit Charge5 model.

We collected and analyzed the data obtained from the Fitbit. For the overall analysis, three patients without data on sleep and exercise from the Fitbit were excluded, and 51 patients were analyzed. For the comparative analysis between August and December, 11 participants without data for those months were excluded, resulting in 40 participants. For the analysis of blood pressure (BP) variability, 29 participants without BP data were excluded, and 22 participants were analyzed. Informed consent was not required for this study because it was a retrospective study using pseudonymized data.

Parameters Obtained from Fitbit

Bedtime was defined as the time from bedtime to awakening. Sleep time was calculated as the total sleep time recorded by the Fitbit minus the time spent awake or in restless sleep. Sleep efficiency was calculated by dividing sleep time by bedtime and multiplying it by 100. Rmssd is calculated as the square root of the mean of the squares of the differences between consecutive adjacent RR intervals in heart rate variability and is an indicator of parasympathetic activity (Kleiger et al., 2005). The target values for the percentage of each sleep stage were based on previous reports (Ministry of Science and Innovation, n.d.; Patel et al., 2023; Welch & Goldberg, 2008). Target values were set at 10% to 25% for deep sleep, 50% to 60% for shallow sleep, and 20% to 25% for REM sleep. Δ was calculated by subtracting the August values from the December values. The number of sleep stage targets achieved was noted as 0, 1, 2, and 3. The improved group was defined as the group with increased number of sleep stages within the target period in December; the unchanged group was defined as the group that remained the same; and the worsened group was defined as the group that decreased in December.

Statistical Analysis

Clinical characteristics are represented as number (%), mean ± standard deviation for normally distributed data, and median (interquartile range) for non-normally distributed data. Activity and sleep profiles were analyzed in August and December for each of the three groups: improved, unchanged, and worsened. Changes between August and December were analyzed using paired *t*-tests for normally distributed data and Wilcoxon signed-rank sum tests for non-normally distributed data. Intergroup differences were evaluated using ANOVA with Tukey's test for post hoc comparisons (normally distributed data) or Kruskal–Wallis test with Steel–Dwass test for post hoc comparisons (non-normally distributed data). Nominal variables were analyzed using Fisher's exact test. Continuous variables between two groups were compared using *t*-tests (normally distributed) or Mann–Whitney *U* tests (non-normally distributed).

All statistical analyses were performed using EZR version 1.52 (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R version 4.02 (The R Foundation for Statistical Computing, Vienna, Austria; Kanda, 2013). More precisely, it is a modified version of the R commander designed to add statistical functions frequently used in biostatistics. Missing values were analyzed using participants with no missing values in the data required for individual analysis. Values of $p < .05$ were considered significant.

Results

Clinical Characteristics

The clinical characteristics of the participants are shown in Table 1. The median (interquartile range) age was 71 (68–74) years and more than half of the participants were men. Sex comparisons are shown in Table S1 (see Supplementary Material). Men were heavier and burned more calories than women during physical activity. Women had longer periods of deep sleep and REM sleep than men. Comparisons by age are shown in Table S2 (see Supplementary Material). Older people (>71 years old) had a greater proportion of shallow sleep and a lower proportion and duration of REM sleep than those aged under 71 years.

Table 1. Clinical Characteristics of Participants.

Characteristics	All participants (n = 51)
Age, years	71 (68–74)
Men	31 (61%)
Body weight (kg)	59.0 (53.8–65.0)
BMI (kg/m^2)	22.5 (21.2–24.4)
sBP (mmHg)	127 ± 14
dBP (mmHg)	75 ± 9
RHR (times/min)	63 ± 8
Rmssd (ms)	22.6 (18.3–36.1)
Calories burned in physical activity (kcal/day)	966 ± 329
Number of steps (steps/day)	9,049 ± 3,665
Bedtime (min)	396 (375–432)
Sleep time (min)	342 (323–372)
Sleep efficiency (%)	86 ± 2
Duration of deep sleep (min)	50 ± 11
Percentage of deep sleep (%)	15 ± 3
Duration of shallow sleep (min)	231 ± 42
Percentage of shallow sleep (%)	67 ± 6
Duration of REM sleep (min)	63 ± 19
Percentage of REM sleep (%)	18 ± 5
Duration of awakening (min)	55 ± 12
Percentage of awakening (%)	16 ± 3

Note. The data are presented as the median (interquartile range), mean ± standard deviation, or number (%). BMI = body mass index; sBP = systolic blood pressure; dBP = diastolic blood pressure; RHR = resting heart rate; Rmssd = root mean square successive difference; REM = rapid eye movement.

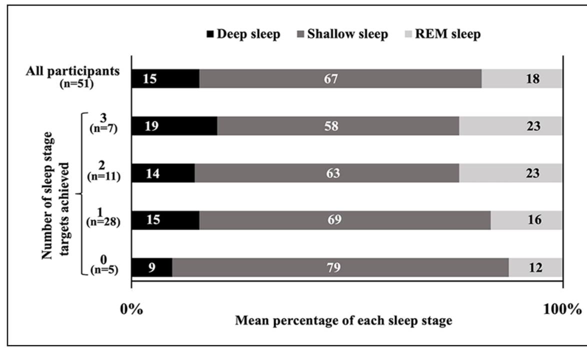

Figure 1. Mean percentages of each sleep stage.
Note. Histogram showing the percentage of each sleep stage. Comparison of the number of sleep stage targets achieved.

Number of Sleep Stage Targets Achieved

Table S3 (see Supplementary Material) compares the characteristics of participants who achieved zero, one, two, or three sleep stage targets from July to December. The ages of those who achieved two targets were younger than those who achieved one. As the number of sleep stage targets achieved increased, the median age tended to be lower. The group that achieved three targets had a greater proportion of deep sleep than the other groups. In addition, the group that achieved three targets had a lower proportion of shallow sleep and a greater proportion of REM sleep than the groups that achieved zero and one target. The mean percentages of each sleep stage by all participants and the number of sleep stage targets achieved are shown in Figure 1. As the number of sleep stage targets achieved increased, the percentages of deep and REM sleep tended to increase, whereas the percentage of shallow sleep tended to decrease, approaching the ideal data (Figure 1).

Overall Seasonal Change

A comparison of the various parameters for August and December is presented in Table S4 (see Supplementary Material). From August to December, the BP and RHR increased, whereas the Rmssd decreased. Regarding activity-related items, the number of calories burned during physical activity increased. Bedtime, sleep duration, sleep efficiency, and shallow sleep duration also increased. The percentage of deep sleep, and the duration and percentage of awakening decreased.

Comparison by Change in the Number of Target Sleep Stages Between August and December

The changes in the number of sleep stages between August and December are shown in Figure S1 (see Supplementary Material) and Table 2. The median number of targets achieved increased from one to two for the improved group; 74% of the unchanged group achieved one target and decreased from two to one target achieved in the worsened group (Figure S1 in Supplementary Material).

The changes in the three groups between August and December are shown in Table 2. Sleep efficiency increased in the improved and unchanged groups in December. In the worsened group, the duration and percentage of shallow sleep increased, and the percentages of deep and REM sleep decreased.

Comparing the December data among the three groups, the percentage of deep and REM sleep was lower in the worsened group, and the duration and percentage of shallow sleep were greater than those in the improved group. In terms of activity-related items, calories burned during physical activity and the number of steps increased in the improved group towards December, while calories burned during physical activity increased in the unchanged group (Table 2, Figure 2). In the worsened group, number of calories burned during physical activity and the number of steps decreased, although not significantly (Table 2, Figure 2). The mean number of steps per h is shown in Figure S2 (see Supplementary Material). This pattern did not differ between the groups. Comparing August and December, the mean number of steps in August peaked bimodally at 6:00 a.m. and 5:00 p.m., while in December it peaked bimodally at 10:00 a.m. and between 3:00 p.m. and 4:00 p.m. Peak steps in the morning tended to occur later in

Table 2. Comparison of Sleep Quality Changes Between August and December.

	Improved (I) (*n* = 8)			Unchanged (U) (*n* = 23)			Worsened (W) (*n* = 9)					
Parameters	August	December	Δ	August	December	Δ	August	December	Δ	August	December	Δ
Calories burned in physical activity (kcal/day)	915 ± 252	1,052 ± 302	137 ± 137*	826 ± 308	940 ± 352	115 ± 187**	865 ± 257	854 ± 247	−10 ± 145			
Number of steps (steps/day)	7,989 ± 2,094	8,979 ± 1,828	990 ± 1,102*	7,664 ± 3,763	8,374 ± 4,128	710 ± 1,776	8,384 ± 3,648	7,877 ± 3,141	−507 ± 1,638			
Bedtime (min)	388 (361–408)	382 (364–400)	−14 (−22 to −1)	394 (355–437)	420 (373–445)	11 (−6 to 29)	403 (386–418)	428 (412–450)	28 (9–45) *			
Sleep time (min)	335 (306–348)	340 (320–354)	−1 (−15 to 11)	327 (308–372)	355 (323–390)	17 (−7 to 33) **	336 (332–360)	364 (356–385)	31 (24–41) **			
Number of sleep stage targets achieved												
0	1 (13%)	0		3 (13%)	3 (13%)		0	4 (44%)		U vs. W: **	I vs. U: ** I vs. W: **	
1	5 (63%)	0		17 (74%)	17 (74%)		3 (33%)	4 (44%)				
2	2 (25%)	5 (63%)		3 (13%)	3 (13%)		5 (56%)	1 (11%)				
3	0	3 (38%)		0	0		1 (11%)	0				
Sleep efficiency (%)	85 ± 2	87 ± 2	3 ± 2*	85 ± 3	86 ± 3	1 ± 2**	85 ± 1	86 ± 2	1 ± 2			
Duration of deep sleep (min)	58 ± 10	55 ± 9	−3 ± 11	46 ± 11	48 ± 12	2 ± 7	47 ± 6	42 ± 13	−5 ± 10	I vs. U: *		
Percentage of deep sleep (%)	18 ± 4	17 ± 3	−1 ± 3	14 ± 3	14 ± 4	0 ± 2	14 ± 2	11 ± 3	−2 ± 2*	I vs. U: * I vs. W: *	I vs. W: **	
Duration of shallow sleep (min)	208 ± 42	206 ± 30	−2 ± 22	239 ± 48	248 ± 56	9 ± 21	226 ± 21	265 ± 26	39 ± 13**		I vs. W: *	I vs. W: ** U vs. W: **
Percentage of shallow sleep (%)	62 ± 8	61 ± 4	−1 ± 6	71 ± 7	70 ± 7	−1 ± 3	66 ± 5	72 ± 6	6 ± 3**	I vs. U: *	I vs. U: ** I vs. W: **	I vs. W: ** U vs. W: **
Duration of REM sleep (min)	67 ± 15	76 ± 9	9 ± 11	53 ± 23	59 ± 2	6 ± 10**	68 ± 15	62 ± 15	−6 ± 10			I vs. W: ** U vs. W: **
Percentage of REM sleep (%)	20 ± 5	23 ± 2	2 ± 4	15 ± 6	17 ± 5	1 ± 3	20 ± 4	17 ± 4	−3 ± 3**		I vs. U: ** I vs. W: *	I vs. W: * U vs. W: **
Duration of awakening (min)	60 ± 13	48 ± 9	−12 ± 8**	61 ± 15	56 ± 14	−5 ± 10	61 ± 7	60 ± 11	−1 ± 10			
Percentage of awakening (%)	18 ± 3	14 ± 3	−4 ± 3*	18 ± 5	16 ± 4	−2 ± 3**	18 ± 2	16 ± 3	−2 ± 2			

Note. The data are presented as the median (interquartile range), mean ± standard deviation, or number (%). Changes between August and December were analyzed using a paired *t*-test for normally distributed data and a Wilcoxon signed-rank sum test for nonnormally distributed data. Otherwise, normally distributed data were compared with one-way ANOVA. When significance was confirmed, multiple comparisons were performed using the Tukey test. Nonnormally distributed data were analyzed using the Kruskal–Wallis test. When significance was confirmed, multiple comparisons were performed using the Steel–Dwass test. Nominal variables were analyzed using Fisher's exact test. REM = rapid eye movement; Δ = change calculated by subtracting August data from December data; I = improved; U = unchanged; W = worsened.
*$p < .05$. **$p < .01$.

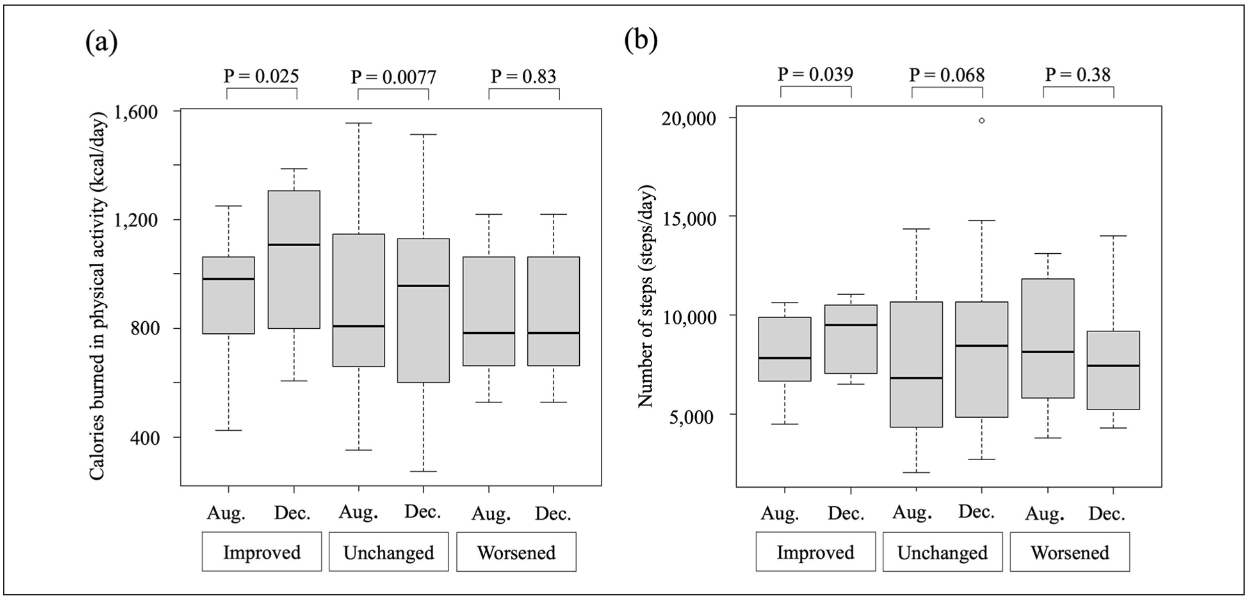

Figure 2. Comparison of activity between the improved, unchanged, and worsened groups between August and December.
Note. The lower and upper lines in the box-and-whisker diagram represent the 25th and 75th percentiles, respectively, and the middle line represents the median values: (a) box-and-whisker diagrams comparing the calories burned during physical activity between the three groups and (b) box-hide diagram comparing the number of steps between the three groups. Aug. = August; Dec. = December.

winter. The peak steps in the morning tended to occur later, and those in the afternoon tended to occur earlier in the winter. Other data for the three groups in August and December are shown in Table S5 (see Supplementary Material).

Comparison of Seasonal BP Variation

Table S6 (see Supplementary Material) shows a comparison of the two groups (systolic blood pressure change (ΔsBP) ≥ 10 mmHg and ΔsBP < 10 mmHg). The group with ΔsBP ≥ 10 mmHg was older and included more men. The diastolic BP and RHR increased in December in both groups. Regarding sleep-related items, the group with ΔsBP < 10 mmHg had a greater proportion of REM sleep and a lower percentage of shallow sleep in December than did the group with ΔsBP ≥ 10 mmHg. In terms of activity-related items, the group with ΔsBP < 10 mmHg showed a significant increase in calories burned during physical activity in December. The number of steps also increased, although this difference was not significant (Figure S3 in the Supplementary Material). In contrast, the group with ΔsBP ≥ 10 mmHg showed a decrease in the mean number of steps in December, although this difference was not significant (Figure S3 in the Supplementary Material).

Discussion

In older people, sleep quality is reduced because of decreased melatonin secretion and amplitude of core body temperature (Suzuki et al., 2017; Tuft et al., 2023), decreased numbers of neurons and decreased glial cell function in the brain (Amzica & Massimini, 2002; Choudhury et al., 2021; Crowley, 2011), decreased synaptic density and reversibility, and cortical atrophy (Romanella et al., 2021), making it difficult to improve sleep quality because of structural changes in the brain. The observations in the present study suggest that exercise may improve sleep quality in older adults.

Compared with Japanese data from the National Nutrition Survey of Japan (NNS-J) (Ministry of Health, Labour and Welfare, 2020), the study participants had a shorter mean sleep time (NNS-J data: most asleep between 360 and 420 min) and more mean daily steps (NNS-J data: 6,793 steps for men and 5,832 for women). This high activity level may be partly because the participants were members of patient associations, civil welfare committees, and social welfare councils, and we recruited people who were willing to wear the Fitbit. Although it may have been difficult to find differences in the amount of physical activity needed to improve sleep quality because the study was conducted in a group that was active to begin with, these results suggest that even those who are active to begin with can improve their sleep quality by becoming even more active.

In most previous studies, sleep quality was subjectively evaluated using sleep diaries and questionnaires, such as the Pittsburgh Sleep Quality Index (Buysse et al., 1989). In contrast, Fitbit has the advantage of objectively assessing sleep quality based on sleep stages, in addition to sleep time. Ensuring sufficient REM sleep and deep sleep is important for maintaining sleep quality (Barbato, 2021; Di et al., 2024; Kaplan et al., 2017), and when disturbed, the following are

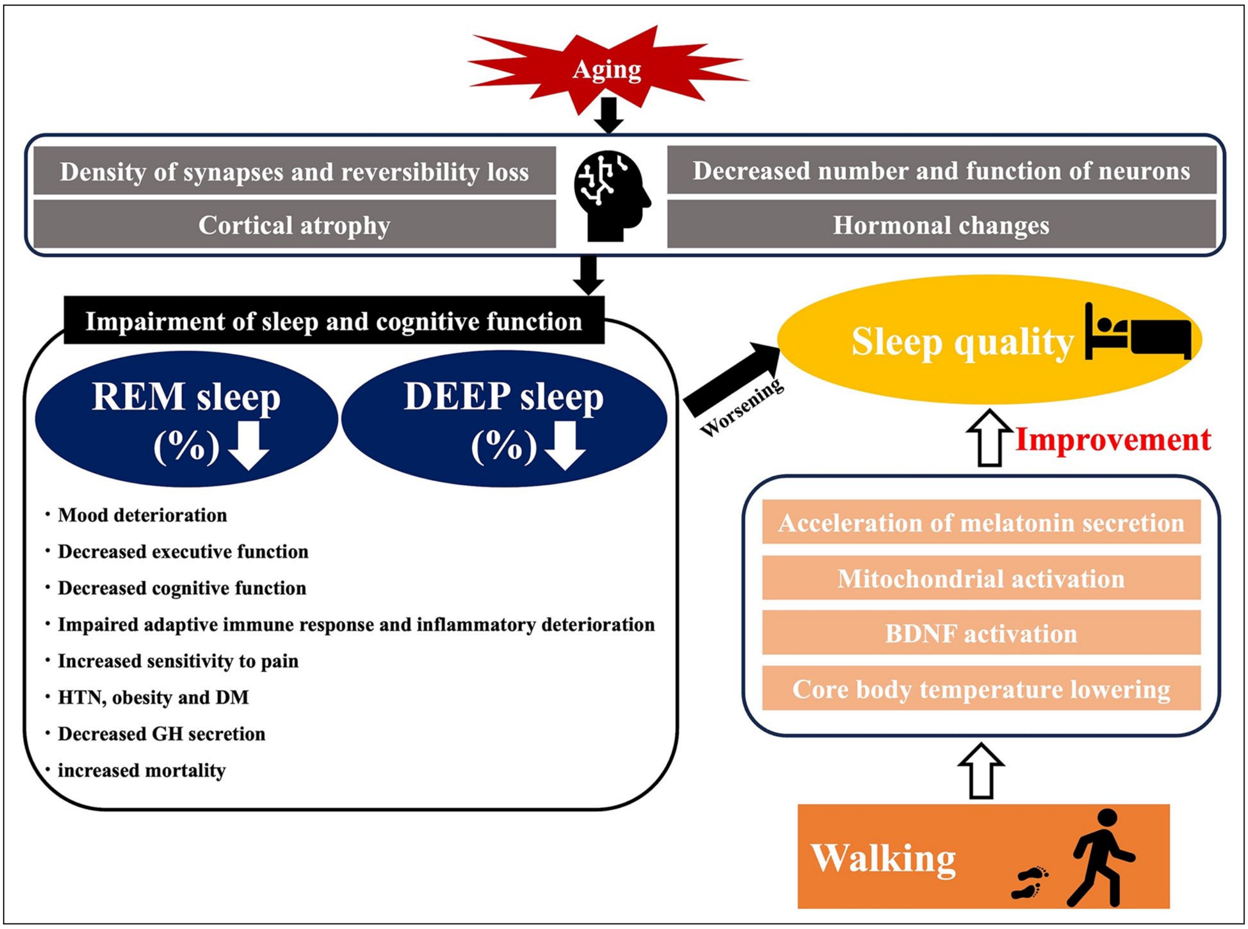

Figure 3. The relationships between aging, sleep quality, and walking.
Note. HTN = hypertension; DM = diabetes mellitus; GH = growth hormone; BDNF = brain-derived neurotrophic factor.

considered to occur: (1) mood deterioration: decreased connectivity between the medial prefrontal cortex and amygdala, which is involved in mood deterioration (Motomura et al., 2017); (2) decreased cognitive function and amyloid accumulation (Ju et al., 2017; Pase et al., 2017; Song et al., 2015; Sunkaria & Bhardwaj, 2022); (3) inflammatory deterioration and increased IL-17 levels (Cui et al., 2019; Yehuda et al., 2009); (4) impaired adaptive immune response, shown by an increase in deep sleep increases when IL-1b and TNF-α are administered (Shoham et al., 1987; Szentirmai & Kapás, 2019); and decreases when IL-10, IL-4, and IL-13 are administered (Kapsimalis et al., 2005); (5) decreased growth hormone secretion (Gohil & Eugster, 2019); and (6) diabetes mellitus and increased insulin resistance (Smiley et al., 2019). REM sleep and deep sleep are not only components of sleep stages but are also involved in systemic effects such as cognitive function, metabolic endocrinology, and immune function. However, aging (Choudhury et al., 2021; Lavoie et al., 2018) and male sex (Luca et al., 2015) are thought to cause a decrease in the proportions of REM and deep sleep, which is in line with our results.

Reports on seasonal changes in sleep quality using subjective measures have been inconsistent, with some reporting worse sleep quality in winter (Johnsen et al., 2012; Pallesen et al., 2001) and others reporting improvement (Sivertsen et al., 2011). Summer, with its longer daylight hours and warmer temperatures, has been suggested to suppress melatonin secretion and shorten sleep time (Mattingly et al., 2021; Suzuki et al., 2019). Studies assessing sleep seasonality in Japanese populations using actigraphy and non-contact biokinetic sensors have reported increased sleep time and sleep efficiency and decreased awakening time in winter compared with summer (Hashizaki et al., 2018; Okamoto-Mizuno & Tsuzuki, 2010). In our study, sleep time increased by a mean of 18 min during the winter months. Sleep efficiency improved as bedtime and sleep time increased, and awakening time decreased. However, sleep quality did not necessarily improve as the duration of shallow sleep increased and the proportion of deep sleep decreased. Seasonal changes in sleep conditions are related to environmental factors, such as temperature, humidity, and daylight hours (Bliwise, 1993; Putilov, 2017); however, the underlying mechanism has not been elucidated. Based on data from the Japan Meteorological Agency (Japan Meteorological Agency, n.d.), we compared the data in August, when the mean temperature was the highest at 27.5°C, with those in

December, when it was the lowest at 5.3°C. We believe that it is significant that we were able to observe seasonal changes in sleep conditions using objective indices in Yamanashi Prefecture, which has one of the largest differences in temperature and sunshine hours among Japanese prefectures.

In this study, the improvement group showed an average increase of nearly 1,000 steps per day during winter. Although previous studies have reported that exercise improves sleep quality, the recommended amount of exercise has not yet been established. Based on our results, changes in sleep quality with age and the relationship between walking and improved sleep quality are shown in Figure 3. The possible mechanisms by which exercise improves sleep quality are as follows: (1) proper secretion of melatonin: exercise causes serotonin secretion and promotes melatonin secretion (Aoyama & Shibata, 2017; Kruk et al., 2021); (2) mitochondrial activation: mitochondrial biosynthesis and antioxidant capacity increase, promoting adaptive responses in the body (Hartmann & Kempf, 2023); (3) activation of brain-derived neurotrophic factor (BDNF): in rodents, BDNF is activated, and BDNF activation increases slow wave sleep and deepens sleep (Tan et al., 2020); and (4) lower core body temperature: an increase in body temperature due to exercise causes peripheral blood vessels to dilate, which lowers core body temperature and promotes sleep onset (Gilbert et al., 2004; Murphy & Campbell, 1997). The most important aspect of this study is that it is the first to report from the sleep stage that increased steps may improve sleep quality during the winter months. The results showed that walking can be a lifestyle adjustment to improve sleep quality, even in the presence of nonmodifiable factors, such as aging and season.

This study had several limitations. As a single-center retrospective study with a short observation period and small sample size, its generalizability is limited. The Hawthorne effect may have influenced participants' behavior due to Fitbit monitoring. Several confounders remained unadjusted, including age, sex, BMI, medical conditions, medications, and lifestyle factors, due to unknown patient backgrounds and the small sample size. Other winter-related factors affecting sleep quality, such as daylight hours, humidity, seasonal affective disorder, and circadian rhythm changes, were not examined. The lack of subjective sleep quality data limited the assessment of overall sleep satisfaction. Although previous studies have shown promising results, the accuracy of Fitbit was not compared with that of polysomnography in this study. Potential biases exist, including selection bias due to participant recruitment sources and information bias in self-reported home BP measurements. Future studies should address these limitations to enhance generalizability and reliability of findings, particularly by adjusting for confounding factors and incorporating both subjective and objective sleep quality measures.

Conclusion

Fitbit data showed increased sleep time and efficiency from summer to winter, with decreased deep sleep and increased shallow sleep. These findings on sleep seasonality in Yamanashi Prefecture provide valuable insights. The group with improved sleep stage percentages also showed increased step count, suggesting winter activity may enhance sleep quality. Proposing lifestyle habits to improve sleep quality in older adults is crucial, given the prevalence of sleep disorders. However, further research considering potential confounders and factors affecting winter sleep is needed to support and extend these findings.

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Declaration of Conflicting Interests

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Ethics Approval and Informed Consent Statements

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Research Ethics Committee at the University of Yamanashi Hospital (No. 2636) on January 16, 2023, with the need for written informed consent waived.

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Supplemental Material

Supplemental material for this article is available online.

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