Characterizing Intra- and Inter-Individual Variability in Nocturnal Sleep Patterns in Alzheimer's Disease Using a Bed Sensor System

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Aim : This study characterized intra- and inter-individual variability in nocturnal sleep patterns in older adults with Alzheimer's disease (AD) using a non-invasive bed sensor system and compared them with cognitively normal (CN) older adults.

Methods : Sleep was continuously monitored for about 30 days in 9 AD and 10 CN participants using the Nemuri SCAN system. Nocturnal total sleep time (N-TST) was classified as short (＜360 min), standard (360-600 min), or long (≥600 min).

Results : The AD group exhibited three distinct N-TST patterns : mostly standard sleep, predominantly long sleep, and highly variable durations. Only one-third of AD participants had ≥75 % standard sleep days compared with 80 % of CN participants, while over half of AD participants had frequent long sleep days.

Conclusion : These findings indicate substantial individual variability and a tendency toward long sleep in AD, emphasizing the importance of personalized sleep assessment and management in this population. *Shinshu Med J 74 : 43—49, 2026*

(Received for publication September 29, 2025 ; accepted in revised form November 20, 2025)

Key words : sleep disturbance, total sleep time, cognitive impairment, Alzheimer's disease, variability

I Introduction

Sleep disturbances in cognitively impaired older adults negatively affect health status and increase caregiver burden[1)-3)]. Moreover, recent studies suggest that disrupted sleep may exacerbate brain damage[4)5)]. Given these consequences, early detection and effective management of sleep disturbances are essential to maintain the quality of life of affected older adults and their caregivers. They are also important to reduce strain on the health care system.

Common sleep-related problems in patients with AD include frequent nocturnal awakenings and reduced total sleep time (TST)[6)-8)]. In contrast, other studies have reported long nocturnal sleep[8)-10)], indicating that the nature of sleep disturbance varies across individuals. Therefore, understanding and characterizing individual sleep patterns are critical for developing personalized care strategies.

Despite the importance of accurate assessment, there is no consensus on a practical and valid method for evaluating sleep disturbance in this population. Although polysomnography (PSG) is considered the gold standard for sleep assessment, it is invasive, burdensome, and unsuitable for monitoring day-to-day variability. Observational tools such as the Neuropsychiatric Inventory-Nursing Home version (NPI-NH) and the Cumulative Sleep Index for Nursing Assessment of Patients with Sleep Problems rely on caregiver reports. However, their results sometimes diverge from objective measurements[11)12)].

To address these challenges, we explored the use of a bed sensor system, Nemuri SCAN, for continu-

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ous and objective sleep monitoring without restraining individuals. Our previous pilot study using this system reported that multiple types of sleep disturbances may coexist in a single patient with AD over a month[13], highlighting the complexity of intra-individual variability.

However, to date, no studies have systematically measured sleep disturbance over an extended period in patients with AD and compared these data with those of cognitively normal older adults without sleep disturbances. Furthermore, little is known about the extent to which sleep disturbance patterns vary within individuals (intra-individual variability) or between individuals (inter-individual variability) in this population.

The aim of this study was to examine whether long-term sleep monitoring using a bed sensor system can classify intra- and inter-individual sleep disturbance patterns in patients with AD compared with older adults without cognitive or sleep impairments.

Ⅱ Materials and Methods

A Study design and participants

This prospective observational study recruited participants through referrals by nurses and care workers at one general hospital and two geriatric care facilities.

Inclusion criteria for the AD group were : (1) a clinical diagnosis of AD as a comorbid condition, with a Functional Assessment Staging Test (FAST) stage of 3 (borderline) to 5 (moderate)[14] ; (2) age ≥70 years ; (3) absence of other conditions known to cause sleep disturbances and not currently using sleep medication ; and (4) expected hospitalization or institutionalization for more than 1 month. Inclusion criteria for the cognitively normal (CN) group were : (1) absence of cognitive impairment (Mini-Cog score ≥3[15]) and absence of sleep disturbances (Pittsburgh Sleep Quality Index [PSQI] score ≤5[16]) ; and criteria (2), (3), and (4) were the same as for the AD group. Exclusion criteria for both groups were : (1) missing data for more than 2 days for reasons other than overnight stay outside the hospital, and (2) fewer than 25 days of data collection.

Participant demographics, including age, sex, medical diagnoses, and modified Barthel Index ambulation score[17)18)] were obtained from medical records. Sleep disturbances in the AD group were evaluated by nurses or care workers using the "Sleep and Nighttime Behavior Disorders" subscale of the NPI-NH. Data were collected between January 2023 and March 2024.

B Equipment

Sleep state was continuously monitored for 1 month using the Nemuri SCAN (Paramount Bed Co., Ltd.), a bed sensor system. The Nemuri SCAN, installed under the mattress, uses a built-in pressure sensor to detect body movements larger than those caused by breathing or heartbeat, and calculates an activity score every minute. Based on a proprietary algorithm, a participant's state was classified into one of three categories each minute : out of bed, awake in bed, or asleep in bed. From these classifications, TST and other metrics were calculated.

The reliability and validity of Nemuri SCAN have been established, with high agreement, sensitivity, and specificity compared with PSG and actigraphy[19]. In this study, the nocturnal period was defined based on the facility's meal schedule : from the first instance of sleep lasting ≥2 min after 18 : 00 until the last instance of sleep lasting ≥2 min before 07 : 30 the next morning. TST during this period was defined as nocturnal total sleep time (N-TST).

C Data analysis

For each participant, a boxplot of N-TST was created to assess intra-individual variability. Nocturnal sleep patterns each day were also classified into three groups : standard, short, or long sleep days. According to a criterion proposed by Kakizaki[20], nocturnal sleep patterns each day were categorized into three groups : days with an N-TST of 360-600 min were classified as normal sleep days, those with ＜360 min as short sleep days, and those with ＞600 min as long sleep days.

Continuous variables with normal distributions were expressed as mean ± standard deviation and compared between groups using the t-test. Non-normally distributed continuous variables were expressed as median and interquartile range (IQR) and analyzed

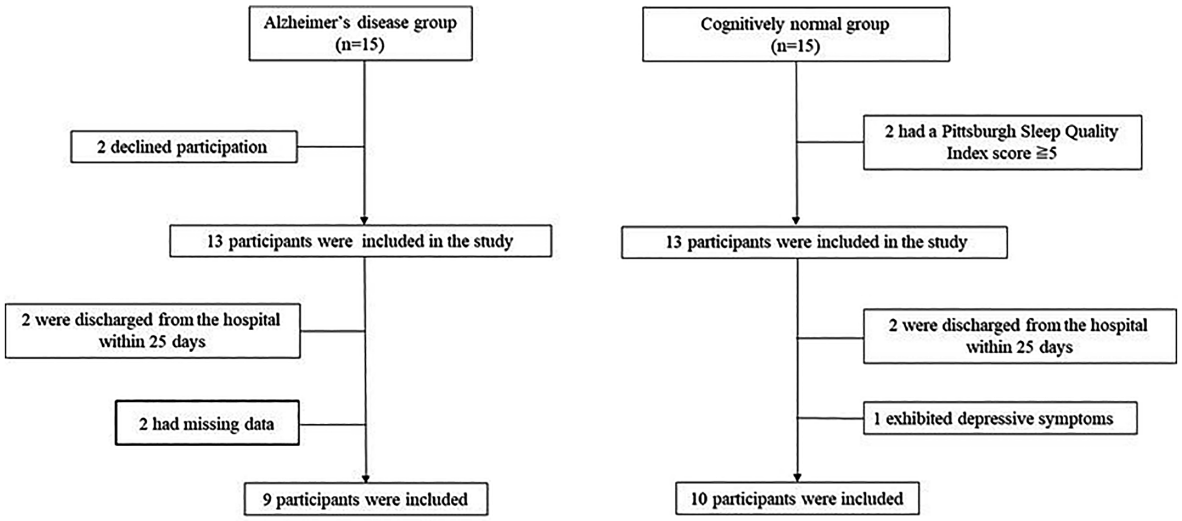

Fig. 1 Flow chart of participants selection

using the Mann-Whitney U test. Categorical variables were expressed as frequencies and percentages, and Fisher's exact test was used for group comparisons. Statistical significance was set at $p<0.05$. All analyses were performed using SPSS version 30.

D Ethical consideration

Written informed consent was obtained from legal representatives of participants in the AD group and from participants in the CN group. The study protocol was approved by the Ethics Committee of Shinshu University (Approval No. 5638).

Ⅲ Results

A Participant characteristics

Fifteen participants were referred to the AD and CN groups. Of these, 2 participants in the AD group declined participation, and 2 in the CN group were excluded because their PSQI scores were >5. Thus, 13 participants from each group were enrolled. After excluding participants discharged within 25 days of measurement initiation, with missing data, or with depressive symptoms, the final analysis included 9 participants in the AD group and 10 in the CN group **(Fig. 1)**.

The mean age in the AD group was 83.9 ± 6.5 years, and all participants were female. The FAST stages were evenly distributed : stage 3 (borderline), stage 4 (mild), and stage 5 (moderate), with 3 participants (33.3 %) in each category. All AD participants were rated as having mild nighttime behavior on the NPI-NH. The median (IQR) modified Barthel Index ambulation score (BI ambulation score) was 5.0 (12.0). The median (IQR) measurement period was 30 (1) days.

In the CN group, the mean age was 82.1 ± 6.9 years, and 9 participants (90 %) were female. The mean Mini-Cog score was 4.4 ± 0.8, and the mean PSQI score was 3.6 ± 1.7. The median (IQR) BI ambulation score was 15.0 (10.0). The median measurement period was 30 (0.75) days **(Table 1)**. Significant group differences were found only in the BI ambulation score.

The most common diagnosis in both groups was hip fracture. Other diagnoses included orthopedic diseases, stroke, cancer, and kidney disease **(Table 2)**.

B Nocturnal total sleep time

Fig. 2 shows the individual N-TST distributions over approximately one month. CN participants mostly slept within the standard range (360-600 min), whereas AD participants had fewer such days. Three sleep patterns were identified in the AD group : (1) mainly standard sleep (Cases A and B) ; (2) predominantly long sleep (Cases C-G) ; and (3) highly variable durations (Cases H and I).

Table 3 summarizes the proportions of short, standard, and long sleep days. Only 3 of 9 AD participants (33.3 %) had ≥75 % standard sleep days, significantly fewer than CN participants (8 of 10 ; 80 %,

Table 1　clinical characteristics of the participants

	Alzheimer's disease group (n = 9)	Cognitively normal group (n = 10)	p value
Age (years)	83.9 ± 6.5	82.1 ± 6.9	0.591
Sex (M/F)	0/9	1/9	1.00
FAST stage			
stage3 (border)	3(33.3 %)		
stage4 (mild)	3(33.3 %)		
stage5 (moderate)	3(33.3 %)		
Sleep and Nighttime Behavior Disorders subscore (NPI-NH) 1	9(100 %)		
Mini-Cog score		4.4 ± 0.8	
PSQI		3.6 ± 1.7	
Modified Barthel Index Ambulation Score	5.0[12.0]	15.0[10.0]	0.033
Duration of monitoring(days)	30[1]	30[0.75]	1.00

Data are presented as n (%), mean ± standard deviation, or median [interquartile range].
FAST : Functional Assessment Staging of Alzheimer's Disease ; NPI-NH : Neuropsychiatric Inventory-Nursing Home Version ; PSQI Pittsburgh Sleep Quality Index.

Table 2　Medical diagnosis of participants by group

	Alzheimer's disease group	Cognitively normal group
Hip fracture	4	5
Stroke	0	2
Knee osteoarthritis	1	1
Lumbar vertebral compression fracture	0	1
Lumber pain	1	0
Osteoporosis	1	0
Rotator cuff tear	0	1
Pyelonephritis	1	0
Rectal cancer	1	0

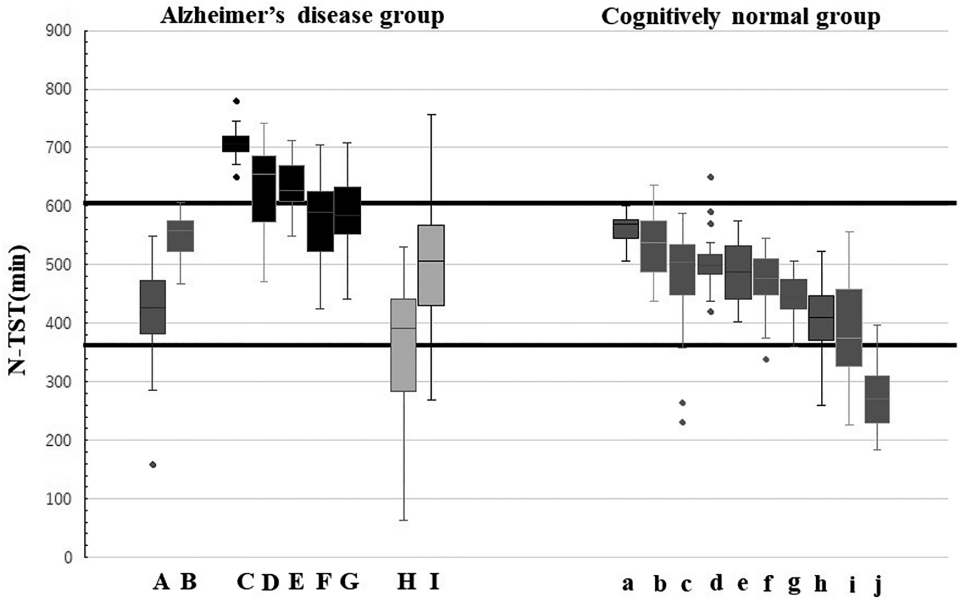

Fig. 2　Nocturnal-Total Sleep Time (N-TST) for each case by 2 groups

Table 3 Proportion of short, standard and long sleep days each participant in the two groups

	BI ambulation score	Short sleep day N-TST＜360min(%)	Standard sleep day 360min≦N-TST≦600min(%)	Long sleep day 600min＜N-TST(%)
Alzheimer's disease group				
Case A	12	20	80	0
B	5	0	96.7	3.3
C	3	0	0	100
D	0	0	17.9	82.1
E	3	0	36.7	63.3
F	0	0	56.7	43.3
G	15	0	60	40
H	15	10	76.7	13.3
I	12	36	64	0
Cognitively normal group				
Case a	5	0	96.7	3.3
b	15	0	85.2	14.8
c	5	13.3	86.7	0
d	15	0	96.7	3.3
e	15	0	100	0
f	15	3.3	96.7	0
g	15	0	100	0
h	15	20.8	79.2	0
i	15	36.7	63.3	0
j	5	96.7	3.3	0

BI ambulation score : Modified Barthel Index ambulation score, N-TST : Nocturnal-Total Sleep Time

$p = 0.024$). Meanwhile, 5 AD participants (55.6 %) (Cases C-G) had long sleep days accounting for ≥40 % of the measurement period, whereas in the CN group, the maximum proportion of long sleep days was 14.8 %. Four of these five AD participants (Cases C-F) with more long sleep days had lower ambulation scores. Short sleep duration was observed in both groups. Notably, Case H in the AD group showed a mixed pattern, with both short and long sleep durations.

Ⅳ Discussion

This study revealed three distinct N-TST patterns among AD participants with mild nocturnal sleep disturbances as assessed by healthcare professionals. These included (1) a group with consistently long sleep days, (2) a group with large day-to-day variability that included both long and short sleep days, and (3) a group with patterns relatively similar to cognitively normal individuals.

These results indicate that non-invasive sleep monitoring of AD patients, even those with the slightest concern about sleep disturbances, may allow early detection of conditions that differ from the norm. Therefore, early responses based on this evaluation may reduce the burden on the patient and caregivers.

Our findings regarding long nocturnal sleep in individuals with AD are consistent with previous studies[8)-10)]. In particular, Wams[9)] reported that individuals with moderate AD living in the community exhibited significantly longer nocturnal sleep than cognitively normal individuals and those with amnestic mild cognitive impairment. This finding suggests a possible link between cognitive decline and altered sleep patterns.

We also identified a subgroup of participants with AD who displayed large day-to-day fluctuations in sleep duration. Fenton[21)] and McCurry[22)] reported that high variability in N-TST may be associated with

AD pathology, which is a clinically important observation.

In contrast, earlier studies have often emphasized frequent nocturnal awakenings or short sleep duration as the primary sleep issues in AD[6)-8)]. The lack of such cases in our study may reflect the exclusion of participants with severe AD and the fact that our participants were not hospitalized or institutionalized primarily for AD.

Using the same measurement method as in our study, Higami[8)] reported both long sleep duration and frequent nocturnal awakenings among patients with AD. However, their study included individuals admitted to dementia treatment wards for sleep disturbances or severe behavioral and psychological symptoms of dementia, where overt sleep disturbances are more prevalent. By contrast, our study, which was conducted in general hospital wards and long-term care facilities, excluded such cases. Consequently, all AD participants in our study were assessed as having only mild nighttime behavioral issues on the NPI-NH.

This study has several limitations. The first is the effect of sample bias due to small sample sizes in both the AD and CN groups, and the fact that the AD group included neither men nor persons with severe AD, which challenges generalizability. In addition, since most of the AD subjects who had significant long nocturnal sleep had low mobility, the observed influence of low mobility on long nocturnal sleep among AD subjects cannot be ruled out. Furthermore, the diagnosis of AD patients was not confirmed by amyloid-beta testing, but only by medical records, which may include patients who are not true AD patients. Second, only nocturnal sleep was evaluated, and the relationship with PSG data and daytime activity level was not examined. These findings are essential to reflect the results of this study in the care strategy for individual AD patients, which is a remaining issue. Third, the bed sensor system may have misclassified quiet wakefulness in bed as sleep, potentially overestimating TST. However, comparisons with CN participants using the same device still revealed longer sleep duration in the AD group, suggesting that the observed difference reflects a genuine trend. Fourth, the bed sensor system failed to detect sleep outside the bed during the night. Nonetheless, regular nursing and caregiving rounds confirmed participants' positions and sleep status, and no participants were found sleeping outside their beds at night, minimizing this limitation.

V Conclusion

This study demonstrated that long-term, non-invasive sleep monitoring in individuals with AD can reveal several distinct patterns of mild nocturnal sleep disturbances. In addition to the frequently reported issues of nocturnal awakenings and short sleep duration, we identified patterns characterized by long sleep duration and high day-to-day variability.

In the future, it is necessary to validate these findings by increasing the sample size and improving research methods.

Acknowledgements

The authors would like to thank all the participants in this study.

Disclosure of potential conflicts

All authors declare that they have no conflicts of interest

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(2025. 9. 29 received ; 2025. 11. 20 accepted)