Objective Evaluation of Sleep Disturbances in Older Adults with Cognitive Impairment Using a Bed Sensor System and Self-Organizing Map Analysis

Tomoko Kamimura[1][a], Risa Otsuka[1], Asaka Domoto[1], Hikofumi Suzuki[2] and Mamino Tokita[3]
[1]*Department of Health Sciences, Graduate School of Medicine, Shinshu University, 3-1-1 Asahi, Matsumoto, Japan*
[2]*Department of Cyber Science Infrastructure Development, National Institute of Informatics, Tokyo, Japan*
[3]*Department of Global Centre for Advanced Research on Logic and Sensibility, Keio University Tokyo, Japan*

Keywords: Sleep Disturbance, Total Sleep Time, Cognitive Impairment, Alzheimer's Disease, Self-Organizing Map.

Abstract: Bed sensor systems are useful for measuring sleep states in cognitively impaired older adults because they can measure unrestrained individuals. However, there are no criteria for identifying sleep abnormalities using them. We developed a method to determine sleep abnormalities by analysing data collected by a bed sensor system using a self-organizing map (SOM). In this study, the sleep states were measured in two cognitively impaired care-facility residents. These recordings were used to calculate total nocturnal sleep time, wake time after sleep onset, frequency of leaving the bed, and frequency of awakening in the bed for each day. The data from these four variables were used to draw an SOM for each individual's sleep state to identify normal or abnormal sleep days. We visually determined whether a main cluster was formed in the SOM. If a main cluster was formed, the days included in the main cluster were defined as the individual's normal days, while other days were defined as the individual's abnormal days. The above parameters were independently compared between the two groups, as determined by the SOM. The characteristics of abnormal sleep days identified by SOM could be explained using these four variables, suggesting the effectiveness of identifying abnormal days by SOM.

1 INTRODUCTION

Sleep disturbances in older adults with cognitive impairment adversely affect health status and increase the burden on caregivers (Webster 2020a; Okuda 2019; Shi 2018). In addition, it has been noted that sleep disturbances may exacerbate brain damage (Irwin 2019; Nedergaard 2020). Therefore, early detection and management of sleep disturbances are important for not only maintaining the quality of life (QOL) of older adults and their caregivers but also for maintaining the health care system.

Sleep disturbances in older adults with cognitive impairment have been estimated to range from 20% to 70% (Guarnieri 2012; Wilfling 2019; Webster 2020b), depending on the assessment method. A meta-analysis of studies using validated proxy questionnaires found a pooled prevalence of sleep disturbance of 20% (95% confidence interval [CI 16%-24%) among cognitively impaired individuals living in care homes.

Sleep assessment methods other than proxy questionnaires include validated self-assessment questionnaires, polysomnography, and wearable actigraphy. However, these methods are often inadequate when individuals are very old or cognitively impaired because the results are unreliable or burdensome to the individuals.

To solve this problem, the sleep state of cognitively impaired older individuals has been measured using a bed sensor system that measures sleep state without restraining the individual, and abnormalities, such as frequency of leaving the bed and prolonged or shortened total sleep time, have been identified (Higami 2018). However, the characteristics of these sleep states vary depending on the measurement index, and the lack of criteria for comprehensively determining abnormalities within

[a] https://orcid.org/0000-0003-2973-2064

Kamimura, T., Otsuka, R., Domoto, A., Suzuki, H. and Tokita, M.
Objective Evaluation of Sleep Disturbances in Older Adults with Cognitive Impairment Using a Bed Sensor System and Self-Organizing Map Analysis.
DOI: 10.5220/0012715000003756

In *Proceedings of the 13th International Conference on Data Science, Technology and Applications (DATA 2024)*, pages 253-258
ISBN: 978-989-758-707-8; ISSN: 2184-285X

and between individuals remains a challenge.

To tackle this issue, we developed a method to detect abnormalities by analysing data measured by a bed sensor system with a self-organizing map (SOM), which is an unsupervised learning clustering method of artificial intelligence (AI). The SOM is a two-dimensional plot of data; the shorter the distance between the data, the higher the similarity of the data. The reason for using this method is that it is suitable for comparing the similarity of data with multidimensional features in an exploratory manner.

In this study, to obtain basic data for the development of a method for the detection of sleep abnormalities in cognitively impaired older adults using a bed sensor system and SOM analysis, we detected abnormalities based on the similarity of sleep states within individuals using SOM to extract their characteristics and confirm whether these abnormalities can be expressed using conventional sleep indicators.

2 METHODS

2.1 Participants

Participants of this study were residents of a geriatric healthcare facility in Japan. The inclusion criteria were (1) a cognitive function score validated by the Japanese Ministry of Health, Labor and Welfare (Tago 2021) of II b (i.e., symptoms, behaviours, and communication difficulties that interfere with daily life are sometimes observed at home, but the patient can be independent if someone pays attention to them) or worse; (2) the need to monitor sleep and leave the bed during the night and use a bed sensor system; and (3) sleep data had been collected for at least 21 consecutive days.

2.2 Equipment

The bed sensor system used in this study was a Nemuri Scan (Paramount Bed Corporation), which was installed under the bed mattress. Equipped with a highly sensitive pressure sensor, the system detects the body movements of the examinee on the bed through a mattress and calculates an activity score every minute that reflects the intensity and frequency of body movements, excluding movements caused by respiration and heartbeats. Nemuri Scan uses a proprietary algorithm to detect one of three states per minute: the examinee leaves the bed, awakens in the bed, or sleeps in the bed.

These results are directly output as comma separated value (CSV) files, as well as daily sleep indices, such as total sleep time and time awake after falling asleep, calculated from the data. The validity of these indicators has already been verified (Kogure 2011). Only the CSV data were used in this study.

2.3 Data Analysis

An SOM was created using CSV data from 6:00 p.m. to 8:00 a.m. during the measurement period for each individual. Days with missing CSV values during the measurement period were excluded from the analysis. Four variables (see Table) were calculated daily using the CSV data: total nocturnal sleep time, wake time four values were used to determine the SOM as the sleep state of the day.

In the SOM, we visually determined whether the main cluster, which accounts for the majority of the data, was formed, and defined days included in the main cluster as the individual's normal sleep days and days not included in the main cluster as the individual's abnormal sleep days. R studio ver. 1.3.1093. was used to create the SOM.

To confirm whether the abnormalities detected by the SOM can be expressed using conventional sleep indicators, the values of each of the above four variables were compared between the two groups of normal and abnormal sleep days in each case, as determined by the SOM. Comparisons between the two groups were made using the Mann–Whitney U test, and a p-value <0.05 was considered statistically significant using SPSS ver. 26.

Table 1: Four variables were calculated daily using the CSV data.

Total nocturnal sleep time	Total minutes between 6:00 and 8:00 a.m. that were judged to be sleeping in the bed.
Wake time after sleep onset (WASO)	Total minutes during nocturnal sleep when judged to leave the bed or be awake in the bed.
Frequency of leaving the bed	Number of times the patient left the bed during nocturnal sleep.
Frequency of awaking in the bed	Number of times the condition awakened in the bed minus the number of times the condition left the bed during nocturnal sleep.

2.4 Ethical Consideration

This study was approved by the Medical Ethics Committee of Shinshu University School of Medicine.

3 RESULTS

Data were collected from a 97-year-old woman for 28 days (case A) and a 91-year-old man for 51 days (case B). There was 1 day of missing data in each case during the measurement period, and the data of that day were excluded from the analysis. The purpose of using the Nemuri scan was as follows. Case A was at risk of falling due to anaemia, cognitive decline, and a history of hip fracture, and required monitoring the transfer of a portable toilet at night. Case B was at risk of falling or getting lost when going to the toilet at night due to Alzheimer's disease and a history of lumbar spinal stenosis and needed to be monitored when going to the toilet at night. The main cluster was formed in the SOM for case A (Figure 1). This cluster consisted of data from 20 normal sleep days. Eight abnormal sleep days fell outside the cluster.

The median (interquartile range) of total nocturnal sleep time, WASO, frequency of leaving the bed, and frequency of awakening in the bed on the abnormal days in case A were 570.0 (482.5-602.5) minutes, 103.0 (69.8-121.8) min, 2.0 (0.5-3.8) times, and 11.0 (6.0-12.8) times, respectively. The median of each of the four variables on abnormal days was lower than that on normal days ($p<0.01$, Figure 1).

The main cluster was also formed in the SOM of Case B (Figure 2). This cluster consisted of data from 35 normal sleep days. There were 16 abnormal sleep days outside this cluster.

The median (interquartile range) of total nocturnal sleep time, WASO, frequency of leaving the bed, and frequency of awakenings in the bed on the abnormal days of case B were 432.0 (379.3-515.0) minutes, 196.5 (156.0-258.5) minutes, 8.5 (6.0-11.8) times, and 14.0 (7.8-24.8) times, respectively. The median total nocturnal sleep time, WASO, and frequency of leaving the bed on abnormal days were significantly worse than those on normal days ($p<0.05$, $p<0.01$, $p<0.01$, respectively). respectively, Figure 2).

Since several clusters were found in the abnormal days group in case B, we performed a supplementary analysis comparing the status of the four variables in the three subgroups (B1, B2, and B3; Figure 3).

All three subgroups had longer WASO than the normal group, but the days belonging to B1 were characterized by the longest WASO, with relatively more frequent leaving the bed and awakening in the bed. The days belonging to B2 were characterized by the most frequent leaving the bed and less frequent awakening in the bed, and the days belonging to B3 were characterized by less frequent leaving the bed and most frequent awakening in the bed.

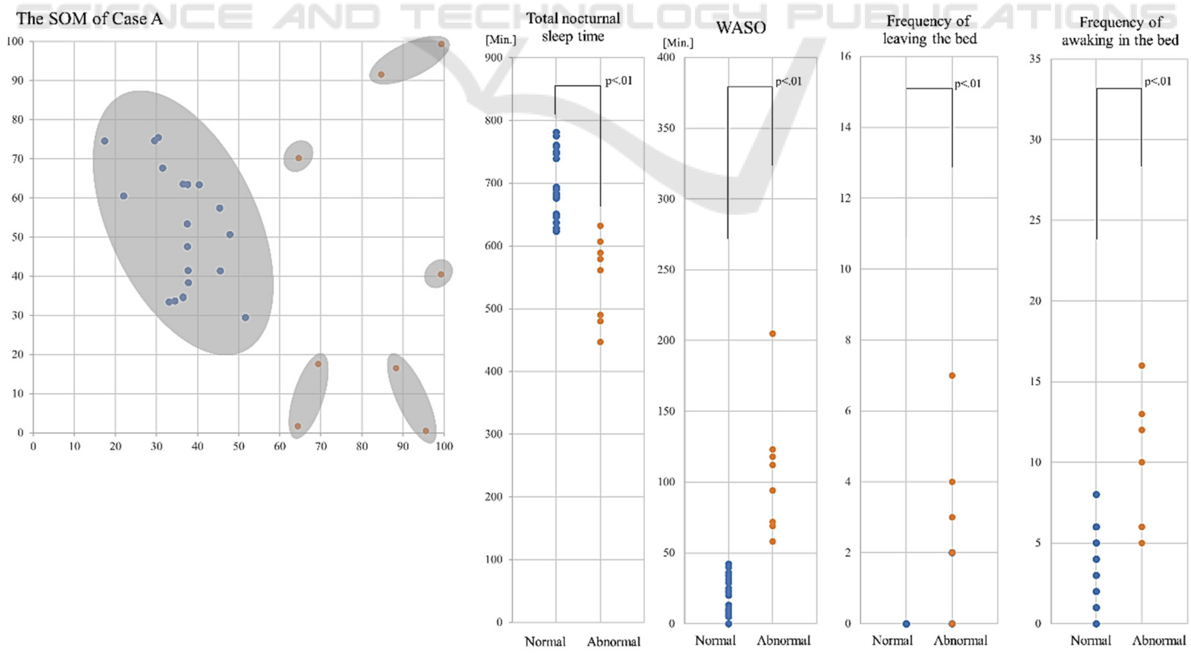

Figure 1.

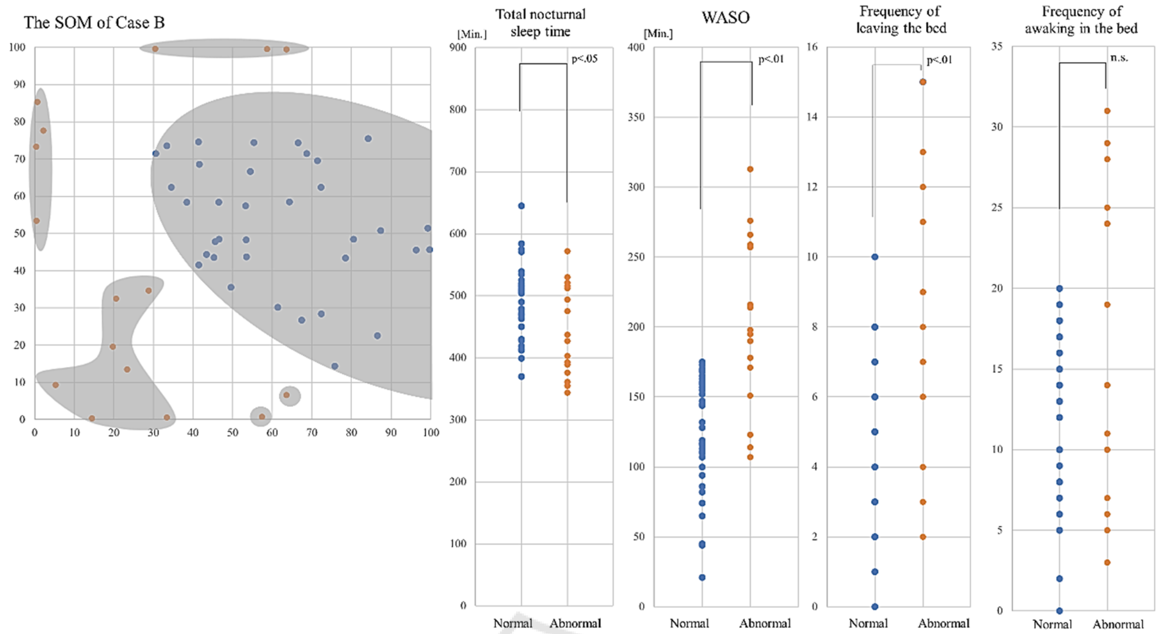

Figure 2.

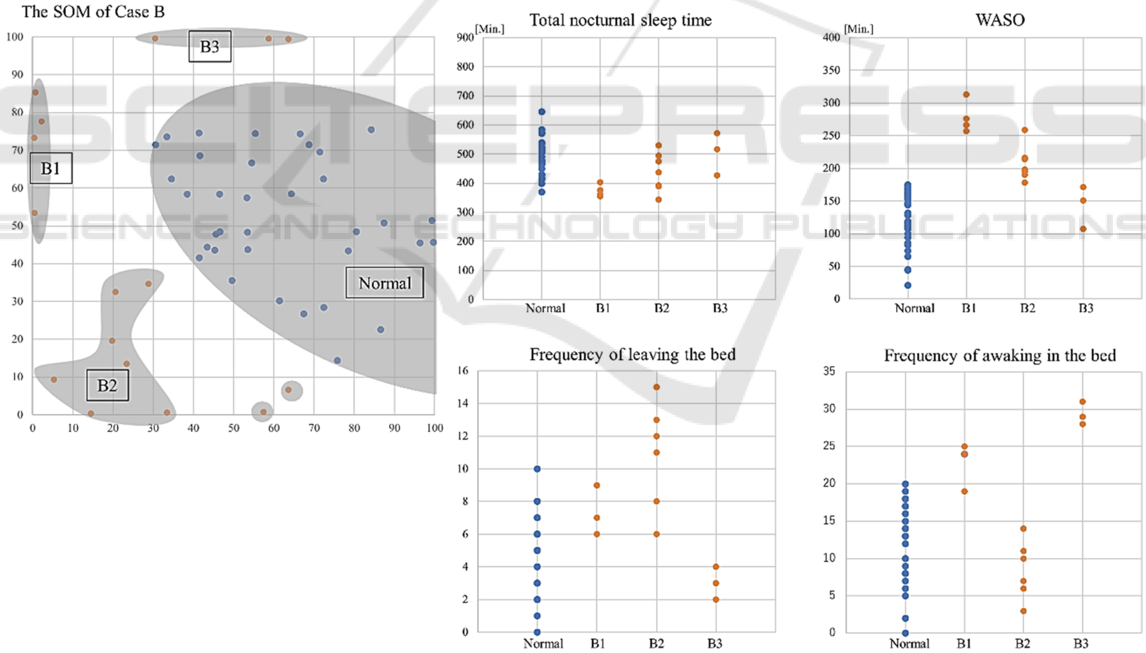

Figure 3.

4 DISCUSSIONS

This study suggests that it is possible to detect abnormal sleep days in older adults with cognitive impairment by measuring using a bed sensor system and performing SOM analysis of the data. We determined that it is possible to simultaneously detect abnormalities in individuals with multiple patterns of abnormalities, such as in case B in this study. Furthermore, the abnormalities discriminated by SOM analysis could be explained by comparing several conventional sleep measures, suggesting the validity of the SOM analysis results.

Previous studies have shown that sleep disturbances in older adults with dementia are characterized by frequent leaving the bed (Higami 2018), prolonged or shortened total sleep time (Higami 2018), decreased sleep efficiency (Cote 2021), and greater inter-daily circadian variability (Cote 2021). Another study reported the characteristics of sleep disturbances that vary according to the cause of cognitive impairment (Fukuda 2022), dementia severity (Blytt 2021), and the presence or absence of complications such as pain and depression (Blytt 2021). However, to the best of our knowledge, this is the first study to detect abnormal days based on intra-individual sleep variability in an older adult with cognitive impairment who had sleep problems and showed that there are different types of abnormalities from day to day.

In the future, we would like to investigate the relationship between the disease and sleep disturbances, such as whether the characteristics of nocturnal sleep shown in case B of Alzheimer's disease in this study indicate variability other than the diurnal variability of the circadian rhythm, which is one of the characteristics of this disease.

One limitation of this study was the small number of individuals in whom abnormal sleep was detected. Therefore, it is necessary to verify the reliability of our findings by including a greater number of older adults with cognitive impairments in subsequent studies.

Another limitation is that the state of normal sleep is not necessarily generally normal since the study focused on the detection of abnormalities.

An important limitation of our measurement is that it is unable to detect sleep disturbances in individuals immediately after the start of data collection because a certain amount of data accumulation is required to detect abnormal sleep. To address this issue, we are currently investigating the possibility of extracting standard sleep patterns by accumulating data from multiple cases, including older adults without cognitive impairment, and conducting an SOM analysis. If this standard pattern can be extracted, it may lead to the early detection of abnormalities in each individual by comparison with the standard pattern.

5 CONCLUSIONS

The characteristics of abnormal sleep days identified by SOM could be explained using these four variables i.e. total nocturnal sleep time, wake time after sleep onset, frequency of leaving the bed, and frequency of awakening in the bed for each day suggesting the effectiveness of identifying abnormal days by SOM. Using SOM analysis, we also showed that there are different abnormalities from day to day in older adults with cognitive impairment.

REFERENCES

Blytt, K. M., Flo-Groeneboom, E., Erdal, A., Bjorvatn, B., & Husebo, B. S. (2021). Sleep and its association with pain and depression in nursing home patients with advanced dementia - across-sectional study. *Frontiers in psychology*, 12, 633959.

Cote, A. C., Phelps, R. J., Kabiri, N. S., Bhangu, J. S., & Thomas, K. K. (2021). Evaluation of wearable technology in dementia: a systematic review and meta analysis. *Frontiers in medicin*e, 7, 501104.

Fukuda, C., Higami, Y., Shigenobu, K., Kanemoto, H., & Yamakawa, M. (2022). Using a non-wearable actigraphy in nursing care for dementia with Lewy Bodies. *American journal of Alzheimer's disease and other dementias*, 37, 15333175221082747.

Guarnieri, B., Adorni, F., Musicco, M., Appollonio, I., Bonanni, E., Caffarra, P., Caltagirone, C., Cerroni, G., Concari, L., Cosentino, F. I., Ferrara, S., Fermi, S., Ferri, R., Gelosa, G., Lombardi, G., Mazzei, D., Mearelli, S., Morrone, E., Murri, L., Nobili, F. M., Sorbi, S. (2012). Prevalence of sleep disturbances in mild cognitive impairment and dementing disorders: a multicenter Italian clinical cross-sectional study on 431 patients. D*ementia and geriatric cognitive disorders*, 33, 50–58.

Higami, Y., Yamakawa, M., Shigenobu, K., Kamide, K., & Makimoto, K. (2019). High frequency of getting out of bed in patients with Alzheimer's disease monitored by non-wearable actigraphy. *Geriatrics & gerontology international*, 19, 130–134.

Irwin, M. R., & Vitiello, M. V. (2019). Implications of sleep disturbance and inflammation for Alzheimer's disease dementia. *The Lancet. Neurology*, 18, 296–306.

Kogure, T., Shirakawa, S., Shimokawa, M., & Hosokawa, Y. (2011). Automatic sleep/wake scoring from body motion in bed: validation of a newly developed sensor placed under a mattress. *Journal of physiological anthropology*, 30, 103–109.

Nedergaard, M., & Goldman, S. A. (2020). Glymphatic failure as a final common pathway to dementia. *Science* (New York, N.Y.), 370, 50–56.

Okuda, S., Tetsuka, J., Takahashi, K., Toda, Y., Kubo, T., & Tokita, S. (2019). Association between sleep disturbance in Alzheimer's disease patients and burden on and health status of their caregivers. *Journal of neurology*, 266, 1490–1500.

Shi, L., Chen, S. J., Ma, M. Y., Bao, Y. P., Han, Y., Wang, Y. M., Shi, J., Vitiello, M. V., & Lu, L. (2018). Sleep disturbances increase the risk of dementia: a systematic review and meta-analysis. *Sleep medicine reviews*, 40, 4–16.

Tago, M., Katsuki, N. E., Yaita, S., Nakatani, E., Yamashita, S., Oda, Y., & Yamashita, S. I. (2021). High inter-rater reliability of Japanese bedriddenness ranks and cognitive function scores: a hospital-based prospective observational study. *BMC geriatrics*, 21, 168.

Webster, L., Powell, K., Costafreda, S. G., & Livingston, G. (2020a). The impact of sleep disturbances on care home residents with dementia: the SIESTA qualitative study. *International psychogeriatrics*, 32, 839–847.

Webster, L., Costafreda Gonzalez, S., Stringer, A., Lineham, A., Budgett, J., Kyle, S., Barber, J., & Livingston, G. (2020b). Measuring the prevalence of sleep disturbances in people with dementia living in care homes: a systematic review and meta-analysis. *Sleep*, 43, zsz251.

Wilfling, D., Dichter, M. N., Trutschel, D., & Köpke, S. (2019). Prevalence of Sleep Disturbances in German Nursing Home Residents with Dementia: A Multicenter Cross-Sectional Study. *Journal of Alzheimer's disease* : JAD, 69, 227–236.