Scientific Reports

https://doi.org/10.1038/s41598-026-38584-7

Article in Press

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Received: 3 June 2025

Accepted: 30 January 2026

Published online: 05 February 2026

Cite this article as: Miyata S., Iwamoto K., Kawai K. *et al.* Telemonitored sleep quality and daily activity are associated with mental health outcomes among Japanese workers. *Sci Rep* (2026). https://doi.org/10.1038/s41598-026-38584-7

**Seiko Miyata, Kunihiro Iwamoto, Keita Kawai, Hiroshige Fujishiro, Kazuyuki Nakagome, Norio Ozaki & Masashi Ikeda**

**Telemonitored sleep quality and daily activity are associated with mental health outcomes among Japanese workers**

Seiko Miyata[1]*, Kunihiro Iwamoto[1], Keita Kawai[2, 3], Hiroshige Fujishiro[1], Kazuyuki Nakagome[4],

Norio Ozaki[2], and Masashi Ikeda[1]

[1] Department of Psychiatry, Nagoya University Graduate School of Medicine, Nagoya, Japan,

[2] Pathophysiology of Mental Disorders, Nagoya University, Graduate School of Medicine, Nagoya, Japan

[3] Department of Psychiatry and Psychotherapy, Medical Center - University of Freiburg, Faculty of Medicine, University of Freiburg, Freiburg, Germany

[4] Department of Psychiatry, National Center of Neurology and Psychiatry, Kodaira, Japan, c

*Corresponding Author:

Seiko Miyata, PhD

Department of Psychiatry, Nagoya University Graduate School of Medicine

Email: miyata.seiko.v4@f.mail.nagoya-u.ac.jp

Tel: +81-52-744-2282

**Abstract**

Reports on the relationship between the sleep/activity cycle and mental health exist. However, self-reported sleep/activity evaluations are ambiguous; thus, objective evaluations are needed. We objectively examined the relationships between sleep parameters, daily activity levels, and mental health outcomes among 81 Japanese adults. Each participant wore a Fitbit Sense 2 for five days to monitor daily activity and underwent one night of sleep electroencephalography. Distress, anxiety, depression, harm avoidance, and sleep symptoms were assessed using questionnaires. Sleep metrics included total sleep time (TST), sleep onset latency (SOL), sleep efficiency (SE), and sleep stages. Subjective ratings of daily sleep-restorativeness were also collected. Longer SOL correlated with higher distress and life interference scores, whereas SE was negatively associated with distress interference. Decreased N2 sleep was linked to elevated anxiety and depression, while increased N3 sleep correlated with lower harm avoidance. A higher TST was associated with reduced insomnia severity. Vigorous activity was associated with lower harm-avoidance scores. Ratings of restorativeness were positively related to vigorous activity and mental health outcomes.  These findings suggest associations between objective sleep metrics, physical activity, and mental health, which may inform future approaches to mental health assessment.

**Keywords**: home sleep monitoring, mental health, sleep disturbance, restorative sleep, daily activity

## Introduction

The coronavirus disease (COVID-19) pandemic has affected global populations, dramatically changing daily routines and public health systems worldwide. From its early stages, restrictive measures such as lockdowns, social distancing mandates, and shifts to remote working have significantly altered individuals' lifestyles worldwide [1, 2]. While these measures were crucial for curbing the spread of the virus, they also led to notable changes in sleep patterns, physical activity levels, and mental well-being. These challenges have highlighted the urgent need for accessible and scalable mental health and sleep care interventions.

Telemedicine also emerged as an important alternative for providing health care services during the pandemic. Beyond improving access to sleep care, telemedicine plays a critical role in addressing mental health problems such as depression and anxiety, which are closely intertwined with sleep disturbances [3]. Particularly, telemedicine provides an avenue for early identification and timely intervention in sleep disturbances and psychological distress, especially in populations that are unable to access traditional care settings.

Several online surveys have investigated the relationship between sleep and mental health during the pandemic. For example, according to an online survey in China, sleep disturbance caused by COVID-19 involves multiple dimensions, such as age, female sex, stress, and urban residency [4]. Furthermore, complete isolation from society, such as lockdowns, can easily lead not only to irregular sleep rhythms but also to heightened psychological distress [4, 5]. Given these observations, examining mental health indicators alongside sleep patterns is essential to clarify how daily sleep and activity influence overall well-being.

Cross-cultural studies further highlight the significance of this issue in Japan. A survey of 4,933 people in 20 countries revealed that Japanese individuals experienced the shortest average sleep duration, averaging 6 hours and 18 minutes [6]. A decrease in sleep duration—especially when accompanied by reduced working hours—was strongly associated with increased psychological distress [7]. Annual Health and Productivity Management survey data in Japan show that better employee sleep and exercise habits reduce mental health-related absenteeism and turnover, with a 1% increase in good sleep habits linked to a 0.02% drop in turnover [8]. These findings indicate that Japanese workers' sleep and mental health are influenced by a multitude of factors, including the environment, the frequency of telework, lifestyle, and psychological factors.

Despite these insights, most prior studies have relied on self-reported sleep data, which are limited by recall bias and subjective perception errors. Symptoms of depression and insomnia, for example, often cause individuals to underestimate their actual sleep duration or quality [9, 10]. To address these limitations, recent technological advances—such as wearable sensors and single-channel electroencephalography (EEG)—now enable objective and continuous assessment of sleep and activity in naturalistic environments [11-13]. These developments provide an unprecedented opportunity to clarify the true relationships among sleep, daily activity, and mental health.



The present study aims to fill this critical gap by leveraging objective sleep and activity measurements alongside psychological assessments in a sample of Japanese workers. By integrating real-world physiological and behavioral data, this study examines associations between objectively measured sleep, daily activity, and mental health. The data were collected during the COVID-19 pandemic; however, because no pre-pandemic or non-pandemic comparison data were available, the pandemic is treated solely as the contextual background for data collection rather than as a factor under investigation. This approach provides descriptive insights into the relationships between objectively measured sleep, activity, and psychological well-being.

## Methods

### Participants

Overall, 81 adults were recruited for this study between November 2020 and March 2024. During this period, there was no lockdown in Japan. However, there were restrictions on daily life, including patient isolation and movement restrictions. Recruitment for this study was conducted in the university location and neighboring cities among university workers and previous study participants. Health interviews and the Structured Clinical Interview for the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) [14] confirmed that none of the participants had physical or psychiatric disorders at enrollment. The inclusion criteria were as follows: (1) no history of mental disorders, (2) absence of severe physical illness that could disrupt normal sleep patterns, (3) no reported difficulties in daily life, (4) no experience as current and/or former night shift or nighttime worker, (5) no prior diagnoses of insomnia or circadian rhythm sleep-wake disorder, and (6) ability to voluntarily provide informed consent.

**Ethics declaration**

The experimental protocols were approved by the Nagoya University Ethics Review Committee (Approval No. 2010-0930) and conformed to the provisions of the Declaration of Helsinki (revised in Brazil, 2013). All participants agreed to the purpose and procedures of this study and provided written consent prior to participation. All participant data were anonymized before processing.

**Procedures**

Participants received instructions about the sleep EEG recorder, activity counter, and questionnaires, either in person or online. They were asked to wear the activity counter for at least five consecutive days, including weekends, and to perform a sleep EEG recording for any night during this period at the convenience of the participant. They were also asked to keep a record of their activities, including the times when they removed their Fitbit and any special events. The questionnaires were completed using an online platform.



**Sleep EEG**

Sleep data were recorded using a portable system (SleepGraph, Proassist Co., Japan) comprising EEG (Fp2-M1), electrooculogram (EOG), and mentalis muscle electromyogram (EMG) electrodes [15, 16]. The EOG electrode was placed approximately 1 cm outside and 1 cm below the left eye socket. Signals were recorded at a 128 Hz sampling frequency with 0.540 Hz filters. Amplified and filtered analog signals were converted to digital signals using a 14-bit A/D converter, transmitted to a bedside receiver, and stored for offline analysis. Initially, the artificial intelligence (AI) software (Sleep Diver, Proassist Co., Japan) evaluated the quality of the recorded data. Data that was identified as abnormal or noisy by the software, as well as data that was deemed unanalyzable by sleep technologists, were excluded from the analysis. The epoch-by-epoch agreement rate for sleep stage classification between the sleep technologist and the AI analysis was 85.33%, with a Cohen's kappa coefficient of 0.785, as provided by Proassist's technical documentation.

The sleep stages were initially identified by the AI software, manually reviewed, and finally determined by a well-trained sleep technologist. Sleep stage scoring adhered to the AASM Manual for the Scoring of Sleep and Associated Events [17]. Parameters included bedtime, wake-up time, mid-time of sleep period, total sleep time (TST), sleep onset latency (SOL), wake after sleep onset (WASO), sleep period time (SPT), sleep efficiency (SE = TST/total recording time × 100), and sleep stages (R, N1, N2, and N3). In this study, the proportion of each sleep stage was calculated using SPT. This was necessary because participants recorded their sleep EEG at home, so bedtime could not be controlled as in PSG [18]. It was also important to assess the time spent awake after sleep onset simultaneously. Participants were instructed to turn on the Sleep Graph before going to sleep and turn it off when they woke up. Thus, bedtime and wake-up time were defined as the times when the participants turned the Sleep Graph on and off, respectively. The total recording time (TRT) was defined as the period from when the device was powered on to when it was powered off. The median of these bedtime and wake-up times was defined as the mid-time of sleep period.

**Daily Activity**

Participants wore a Fitbit Sense 2 (Fitbit Inc, San Francisco, CA, USA) for five consecutive days, including at least two weekend days, to monitor physical activity. The participants recorded the periods when the device was removed (e.g., for charging) in a daily log. The Fitbit-defined metrics analyzed included "Total Activity" (moderate to vigorous activity time), "Vigorous Intensity Activity" (time in high-intensity activity), and "Moderate Intensity Activity" (time in moderate-intensity activity) following the World Health Organization (WHO) Guidelines on Physical Activity and Sedentary Behaviour [19]. Heart rate data were used to estimate the energy expenditure, including "Exercise Calorie Expenditure." Data sets exhibiting less than three days of activity were excluded from the analysis to ensure the integrity and validity of the results. Periods when the device was not worn were excluded, and activity data were normalized to hourly estimates based on device usage.

## Questionnaires

*The Distress and Impact Thermometer (DIT)*

The DIT assesses two dimensions: (1) distress severity, reflecting emotional or psychological discomfort and (2) impact, which measures the extent to which distress interferes with daily activities. Participants rated their experiences on a visual analog scale resembling a thermometer, capturing nuanced variations in emotional and functional states [20].

*The Patient Health Questionnaire-9 (PHQ-9)*

The PHQ-9 is a validated screening instrument for assessing depression severity. It comprises nine questions aligned with the DSM criteria for major depressive disorder [14]. Each question addresses symptoms such as mood changes, sleep disturbances, fatigue, and appetite. Responses are scored from 0 (not at all) to 3 (nearly every day), producing a total score of 0–27 points. Scores are categorized as minimal (0–4), mild (5–9), moderate (10–14), moderately severe (15–19), or severe (20–27) depression [21, 22].

*The State-Trait Anxiety Inventory-State* (STAI-S)

This scale, which is part of the STAI developed by Spielberger, evaluates transient anxiety symptoms (state anxiety) at a particular moment. It includes 20 items scored on a 4-point Likert scale ranging from 1 ("not at all") to 4 ("very much so"), capturing feelings such as nervousness, apprehension, and tension.

Higher scores indicate greater anxiety, providing insight into the participants' acute emotional state [23].

*The Temperament and Character Inventory-Harm Avoidance* (TCI-HA)

The TCI-HA assesses harm avoidance; a personality trait linked to sensitivity to adverse stimuli and behavioral inhibition. This dimension comprises four subscales: anticipatory worry, fear of uncertainty, shyness toward strangers, and fatigability. Each subscale evaluates specific traits, such as the tendency to worry excessively or avoid risks. Scores were categorized as low, moderate, or high, with higher scores indicating greater harm avoidance [24, 25].



*The Pittsburgh Sleep Quality Index* (PSQI)

The PSQI evaluates sleep quality over the preceding month and comprises seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. Each component is scored from 0 (no difficulty) to 3 (severe difficulty), producing a global score of 0–21. A global score >5 indicates poor sleep quality [26, 27].

*The Insomnia Severity Index (ISI)*

The ISI is a seven-item self-report tool for assessing insomnia severity. The items measure difficulty falling asleep, staying asleep, early waking, dissatisfaction with sleep, interference with daytime functioning, noticeability of sleep problems, and distress caused by sleep issues. Scores range from 0 to 28 and are categorized as no clinically significant insomnia (0–7), subthreshold insomnia (8–14), moderate insomnia (15–21), or severe insomnia (22–28) [28].

*The Hyperarousal Scale (HAS)*

This scale measures hyperarousal symptoms associated with conditions such as anxiety. It evaluates physiological and psychological symptoms, including heightened alertness, difficulty in concentrating, and exaggerated startle responses. Participants rated the severity or frequency of their symptoms on a Likert scale, with higher scores indicating greater hyperarousal [29, 30].



*Sleep restorativeness*

Participants also rated their sleep restorativeness (satisfaction with the quality of their sleep) on a scale of 1–10 scale, where 1 indicated the poorest sleep and 10 the best. The mean restorativeness was calculated for each participant during the study period.

**Statistical Analysis**

Categorical data are presented as case numbers and continuous variables as mean ± standard deviation. Data normality was assessed using the Shapiro–

Wilk test. Spearman's rank correlation coefficient was employed to examine the relationships between sleep EEG outcomes, daily activity, and mental/sleep health scales. When the correlation was significant, a generalized linear model was used to confirm the effect of TST on sleep rhythms. A general linear model was fitted using the standard least squares method, with questionnaire scores as the response and TST and bedtime as predictors. Statistical analyses were conducted using JMP (version 17, JMP Statistical Discovery LLC, Cary, NC, USA). Two-sided p-values $<0.05$ were considered statistically significant.

## Results

### Participant characteristics

The participants' demographics and background information are summarized in Table 1. Informed consent was obtained from 81 individuals (Fig. 1). One participant was excluded due to occupational commitments involving night shifts during the study period. Sleep EEG data collection was unsuccessful for 17 participants due to technical issues, including device failure, sensors dropping out in the middle, and forgetting to turn on the power. Sleep stage analysis was incomplete for seven participants due to excessive noise. This resulted in the inclusion of sleep EEG data from 56 participants (69.1%) in the final analysis. Fitbit activity records were insufficient for analysis in 10 cases due to malfunction or forgetting to wear the Fitbit, and one participant was unable to wear it, leaving data from 69 participants (85.1%) for analysis. Questionnaire data were available for 79 participants (97.5%), excluding one case with partially missing responses.

**Relationship between Sleep EEG Outcomes and Mental/Sleep Health Scales**

The analysis revealed significant associations between various sleep EEG parameters and mental/sleep health scores (Table 2 and 3). Late bedtime was significantly correlated with an increase in STAI-S ($\rho = 0.30$, $p = 0.024$); this relationship was not affected by TST ($\beta = 0.0004$, standard error = 0.0002, t value = 2.26, $p = 0.028$). A longer SOL was correlated with higher DIT distress ($\rho = 0.28$, $p = 0.034$) and DIT impact scores ($\rho = 0.33$, $p = 0.010$), while reduced SE was negatively correlated with DIT impact scores ($\rho = -0.31$, $p = 0.017$). A decrease in Stage N2 sleep was associated with increases in STAI-S ($\rho = -0.29$, $p = 0.028$) and PHQ-9 ($\rho = -0.26$, $p = 0.049$) scores. Conversely, an increase in Stage N3 sleep was linked to a decrease in TCI-HA scores ($\rho = -0.39$, $p = 0.002$) and showed a significant relationship with HAS ($\rho = -0.30$, $p = 0.022$). Longer TST was correlated with lower ISI scores ($\rho = -0.26$, $p = 0.043$).

**Relationship between Daily Activity and Mental/Sleep Health Scales**

As shown in Table 4, daily vigorous-intensity activity was significantly associated with lower scores on the TCI-HA scale ($\rho = -0.35$, $p = 0.002$). No significant correlations were observed between the other daily activity metrics and the remaining mental and sleep health scales.

**Relationship between Restorativeness and Sleep EEG Outcomes, Daily Activity, and Mental/Sleep Health Scales**

The correlation analysis summarized in Table 5 indicates no significant associations between restorativeness ratings and sleep EEG outcomes. However, daily moderate-intensity activity was negatively correlated with higher restorativeness scores ($\rho = -0.26$, $p = 0.025$). Among the mental health scales, all except the TCI-HA scale showed significant negative correlations with restorativeness, including the DIT distress scale ($\rho = -0.42$, $p < 0.0001$), the DIT impact scale ($\rho = -0.48$, $p < 0.0001$), the PHQ-9 scale ($\rho = -0.62$, $p < 0.0001$), and the STAI-S scale ($\rho = -0.49$, p.< 0.0001). Similarly, significant negative correlations were observed between sleep health scales and restorativeness including the PSQI ($\rho = -0.45$, $p < 0.0001$), the ISI ($\rho = -0.45$, $p < 0.0001$), and HAS ($\rho = -0.36$, $p = 0.001$).

## Discussion

We explored the relationship between mental and sleep health, objective sleep measures, and daily activity levels in Japanese workers. The results indicated significant associations between objective sleep metrics and distress levels, whereas vigorous activity was linked to a harm-avoidance character. Notably, restorativeness demonstrated significant correlations with mental health scales and daily activity levels. These findings suggest relationships between physiological sleep patterns, activity levels, and perceived mental well-being, and may point to the potential utility of remote sleep and activity monitoring as a non-invasive approach. The findings should be interpreted as associations observed within the specific contextual setting because the data were collected during the COVID-19 pandemic without pre-pandemic comparison.

The correlation between sleep EEG outcomes and mental/sleep health scales revealed notable associations that aligned with prior research on the impact of the pandemic on sleep and mental health. For example, one cohort study in Canada reported a significant worsening of sleep quality, fatigue, anxiety, and depression during the pandemic compared with pre-pandemic levels [31]. A Japanese study observed significant delays in sleep phase timing during the pandemic, with greater delays observed among students than among workers [32]. Similar associations have also been described outside the context of the pandemic, including findings indicating that delayed sleep phase is linked with increased anxiety [33] and that patients with insomnia show higher HAS scores reflecting reduced deep sleep [34, 35]. Since our study was cross-sectional and did not include longitudinal pre-/post-pandemic comparisons, causal inferences about the impact of the COVID-19 pandemic cannot be drawn. Instead, these prior studies are cited as contextual evidence demonstrating that the associations we observed are consistent with a broader body of literature linking sleep characteristics and mental health. These findings suggest a robust relationship between sleep and mental health across different populations and contexts. The current study extends this evidence by providing objective sleep measurements to complement previous self-reported findings.

In our study, several specific sleep parameters showed significant associations with psychological measures. Later bedtimes and longer sleep onset latency were linked with greater states of anxiety and distress, consistent with prior findings reporting that difficulty of initiating sleep contributes to emotional dysregulation [33, 36, 37]. Reduced sleep efficiency was also associated with higher DIT impact, reflecting the broader impact of fragmented sleep on daily functioning. Importantly, stage-specific differences emerged: decreased N2 sleep was related to higher anxiety and depressive symptoms, while increased N3 sleep was associated with lower harm avoidance and hyperarousal. These results are consistent with previous studies that have pointed out the association between increased light sleep and decreased deep sleep and mood disorders and personality traits [38, 39]. Our findings suggest that alterations in different non-rapid eye movement sleep stages may have distinct implications for psychological well-being. Furthermore, longer TST was associated with reduced insomnia severity, reinforcing the role of sufficient sleep duration as a protective factor. These results indicate that some aspects of sleep architecture—especially N2 and N3 sleep—may have specific relevance to mental health outcomes.

Restorativeness was significantly associated with moderate daily activity and various mental health scales but not with sleep EEG outcomes. This discrepancy highlights that subjective nonrestorative sleep and objective sleep parameters may capture different aspects of the sleep experience. Subjective nonrestorative sleep has consistently been linked to psychiatric symptoms and impairments in physical, cognitive, and emotional functioning [40]. Furthermore, data from the Sleep Heart Health Study showed that unrestful sleep along with objectively shorter sleep in middle-aged adults and along with longer time in bed in older adults were associated with an increased mortality risk [41], underscoring the independent relevance of sleep perception. Such findings suggest that misperception of sleep — often influenced by mental and sleep disorders [9, 42] — may explain why subjective restorativeness does not always align with EEG-derived outcomes. These results emphasize the importance of integrating subjective and objective sleep assessments: in research, to accurately characterize the complex relationship between sleep and mental health; and in at-home monitoring, to ensure that wearable devices providing only objective data are interpreted within the context of users' subjective experiences.

Harm-avoidance personality showed a significant negative correlation with both deep sleep and physical activity in this study. To the best of our knowledge, no study has reported an association between sleep and exercise habits and harm-avoidant personality. In the context of personality and polysomnography, high-level perfectionism showed increased arousal frequency and poor sleep quality on the first night of polysomnography [43]. The relationship between various personality traits and insomnia has also been well studied; particularly, neuroticism has been associated with insomnia severity and predicted future insomnia onset [44]. Our findings revealed that a harm-avoidant personality, characterized by heightened nervousness and future-oriented worry, was negatively correlated with deep sleep and physical activity, suggesting significant links between psychological disposition and physiological health outcomes.

Here, higher HASs were associated with reduced deep sleep and poorer subjective sleep restorativeness, consistent with previous reports showing elevated HAS in patients with insomnia [30, 34]. Although prior studies suggest group differences between patients with insomnia and controls, the reported score ranges vary considerably, and no standardized cutoff has been established. Therefore, HAS was interpreted as a continuous measure reflecting interindividual variability in hyperarousal.

One notable limitation of previous cohort studies is their complete reliance on subjective sleep duration, which is inherently prone to misperceptions. Our previous studies revealed that sleep structure, obstructive sleep apnea, and depression can significantly influence wake time and sleep perception, with sex differences and disease severity playing key roles in sleep time misestimation [9, 45]. Consequently, further research is required to validate the relationship between objective sleep metrics and perceived sleep quality, with careful consideration of the roles of mental- and sleep-related issues in this relationship.

This study found no significant correlations between daily activity levels and most mental or sleep health scales, except for the TCI-HA. Previous research has shown that the pandemic caused a substantial decrease in physical activity, with less active individuals experiencing the greatest reduction [46]. However, regular exercise has been found to alleviate depressive and anxiety symptoms [47]. The lack of significant associations in this study may indicate the unique characteristics of the study population, which comprised workers who maintained their regular routines.



Although night-to-night variability in sleep is well documented, previous research indicates that single-night at-home EEG recordings can still capture meaningful interindividual differences in objective sleep parameters. Several EEG-derived sleep biomarkers show moderate stability across nights, and intraindividual variability does not preclude the identification of stable between-person differences [48, 49]. Nevertheless, the present findings should be interpreted cautiously, as the recorded night may not fully reflect habitual sleep patterns.

This study has some limitations. First, as a cross-sectional study, causality cannot be established. Second, objective sleep was monitored only for a single night at the participants' convenience, which did not allow us to compare workday and free-day sleep patterns. Third, technical challenges, such as sensor malfunctions and excessive noise, limit the quality and quantity of sleep EEG data, underscoring the need for improved data collection protocols in non-laboratory settings. Sleep data obtained from Fitbit were not analyzed because their validity has not been fully established in populations with psychological or physiological conditions [50, 51] sand the current data were insufficient for reliable analysis. Fourth, although non-restorative sleep and the PSQI are correlated, they reflect distinct constructs—subjective restorativeness versus multidimensional sleep disturbance—and were analyzed separately to explore whether subjective sleep satisfaction provides unique insights into mental health. Then, previous longitudinal studies have shown that anxiety and depression symptoms fluctuated over time. During the COVID-19 pandemic, for instance, more stringent public health measures were associated with increased depressive and anxiety symptoms during lockdown periods in England [52]. In the present study, data were collected exclusively during the COVID-19 pandemic, and no pre-pandemic or non-pandemic comparison data were available. Although our study focuses on remote monitoring rather than direct pandemic effects, these temporal variations in mental health are a contextual limitation. Finally, the relatively small sample size may have limited statistical power, and the study population, which consisted of university-affiliated workers, may constrain the generalizability of the findings to broader populations. Despite these limitations, this study demonstrates the utility of combining self-reported measures with objective home monitoring for health assessments.

**Conclusions**

This study indicates the significant associations between objective sleep metrics and distress levels, and between vigorous activity and subjective restorativeness. We also observed the correlation between perceived restorativeness and mental and sleep health. These results suggest that integrating subjective restorativeness with objective activity and sleep data may help enhance the clinical value of at-home monitoring, offering insights beyond general activity tracking. However, given the modest sample size and cross-sectional design, the findings should be interpreted with caution. Further research with larger and more diverse populations is warranted to clarify the extent to which home-based monitoring can contribute to personalized health assessments and interventions.

**Data availability statement**

The datasets generated and/or analyzed during the current study are not publicly available because we did not get consent to provide data to a public database but are available from the corresponding author on reasonable request.

**Funding**

The JSPS KAKENHI (Grant Number 23K10934), AMED (Grant Number JP24zf0127011), JST CREST (Grant Number JP23gm1910005), and Aichi Health Promotion Foundation

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## Acknowledgments

This study was financially supported by grants from the JSPS KAKENHI (Grant Number 23K10934), AMED (Grant Number JP24zf0127011), JST CREST (Grant Number JP23gm1910005), and Aichi Health Promotion Foundation.



## Author Contributions

Authors S.M., K.I, K.N., and N.O. conceptualized the study. Authors S.M., K.I. and K.K. were involved in the data collection processes. Statistical analysis was done by S.M. and data interpretation was performed by S.M., K.I., K.K., H.F., N.K., N.O. and M.I. Writing of the initial draft was done by S.M. All the authors revised and approved the final draft.

## Competing Interests

The authors declare no competing interests

## Ethics approval

The experimental protocols were approved by the Nagoya University Ethics Review Committee (Approval No. 2010-0930) and conformed to the provisions of the Declaration of Helsinki (revised in Brazil, 2013). All participants agreed to the purpose and procedures of this study and provided written consent prior to participation. All participant data were anonymized before processing.

**Figure 1. Flow of participants through analysis**

EEG indicates electroencephalography.

**Tables**

**Table 1. Demographic and background characteristics of participants**

| Characteristic | Value | Data range |
|---|---|---|
| Sex (male, %) | 34 (41.9%) | |
| Age (years) | 38.21±11.88 | |
| BMI (kg/m2) | 22.04±3.41 | |
| Restorativeness | 6.42±1.40 | 2 - 9 |
| **Sleep EEG** (n=56) | | |
| Bedtime | 0:20±1:39 | |
| Wake-up time | 6:24±1:41 | |
| Mid-time of sleep period | 3:40±2:53 | |
| TST (min) | 335.91±88.28 | |
| SOL (min) | 25.42±29.66 | |
| WASO (min) | 13.23±20.20 | |
| SE (%TRT) | 87.19±11.39 | |
| Stage R, min (%SPT) | 76.33±30.69 (21.26±7.26) | |
| Stage N1, min (%SPT) | 19.60±18.25 (5.47±4.05) | |
| Stage N2, min (%SPT) | 166.53±55.05 (47.78±7.89) | |

| | | |
|---|---|---|
| Stage N3, min (%SPT) | 70.82±22.71 (21.24±7.40) | |
| **Activity counters** (n=69) | | |
| Exercise calorie expenditure (kcal/h) | 45.33±17.61 | |
| Total Activity (min/h) | 11.17±3.87 | |
| Moderate Intensity Activity (min/h) | 0.75±0.67 | |
| Vigorous Intensity Activity (min/h) | 1.16±2.06 | |
| **Mental health scales** (n=79) | | |
| DIT distress | 3.08±2.30 | 0 - 10 |
| DIT impact | 2.02±2.25 | 0 - 10 |
| PHQ-9 | 3.31±3.43 | 0 - 15 |
| STAI-S | 39.86±9.12 | 25 - 63 |
| TCI-HA | 10.67±4.95 | 0 - 19 |
| **Sleep health scales** (n=79) | | |
| ISI | 5.92±4.50 | 0 - 24 |
| HAS | 25.45±10.44 | 2 - 62 |
| PSQI | 5.25±3.18 | 0 - 16 |

Abbreviations: BMI, body mass index; EEG, electroencephalography, DIT, Distress and Impact Thermometer; STAI-S, State-Trait Anxiety Inventory-State; PHQ-9, Patient Health Questionnaire-9; TCI-HA, Temperament and Character Inventory-Harm Avoidance; PSQI, Pittsburgh Sleep Quality Index; ISI, Insomnia Severity Index; HAS, Hyperarousal scale; TST, total sleep time; SOL, sleep onset latency; WASO, wake after sleep onset; SE, sleep efficiency; TRT, total recording time; SPT, sleep period time.

**Table2. Correlation analysis of sleep EEG outcomes with mental health scales**

| n=56 | **DIT distress** | | **DIT impact** | | **STAI-S** | | **PHQ-9** | | **TCI-HA** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ρ | p value | ρ | p value | ρ | p value | ρ | p value | ρ | p value |
| Bedtime | 0.14 | 0.313 | 0.20 | 0.146 | **0.30** | **0.024** | 0.24 | 0.072 | 0.17 | 0.209 |
| Wake-up time | 0.10 | 0.447 | 0.15 | 0.256 | 0.17 | 0.199 | 0.08 | 0.536 | 0.04 | 0.780 |
| Mid-time of sleep period | 0.03 | 0.843 | 0.12 | 0.376 | 0.16 | 0.239 | 0.11 | 0.434 | 0.05 | 0.705 |
| TST | -0.07 | 0.591 | -0.09 | 0.507 | -0.17 | 0.202 | -0.20 | 0.133 | -0.12 | 0.356 |
| SOL | **0.28** | **0.034** | **0.33** | **0.010** | 0.24 | 0.065 | 0.12 | 0.355 | 0.12 | 0.339 |
| WASO | -0.03 | 0.825 | 0.03 | 0.792 | 0.002 | 0.988 | 0.13 | 0.306 | 0.16 | 0.218 |
| SE (%TRT) | -0.19 | 0.153 | **-0.31** | **0.017** | -0.21 | 0.115 | -0.19 | 0.154 | -0.24 | 0.066 |
| Stage R (min) | -0.10 | 0.458 | -0.16 | 0.232 | -0.08 | 0.513 | -0.22 | 0.094 | -0.09 | 0.502 |
| Stage R (%SPT) | -0.07 | 0.565 | -0.19 | 0.150 | 0.02 | 0.881 | -0.18 | 0.170 | -0.07 | 0.557 |
| Stage N1 (min) | 0.07 | 0.597 | 0.01 | 0.909 | 0.05 | 0.684 | 0.08 | 0.551 | 0.17 | 0.206 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stage N1（%SPT ） | 0.14 | 0.295 | 0.10 | 0.429 | 0.14 | 0.267 | 0.12 | 0.340 | 0.25 | 0.056 |
| Stage N2 (min) | -0.16 | 0.217 | -0.12 | 0.341 | **-0.29** | **0.028** | **-0.26** | **0.049** | -0.11 | 0.403 |
| Stage N2（%SPT ） | -0.17 | 0.194 | 0.003 | 0.980 | -0.20 | 0.119 | -0.22 | 0.091 | 0.002 | 0.989 |
| Stage N3 (min) | -0.01 | 0.917 | -0.09 | 0.472 | -0.16 | 0.227 | -0.05 | 0.665 | **-0.39** | **0.002** |
| Stage N3（%SPT ） | 0.18 | 0.175 | 0.12 | 0.341 | 0.11 | 0.380 | 0.16 | 0.213 | -0.23 | 0.082 |

Abbreviations: ρ: Spearman's rank correlation coefficient. EEG, electroencephalography, DIT, Distress and Impact Thermometer; STAI-S, State-Trait Anxiety Inventory-State; PHQ-9, Patient Health Questionnaire-9; TCI-HA, Temperament and Character Inventory-Harm Avoidance; TST, total sleep time; SOL, sleep onset latency; WASO, wake after sleep onset; SE, sleep efficiency; TRT, total recording time; SPT, sleep period time.

**Table3. Correlation analysis of sleep EEG outcomes with sleep health scales**

| n = 56 | **PSQI** | | **ISI** | | **HAS** | |
|---|---|---|---|---|---|---|
| | ρ | p value | ρ | p value | ρ | p value |
| Bedtime | 0.162 | 0.233 | 0.237 | 0.076 | 0.207 | 0.126 |
| Wake-up time | 0.008 | 0.953 | 0.063 | 0.642 | 0.077 | 0.573 |
| Mid-time of sleep period | 0.032 | 0.815 | 0.092 | 0.497 | 0.083 | 0.544 |
| TST | -0.25 | 0.058 | **-0.26** | **0.043** | -0.10 | 0.461 |
| SOL | 0.18 | 0.164 | 0.16 | 0.213 | 0.12 | 0.343 |
| WASO | -0.01 | 0.936 | 0.03 | 0.785 | 0.03 | 0.811 |
| SE (%TRT) | -0.19 | 0.145 | -0.17 | 0.196 | -0.13 | 0.315 |
| Stage R (min） | -0.17 | 0.192 | -0.23 | 0.075 | 0.01 | 0.914 |
| Stage R (%SPT） | -0.13 | 0.331 | -0.18 | 0.177 | 0.07 | 0.596 |
| Stage N1 (min) | -0.19 | 0.152 | -0.11 | 0.378 | 0.006 | 0.966 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Stage N1（%SPT） | -0.17 | 0.207 | -0.08 | 0.553 | 0.06 | 0.612 |
| Stage N2 (min) | -0.16 | 0.219 | -0.20 | 0.127 | -0.10 | 0.449 |
| Stage N2（%SPT） | 0.05 | 0.687 | -0.08 | 0.540 | -0.03 | 0.798 |
| Stage N3 (min) | -0.17 | 0.187 | -0.11 | 0.407 | **-0.30** | **0.022** |
| Stage N3（%SPT） | 0.04 | 0.731 | 0.13 | 0.312 | -0.12 | 0.356 |

Abbreviations: ρ: Spearman's rank correlation coefficient. EEG, electroencephalography, PSQI, Pittsburgh Sleep Quality Index; ISI, Insomnia Severity Index; HAS, Hyperarousal scale; TST, total sleep time; SOL, sleep onset latency; WASO, wake after sleep onset; SE, sleep efficiency; TRT, total recording time; SPT, sleep period time.

**Table 4. Correlation analysis of daily activity levels with mental and sleep health scales**

| **Mental health scales** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| n=69 | **DIT distress** | | **DIT impact** | | **PHQ-9** | | **STAI-S** | | **TCI-HA** | |
| | ρ | p value | ρ | p value | ρ | p value | ρ | p value | ρ | p value |
| Exercise calorie expenditure | 0.12 | 0.319 | 0.13 | 0.262 | 0.07 | 0.553 | 0.12 | 0.310 | -0.01 | 0.873 |
| Total activity | -0.004 | 0.974 | -0.02 | 0.850 | -0.05 | 0.669 | -0.003 | 0.976 | 0.14 | 0.215 |
| Moderate intensity activity | 0.01 | 0.925 | 0.03 | 0.807 | 0.07 | 0.553 | 0.04 | 0.719 | -0.20 | 0.081 |
| Vigorous intensity activity | -0.02 | 0.822 | 0.06 | 0.568 | -0.09 | 0.452 | -0.13 | 0.267 | **-0.35** | **0.002** |
| **Sleep health scales** | | | | | | | | | | |
| n=69 | **PSQI** | | **ISI** | | **HAS** | | | | | |
| | ρ | p value | ρ | p value | ρ | p value | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Exercise calorie expenditure | 0.01 | 0.911 | 0.04 | 0.686 | 0.03 | 0.764 |
| Total activity | -0.01 | 0.919 | 0.05 | 0.640 | -0.05 | 0.633 |
| Moderate intensity activity | 0.04 | 0.713 | -0.02 | 0.868 | -0.008 | 0.950 |
| Vigorous intensity activity | 0.03 | 0.762 | -0.08 | 0.460 | -0.01 | 0.909 |

Abbreviations: ρ, Spearman's rank correlation coefficient; DIT, Distress and Impact Thermometer; STAI-S, State-Trait Anxiety Inventory-State; PHQ-9, Patient Health Questionnaire-9; TCI-HA, Temperament and Character Inventory-Harm Avoidance; PSQI, Pittsburgh Sleep Quality Index; ISI, Insomnia Severity Index.

**Table 5. Correlation analysis of restorativeness with sleep EEG outcomes, daily activity levels, and mental/sleep health scales**

| **Sleep EEG (**n=56) | ρ | p value |
|---|---|---|
| Bedtime | -0.184 | 0.172 |
| Wake-up time | -0.138 | 0.307 |
| Mid-time of sleep period | -0.156 | 0.247 |
| TST | 0.09 | 0.470 |
| SOL | -0.20 | 0.127 |
| WASO | 0.08 | 0.524 |
| SE%TRT | 0.08 | 0.550 |
| Stage R (min) | 0.03 | 0.827 |
| Stage R (%SPT) | -0.001 | 0.994 |
| Stage N1 (min) | 0.15 | 0.242 |
| Stage N1 （%SPT） | 0.15 | 0.265 |
| Stage N2 (min) | 0.13 | 0.315 |
| Stage N2 （%SPT） | 0.09 | 0.472 |
| Stage N3 (min) | -0.04 | 0.758 |
| Stage N3 （%SPT） | -0.14 | 0.271 |
| **Daily activity** (n=69) | ρ | p value |

| | | |
|---|---|---|
| Exercise calorie expenditure | -0.21 | 0.069 |
| Total activity | -0.08 | 0.511 |
| Moderate intensity activity | **-0.26** | **0.025** |
| Vigorous intensity activity | -0.16 | 0.186 |
| **Mental health scales** (n=79) | ρ | p value |
| DIT distress | **-0.42** | **<0.0001** |
| DIT Impact | **-0.48** | **<0.0001** |
| PHQ-9 | **-0.62** | **<0.0001** |
| STAI-S | **-0.49** | **<0.0001** |
| TCI-HA | -0.20 | 0.071 |
| **Sleep health scales** (n=79) | ρ | p value |
| PSQI | **-0.45** | **<0.0001** |
| ISI | **-0.45** | **<0.0001** |
| HAS | **-0.36** | **0.001** |



Abbreviations: ρ, Spearman's rank correlation coefficient; EEG, electroencephalography; DIT, Distress and Impact Thermometer; STAI-S, State-Trait Anxiety Inventory-State; PHQ-9, Patient Health Questionnaire-9; TCI-HA, Temperament and Character Inventory-Harm Avoidance; PSQI, Pittsburgh Sleep Quality Index; ISI, Insomnia Severity Index; HAS, Hyperarousal scale; TST, total sleep time; SOL, sleep onset latency; WASO, wake after sleep onset; SE, sleep efficiency; TRT, total recording time; SPT, sleep period time.

**Figure 1**