Research Report

JMST

Associations of Wearable-Derived Physical Activity and Sleep Patterns with Depressive Symptoms in Community-Dwelling Older Adults

Sihyun Kim, PT, Ph.D

Department of Physical Therapy, Sangji University, Wonju, South Korea

Background Depression is widely recognized as a common mental disorder and is often associated with changes in physical activity and sleep in older adults. Wearable devices enable objective monitoring of daily behaviors in real-life settings.

Purpose The aim of this study was to explore the association between depressive symptoms and wearable-derived physical activity and sleep patterns among community-dwelling older adults.

Study design A cross-sectional study

Methods Community-dwelling older adults aged 65 years or older were recruited. Physical activity and sleep were assessed using a wrist-worn wearable device under free-living conditions. Depressive symptoms were assessed using the Center for Epidemiologic Studies Depression Scale (CES-D), and participants were classified into groups with and without depressive symptoms based on a cut-off score of 16. For statistical analysis, between-group comparisons were conducted for physical activity and sleep variables. Pearson or Spearman correlation analyses were used to assess bivariate associations, and logistic regression analyses were performed to examine the relationships among depressive symptoms, physical activity, and sleep parameters.

Results Participants were classified into groups without depressive symptoms (n=56) and with depressive symptoms (n=19). There were significant differences in moderate-to-vigorous physical activity (MVPA), light sleep, and deep sleep (all p<0.05) between the groups. CES-D scores were negatively correlated with MVPA (r_s=−0.282, p=0.014) and positively correlated with light sleep (r=0.287, p=0.012), total sleep time (r=0.255, p=0.027), and time in bed (r=0.239, p=0.039). In the logistic regression analysis, a lower standardized deep-to-light sleep ratio was associated with depressive symptoms, even after adjusting for age (odds ratio=0.485, p=0.049).

Conclusions Lower levels of MVPA and altered sleep architecture were observed in older adults with depressive symptoms. Reduced deep sleep and/or increased light sleep were associated with depressive symptoms, whereas MVPA was not independently associated with depressive symptoms. These findings suggest that wearable-derived data may provide useful indicators for identifying patterns of physical activity and sleep architecture in older adults with depressive symptoms.

J Musculoskelet Sci Technol
2026; 10(1): 96-103

pISSN 2635-8573
eISSN 2635-8581

Article History
Received 2 Apr 2026
Revised 24 Apr 2026
(1st)
Accepted 4 May 2026

CONTACT
sihyunkim0411@gmail.com
Sihyun Kim
Department of Physical Therapy, Sangji University, Wonju, South Korea

Key words Depression; Older adults; Physical activity; Sleep; Wearable devices.

INTRODUCTION

The global population is rapidly aging, with a marked increase in the proportion of older adults worldwide. The proportion of people aged 60 years and above is expected to increase from approximately 12% in 2015 to 22% by 2050.[1]

In absolute numbers, the global population aged ≥60 years is projected to increase from approximately 1 billion in 2019 to 2.1 billion by 2050.[2] This demographic shift has led to growing concerns regarding age-related health problems, particularly mental health issues.

Depression is widely recognized as one of the most common and disabling mental health conditions among older adults. Previous meta-analyses have reported that the prevalence of depressive symptoms ranges from approximately 17% to over 30% in older adults, depending on the population and measurement tools used.[3,4] Depression in later life is associated with a high risk of chronic diseases, functional decline, cognitive impairment, and mortality, as well as substantial reductions in quality of life.[5]

Physical activity has been recognized as a key modifiable factor associated with depressive symptoms. Previous research has shown that greater engagement in physical activity is linked to reduced levels of depression.[6,7] In contrast, low activity levels and extended periods of sedentary behavior have been associated with a higher likelihood of depressive symptoms among older adults. Moreover, meta-analytic evidence further supports these associations.[6,7] Furthermore, meta-analytic evidence indicates that sedentary behavior is independently associated with an elevated risk of depression, with a relative risk of 1.10.[7] Therefore, assessing both physical activity and sedentary behavior in real-world conditions may provide valuable insights into their associations with depressive symptoms.

Sleep is another important behavioral factor influencing depression in older adults. As individuals age, changes in sleep architecture commonly occur, including an increased proportion of lighter sleep and reduced proportions of rapid eye movement (REM) sleep and slow-wave sleep.[8] Moreover, poor sleep quality, sleep fragmentation, and alterations in sleep stages have been linked to depressive symptoms.[9] However, previous findings on the association between objectively measured sleep parameters and depression remain inconsistent, highlighting the need for further investigation.[10,11] Accordingly, there is a need for studies employing objective, cost-effective, and easily applicable approaches to assess sleep characteristics in real-life settings

Recent advances in consumer wearable devices have enabled continuous and objective monitoring of physical activity and sleep under free-living conditions.[12-15] These devices provide detailed and ecologically reliable data on physical activity and sleep duration, while overcoming the limitations of self-reported measures.[15,16] The use of wearable devices has therefore emerged as a promising approach for investigating behavioral factors in older adults. Therefore, the present study aimed to examine differences in physical activity and sleep parameters between older adults with and without depressive symptoms using data obtained from a wrist-worn wearable device. In addition, this study sought to examine the relationships among depressive symptoms, physical activity, and sleep parameters. This study hypothesized that older adults with depressive symptoms would exhibit lower levels of physical activity and altered sleep patterns compared to those without depressive symptoms. It was further hypothesized that wearable-derived physical activity and sleep parameters would be independently associated with depressive symptoms.

METHODS

Participants

Community-dwelling individuals aged 65 years or older were recruited for this study. Participants were eligible if they had no diagnosed neurological or musculoskeletal conditions affecting mobility, were able to walk independently with or without assistive devices, and had no history of diagnosed sleep disorders or clinical depression. Individuals were excluded if they had severe physical or mental disabilities, were wheelchair-dependent or bedridden, or had significant cognitive impairment. All participants received information regarding the study purpose and procedures and provided written informed consent prior to participation. The study protocol was approved by the Institutional Review Board of Sangji University (approval number: 1040782-181115-HR-18-37).

Depression measurement

Depressive symptoms experienced during the previous week were assessed using the Center for Epidemiologic Studies Depression Scale (CES-D).[17] The CES-D consists of 20 items scored on a 4-point scale (0-3), yielding a total score of 0-60, where higher scores indicate greater depressive symptom severity. Participants were divided into two groups based on the CES-D cut-off. A score of ≥16 defined participants with depressive symptoms, whereas a score <16 defined those without depressive symptoms, based on criteria established for the Korean population.[18,19] This cut-off has been widely used in epidemiological studies to identify individuals at risk for depression.

Physical activity and sleep data collection and analysis

Physical activity and sleep data were collected using a wrist-worn consumer wearable device (Fitbit; Fitbit Inc., San Francisco, CA, USA) under free-living conditions over 7 consecutive days. The device incorporates a triaxial accelerometer and a photoplethysmography sensor to estimate physical activity and sleep parameters. Data were recorded continuously and processed using the manufacturer's proprietary algorithms.

Physical activity intensity was classified using Fitbit-derived categories based on a proprietary algorithm incorporating accelerometry and physiological signals.[20] Moderate-to-vigorous physical activity (MVPA) was defined as activity corresponding to ≥3 METs, including "fairly active" (3–6 METs) and "very active" (≥6 METs or ≥145 steps/min) categories accumulated in bouts of at least 10 minutes.[21] Sedentary behavior was defined as time spent in sedentary activity.

Sleep variables were derived using validated algorithms based on movement and heart rate signals. The sleep parameters included time spent in awake, light, deep, and REM sleep, time in bed (TIB), and total sleep time (TST). Sleep stage variables (time spent in awake, light, deep, and REM sleep) were analyzed only when TST was at least 3 hours per night. Sleep efficiency was defined as the percentage of TST relative to TIB. The validity of Fitbit devices has been reported in comparison with polysomnography, demonstrating a sensitivity of 88.1% for sleep detection and a specificity of 51.9% for wake detection.[22] Previous study has also reported accuracy in sleep stage classification, with sensitivity ranging from approximately 54–86% and specificity from 50–62% across deep, light, and REM sleep stages.[23]

Data were included in the analysis if at least 4 valid days of physical activity data were available, as prior studies have shown that a minimum of 4 days of monitoring provides reliable estimates of habitual physical activity.[24] Mean daily values of all physical activity and sleep variables were used in the final analysis.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics, version 29 (IBM Corp., USA). The normality of the collected data was assessed using the Shapiro–Wilk test. General characteristics, wearable-derived sleep variables, and physical activity variables were compared between older adults with and without depressive symptoms. Independent t-tests were employed for normally distributed variables, whereas the Mann–Whitney U test was used for non-normally distributed variables. To examine the relationships between CES-D scores and wearable-derived sleep parameters (time spent in awake, light, deep, and REM sleep, TST, TIB, and sleep efficiency), as well as physical activity variables (MVPA and sedentary time), Pearson or Spearman correlation analyses were conducted, as appropriate, based on data distribution.

Logistic regression analyses were performed to examine the associations between physical activity, sleep parameters, and depressive symptoms. Variables that showed significant differences between groups and were associated with CES-D scores in correlation analyses were considered for inclusion in the regression models. In addition, variables with *p*-values ≤0.20 in univariable logistic regression analyses were entered into the multivariable model to avoid excluding potentially important predictors.[25] To address potential multicollinearity among sleep variables, a deep-to-light sleep ratio was calculated to reflect sleep architecture. The ratio variable was then standardized (z-score) to reduce the influence of skewed distribution and to improve model stability. Based on these criteria, MVPA and the standardized deep-to-light sleep ratio were included in the final age-adjusted logistic regression model. In the regression analyses, odds ratios (ORs) and 95% confidence intervals were calculated to quantify the strength of the associations between variables. Statistical significance was set at $\alpha=0.05$.

RESULTS

Subject characteristics

The general characteristics of the participants according to depressive symptoms are presented in Table 1. A total of 75 older adults participated in this study (with depressive symptoms, n=19 [25.3%]; without depressive symptoms, n=56 [74.7%]). There were no significant between-group differences in sex distribution, age, height, weight, or body mass index (all $p>0.05$). However, CES-D scores were significantly elevated in older adults with depressive symptoms compared to those without ($p<0.001$).

Comparison of physical activity and sleep variables between older adults with and without depressive symptoms

Table 2 presents the comparison of physical activity and sleep variables between the two groups. MVPA was significantly higher in older adults without depressive symptoms than in those with depressive symptoms ($p=0.022$). However, sedentary time did not differ significantly between the two groups ($p=0.503$). For sleep variables, older adults with depressive symptoms had significantly longer light sleep duration ($p=0.025$) and shorter deep sleep

Table 1. Characteristics of participants according to depressive symptoms

Variable	Without depressive symptoms (n=56)	With depressive symptoms (n=19)	*p*-value
Sex (male/female, n)	26/30	5/14	0.178
Age (years)	71.43±4.48	73.16±5.93	0.307
Height (cm)	160.55±9.88	156.18±9.26	0.095
Weight (kg)	62.29±9.96	63.04±10.25	0.779
BMI (kg/m²)	24.14±3.03	25.95±4.42	0.111
CES-D (score)	8.64±3.62	25.79±9.05	<0.001

Abbreviations: BMI, body mass index; CES-D, center for epidemiologic studies depression scale.

Continuous variables are presented as mean±standard deviation; categorical variable is presented as number.

Table 2. Comparison of physical activity and sleep variables between older adults with and without depressive symptoms

Variable	Without depressive symptoms (n=56)	With depressive symptoms (n=19)	*p*-value
MVPA	60.80±50.46	33.17±26.82	0.022
Sedentary	607.15±202.12	653.71±144.65	0.503
Awake	63.49±11.98	65.86±13.75	0.475
Light sleep	236.99±41.84	263.04±45.50	0.025
Deep sleep	56.69±12.24	49.62±12.17	0.032
REM sleep	74.38±22.91	65.54±22.28	0.148
TST	384.73±62.99	407.41±58.14	0.171
TIB	451.25±74.82	475.96±67.80	0.207
Sleep efficiency	85.73±1.76	85.63±2.15	0.836

Abbreviations: MVPA, moderate-to-vigorous physical activity; REM, rapid eye movement sleep; TST, total sleep time; TIB, time in bed. Values are presented as mean±standard deviation.

Time-based variables (MVPA, sedentary, awake, sleep stages, TST, and TIB) are expressed in minutes per day, and sleep efficiency is expressed as a percentage (%).

duration (*p*=0.032) than those without depressive symptoms. No significant differences were observed in time spent in awake, REM sleep, TST, TIB, or sleep efficiency between the groups (all *p*>0.05).

Correlation between physical activity, sleep variables, and depressive symptoms

CES-D scores showed a significant negative correlation with MVPA (r_s=–0.282, *p*=0.014, Table 3). However, CES-D scores were not significantly associated with sedentary time. Among sleep variables, CES-D scores showed a significant positive correlation with light sleep (r=0.287, *p*=0.012), TST (r=0.255, *p*=0.027), and TIB (r=0.239, *p*=0.039) (Table 3). No significant correlations were observed between CES-D scores and time spent in awake, deep sleep, REM sleep, or sleep efficiency.

Logistic regression analysis of physical activity, sleep, and depressive symptoms

After adjusting for age, MVPA (OR=0.981, *p*=0.047) and light sleep (OR=1.014, *p*=0.042) were significantly associated with depressive symptoms (Table 4). In contrast, deep sleep (*p*=0.081), TST (*p*=0.240), and TIB (*p*=0.268) were not significantly associated with depressive symptoms (Table 4).

Table 3. Correlations between CES-D scores and physical activity and sleep variables

Variable	Correlation coefficient (r or r_s)	*p*-value
MVPA	–0.282	0.014
Sedentary	0.000	0.997
Awake	0.130	0.266
Light sleep	0.287	0.012
Deep sleep	–0.118	0.314
REM sleep	–0.030	0.801
TST	0.255	0.027
TIB	0.239	0.039
Sleep efficiency	0.066	0.571

Abbreviations: CES-D, Center for Epidemiologic Studies Depression Scale; MVPA, moderate-to-vigorous physical activity; REM, rapid eye movement sleep; TST, total sleep time; TIB, time in bed.

Correlation coefficients are presented as Pearson's r or Spearman's r_s , as appropriate.

Table 4. Univariable logistic regression analysis of factors associated with depressive symptoms

Variable	B	SE	OR (95% CI)	*p*-value
MVPA	–0.019	0.009	0.981 (0.963–1.000)	0.047
Light sleep	0.014	0.007	1.014 (1.000–1.027)	0.042
Deep sleep	–0.042	0.024	0.959 (0.915–1.005)	0.081
TST	0.005	0.004	1.005 (0.996–1.014)	0.240
TIB	0.004	0.004	1.004 (0.997–1.012)	0.268

Abbreviations: CI, confidence interval; MVPA, moderate-to-vigorous physical activity; OR, odds ratio; SE, standard error; TST, total sleep time; TIB, time in bed.

Table 5. Multivariable logistic regression analysis of factors associated with depressive symptoms

Variable	B	SE	OR (95% CI)	*p*-value
MVPA	–0.014	0.010	0.986 (0.967–1.005)	0.149
Deep-to-light sleep ratio	–0.723	0.367	0.485 (0.236–0.997)	0.049

Abbreviations: CI, confidence interval; MVPA, moderate-to-vigorous physical activity; OR, odds ratio; SE, standard error.

The standardized deep-to-light sleep ratio showed a significant association with depressive symptoms (OR=0.485, *p*=0.049) (Table 5). Higher values of deep-to-light sleep ratio were inversely associated with depressive symptoms. In contrast, MVPA was not significantly associated with depressive symptoms (*p*=0.149) (Table 5).

DISCUSSION

The present study demonstrated the associations between daily physical activity and sleep patterns in older adults with and without depressive symptoms using consumer wearable devices. The results indicated that older adults with depressive symptoms had significantly lower MVPA and altered sleep architecture, characterized by reduced deep sleep and increased light sleep time, compared with those without depressive symptoms. In the multivariable model, the standardized deep-to-light sleep ratio was inversely associated with depressive symptoms, indicating that a higher proportion of deep sleep relative to light sleep was associated with lower odds of depressive symptoms. This finding highlights the importance of sleep architecture, rather than individual sleep stages alone, in understanding mental health outcomes. Overall, these results provide evidence that both sleep characteristics and physical activity are associated with depressive symptoms, and suggest that consumer wearable devices may serve as potential tools for therapeutic interventions; however, further validation is needed to establish their clinical utility.

The use of a standardized ratio allowed us to capture the relative distribution of sleep stages while accounting for differences in scale and variability, thereby providing a more stable and interpretable measure of sleep structure. Given that sleep stages are inherently interdependent, an increase in one stage necessarily reflects a decrease in another, suggesting that the balance between restorative deep sleep and lighter sleep stages may be a key factor in emotional regulation.[26] In particular, deep sleep plays a critical role in physical restoration, immune function, and memory consolidation, whereas light sleep primarily serves as a transitional stage that supports sleep continuity but provides less restorative benefit.[27] In addition, light sleep is characterized by increased cortical arousability, which may increase susceptibility to sleep fragmentation and frequent awakenings.[28] Such instability may lead to insufficient restoration and dysregulation of emotional processing, both of which have been linked to depressive symptoms.[29] Therefore, an increased proportion of light sleep may reflect impaired sleep regulation and reduced restorative capacity, potentially contributing to the development or persistence of depressive symptoms. These findings suggest that not only sleep duration but also the relative distribution of sleep stages (i.e., deep and light sleep) should be considered when evaluating the relationship between sleep and depression in older adults.

Previous literature has indicated an inverse association between MVPA and depression.[6,30] For example, a recent meta-analysis of prospective cohort studies reported that 8.8 mMET-hours per week was associated with approximately a 25% lower risk of depression among individuals meeting recommended activity levels.[30] Similarly, a systematic review found that MVPA was significantly associated with reduced depressive symptoms (OR=0.91).[6] In the present study, MVPA differed significantly between older adults with and without depressive symptoms and was associated with depressive symptoms in the univariable analysis.

However, this association was no longer significant after the standardized deep-to-light sleep ratio was included in the multivariable model. This discrepancy from previous findings may be explained by the inclusion of sleep-related variables, which may have influenced the observed association between physical activity and depressive symptoms. These findings suggest that while MVPA is associated with depressive symptoms in the unadjusted model, this association may be attenuated after adjusting for sleep architecture.

Although TST and TIB showed significant correlations with CES-D scores, they were not independently associated with depressive symptoms in logistic regression analyses. This discrepancy may be explained by differences in outcome measures, as correlation analyses reflect associations with symptom severity, whereas logistic regression evaluates the ability to distinguish between groups with and without depressive symptoms. These findings suggest that sleep duration may be related to the severity of depressive symptoms but may not be sufficient to distinguish between individuals with and without depressive symptoms. Therefore, sleep duration alone, including TST and TIB, may not adequately capture the association between sleep and depressive symptoms.

These findings should be interpreted in light of several limitations. First, as this study employed a cross-sectional design, it is difficult to infer causal relationships between depressive symptoms and physical activity and sleep variables. Thus, it remains unclear whether reduced physical activity and altered sleep patterns contribute to depressive symptoms or vice versa. Second, the sample size was imbalanced between the depressive symptoms and non-depressive symptom groups, which may have reduced statistical power and increased the risk of bias, thereby limiting the generalizability of the findings. Third, physical activity and sleep were assessed using a consumer wearable device. Although such devices provide objective and ecologically valid measurements under free-living conditions, their accuracy may be lower than that of gold-standard methods, such as polysomnography for sleep and research-grade accelerometers for physical activity. Fourth, depressive symptoms were assessed using a self-reported questionnaire (CES-D) rather than a clinical diagnosis. Therefore, the findings reflect depressive symptoms rather than clinically diagnosed depression. Despite these limitations, this study highlights the utility of wearable devices for capturing real-life physical activity and sleep characteristics in older adults with depressive symptoms. Future studies are needed to validate these findings in larger populations with a more balanced sample size between groups.

CONCLUSION

The present study demonstrated that older adults with depressive symptoms exhibited lower levels of MVPA and altered sleep architecture, as reflected by reduced deep sleep and increased light sleep. Notably, the standardized deep-to-light sleep ratio was independently associated with depressive symptoms, whereas the association between MVPA and depressive symptoms was attenuated after adjusting for sleep architecture. These findings suggest that the relative distribution of sleep stages may play a more important role in relation to depressive symptoms in older adults. Furthermore, this study highlights the feasibility and utility of consumer wearable devices for objectively monitoring physical activity and sleep patterns in real-life settings. Future longitudinal studies are warranted to clarify causal relationships and to further explore the role of sleep architecture in mental health among older adults.

Key Points

Question Older adults with depressive symptoms exhibited significantly lower MVPA and altered sleep architecture, as measured by a wearable device.

Findings Altered sleep architecture, characterized by a lower deep-to-light sleep ratio (i.e., reduced deep sleep and increased light sleep duration), was associated with depressive symptoms.

Meaning Wearable devices offer a practical and objective tool for monitoring real-life physical activity and sleep patterns and may help identify behavioral indicators of depressive symptoms in older adults.

Article information

Conflict of Interest Disclosures: None.

Funding/Support: This research was supported by Sangji University Research Fund, 2024.

Acknowledgment: None.

Ethic Approval: The study protocol was approved by the Institutional Review Board of Sangji University (Approval number: 1040782-181115-HR-18-37).

Data Availability: The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions

Conceptualization: SH Kim.

Data acquisition: SH Kim.

Design of the work: SH Kim.

Data analysis: SH Kim.
Project administration: SH Kim.
Interpretation of data: SH Kim.
Writing – original draft: SH Kim.
Funding acquisition: SH Kim.
Writing–review&editing: SH Kim.

REFERENCES

1. World Health Organization. *Ageing and health*, https://www.who.int/news-room/factsheets/detail/ageing-and-health?utm_source. 2025.
2. World Health Organization. *Mental health of older adults*, https://www.who.int/news-room/factsheets/detail/mental-health-of-older-adults?utm_source, 2025.
3. Melo D, Midão L, Mimoso I, et al. Prevalence and determinants of depressive symptoms in older adults across Europe: evidence from SHARE wave 9. *J Clin Med*. 2025;14(15):5340.
4. Jalali A, Ziapour A, Karimi Z, et al. Global prevalence of depression, anxiety, and stress in the elderly population: a systematic review and meta-analysis. *BMC Geriatr*. 2024;24(1):809.
5. Zenebe Y, Akele B, M WS, Necho M. Prevalence and determinants of depression among old age: a systematic review and meta-analysis. *Ann Gen Psychiatry*. 2021; 20(1):55.
6. Wang D, Zhang Y, Guo Z, Lu S. Sedentary behavior and physical activity are associated with risk of depression among adult and older populations: a systematic review and dose-response meta-analysis. *Front Psychol*. 2025; 16:1542340.
7. Huang Y, Li L, Gan Y, et al. Sedentary behaviors and risk of depression: a meta-analysis of prospective studies. *Transl Psychiatry*. 2020;10(1):26.
8. Crowley K. Sleep and sleep disorders in older adults. *Neuropsychol Rev*. 2011;21(1):41-53.
9 Pesonen A-K, Gradisar M, Kuula L, et al. REM sleep fragmentation associated with depressive symptoms and genetic risk for depression in a community-based sample of adolescents. *J Affect Disord*. 2019;245:757-763.
10. O'Callaghan VS, Couvy-Duchesne B, Strike LT, et al. A meta-analysis of the relationship between subjective sleep and depressive symptoms in adolescence. *Sleep Med*. 2021;79:134-144.
11. Lovato N, Gradisar M. A meta-analysis and model of the relationship between sleep and depression in adolescents: recommendations for future research and clinical practice. *Sleep Med Rev*. 2014;18(6):521-529.
12. Park K, Kim S. Objective sleep patterns across frailty levels in older adults using wearable data. *Clin Gerontol*. 2026:1-11.
13. Osuka Y, Chan LLY, Brodie M, Okubo Y, Lord SR. Frailty assessed by a wrist-worn device can predict hospitalisation and mortality in middle-aged and older adults: a UK Biobank study. *Age Ageing*. 2025;54 (8):afaf210.
14. Park K, Kim S. Classification of the frailty status of community-dwelling older adults using physical activity data collected through consumer activity trackers. *Int J Gerontol*. 2024;18(2):75-79.
15. VandeBunte A, Gontrum E, Goldberger L, et al. Physical activity measurement in older adults: wearables versus self-report. *Front Digit Health*. 2022; 4:869790.
16. Scarlett S, Nolan HN, Kenny RA, O'Connell MDL. Discrepancies in self-reported and actigraphy-based sleep duration are associated with self-reported insomnia symptoms in community-dwelling older adults. *Sleep Health*. 2021;7(1):83-92.
17. Radloff LS. The CES-D scale: a self-report depression scale for research in the general population. *Appl Psychol Meas*. 1977;1(3):385-401.
18. Cho MJ, Nam JJ, Suh GH. Prevalence of symptoms of depression in a nationwide sample of Korean adults. *Psychiatry Res*. 1998;81(3):341-352.
19. Park JH, Kim KW. A review of the epidemiology of depression in Korea. *J Korean Med Assoc*. 2011;54 (4):362-369.
20. Fibit Inc. Fitbit Web API: Intraday activity time series. Retrieved.
21. Semanik P, Lee J, Pellegrini CA, et al. Comparison of physical activity measures derived from the fitbit flex and the ActiGraph GT3X+ in an employee population with chronic knee symptoms. *ACR Open Rheumatol*. 2020;2(1):48-52.
22. Moreno-Pino F, Porras-Segovia A, López-Esteban P, Artés A, Baca-García E. Validation of fitbit charge 2 and fitbit alta HR against polysomnography for assessing sleep in adults with obstructive sleep apnea. *J Clin Sleep Med*. 2019;15(11):1645-1653.
23. Lim SE, Kim HS, Lee SW, Bae KH, Baek YH. Validation of fitbit inspire 2(TM) against polysomnography in adults considering adaptation for use. *Nat Sci Sleep*. 2023;15:59-67.
24. Barreira TV, Schuna JM, Tudor-Locke C, et al. Reliability of accelerometer-determined physical activity and sedentary behavior in school-aged children: a 12-country study. *Int J Obes Suppl*. 2015;5(Suppl 2): S29-35.

25. Kjelsberg FN, Ruud EA, Stavem K. Predictors of symptoms of anxiety and depression in obstructive sleep apnea. *Sleep Med*. 2005;6(4):341-346.
26. Le F, Yap Y, Dumuid D, Wiley JF. Daily, prospective associations between sleep architecture and affect: insights from Bayesian multilevel compositional data analysis. *Ann Behav Med*. 2025;59(1):kaaf050.
27. Rasch B, Born J. About sleep's role in memory. *Physiol Rev*. 2013;93(2):681-766.
28. Kryger MH, Roth T, Dement WC. *Principles and practice of sleep medicine*. 5th ed. Philadelphia, PA: Saunders/Elsevier; 2010.
29. Walker MP, van der Helm E. Overnight therapy? the role of sleep in emotional brain processing. *Psychol Bull*. 2009;135(5):731-748.
30. Pearce M, Garcia L, Abbas A, et al. Association between physical activity and risk of depression: a systematic review and meta-analysis. *JAMA Psychiatry*. 2022;79(6):550-559.