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Sleep regularity and duration are associated with depression severity in a nationally representative United States sample

Katherine A. Maki *, Li Yang, Nicole Farmer, Shreya Papneja, Gwenyth R. Wallen, Jennifer J. Barb

Translational Biobehavioral and Health Promotion Branch, Clinical Center, National Institutes of Health, Bethesda, MD, United States of America

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ABSTRACT

Background: Sleep hygiene is integral to health, and sleep regularity may be associated with mental health outcomes in addition to duration. Although sleep and depression relationships are well-studied, the relative impact of different sleep factors remains unclear. As patient-specific factors and health behaviors influence sleep and mental health, we investigated associations between sleep and depression severity considering such factors in a United States sample of adults.

Methods: Two cycles (2011–2012, 2013–2014) from the National Health and Nutritional Examination Survey were studied. Objective sleep duration (day and night), and the sleep regularity index (SRI) were calculated from physical activity monitors worn for seven days. Complex survey procedures with four-year weights were used, and backward selection was used to test relevant variables in the fully adjusted regression model.

Results: Among participants ($n = 7297$), we found associations between sleep-associated variables and SRI, with increased daytime sleep being the strongest correlate of decreased SRI. In the fully adjusted model, lower SRI scores and reduced subjective night sleep remained significantly associated with depression. Sex was an additional independent predictor, with females exhibiting higher depression scores, and a significant sex $\times$ SRI interaction revealed that the inverse relationship between SRI and depressive symptoms was stronger in females than in males. Health behaviors, including active tobacco and cannabis use, were also associated with increased depression severity in the adjusted model.

Conclusions: Daytime sleep may serve as an SRI proxy, although additional cohorts should confirm relationships. Higher depression severity was associated with different sleep components, emphasizing the importance of sleep hygiene in mental health. Behaviors like current smoking and cannabis use were also associated with increased depression. Research exploring the temporality and interactions between these factors may assist in non-pharmacologic depression treatment.

1. Background

Healthy sleep is a key determinant of overall health and disease prevention, with evidence supporting the role of sleep in maintaining physiological and psychological homeostasis (Li et al., 2023; Lloyd--Jones et al., 2022). Adequate sleep duration, high-quality sleep, and consistent sleep and wake times are crucial for immune function, metabolic regulation, and cognitive performance (Sharma and Kavuru, 2010; Besedovsky et al., 2019; Van Dongen et al., 2003). Disrupted or insufficient sleep is linked to increased risks for chronic conditions, including cardiovascular disease, diabetes, and mental health disorders (Hale et al., 2020; Yang et al., 2024). Beyond duration, emerging research underscores the importance of sleep quality and regularity in achieving the full physiological and psychological benefits of sleep (Sletten et al., 2023). Sleep duration refers to the total time spent sleeping, sleep quality refers to the ease of initiation, maintenance, and restfulness, and sleep regularity refers to the consistency of sleep-wake cycles. While these factors are interrelated, each may have distinct effects on human health and particularly, mental health. Irregular sleep patterns, for example, can disrupt circadian rhythms and contribute to mood dysregulation, increasing the risk of depressive symptoms (Zee and Vitiello, 2009). Understanding the differential impact of these sleep dimensions on health, especially mental health, requires further research to guide effective interventions.

The concept of sleep regularity and its connection to health has

* Corresponding author. National Institutes of Health, Building 10 Rm 2B10 10 Center Drive, Bethesda, MD, 20814, United States of America.
E-mail address: Katherine.maki@nih.gov (K.A. Maki).

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Abbreviations

AUD	Alcohol Use Disorder
BMI	Body Mass Index
HEI-2015	Healthy Eating Index 2015
NHANES	National Health and Nutrition Examination Survey
PHQ-9	Patient Health Questionnaire
SE	Standard Error
SRI	Sleep Regularity Index
US	United States

emerged in the literature, and consistency in sleep and wake times have been linked to various health outcomes (Phillips et al., 2017; Lunsford-Avery et al., 2018). The Sleep Regularity Index (SRI), introduced in 2017, quantifies an individual's sleep/wake cycle consistency over time, by measuring the likelihood of being in the same state (asleep or awake) at two points separated by 24 h (Phillips et al., 2017). Research has associated the SRI with factors such as circadian misalignment (Phillips et al., 2017), academic performance (Phillips et al., 2017), cardiovascular risk (Lunsford-Avery et al., 2018), and self-reported depression severity (Lunsford-Avery et al., 2018). Lower SRI scores have also been linked to relapse and excessive daytime napping during inpatient treatment in individuals with alcohol use disorder (Barb et al., 2022; Brooks et al., 2020). Conversely, higher SRI scores, indicating more regular sleep and wake times, were associated with decreased mental exhaustion in the same population (Brooks et al., 2020). Since its introduction, the SRI has garnered significant interest for its increasing association with health outcomes, and growing evidence supporting the protective effects of sleep regularity on mental health in specific populations like adolescents and early late life women (Swanson et al., 2023; Castiglione-Fontanellaz et al., 2023). Examining the relationship between SRI and self-reported depression severity in a nationally representative United States (U.S.) sample could enhance understanding of sleep's role in psychological well-being by validating previous research on SRI and mental health.

Although the association between self-reported depression severity with sleep duration and sleep quality, respectively, has been well established, the relative contribution of these sleep characteristics as additive factors to depression severity remains unclear (Um et al., 2023; Scott et al., 2021). Epidemiological studies indicate that insufficient sleep duration is strongly linked to an increased risk of depression, with both short and excessively long sleep durations correlating with higher depression severity (Dong et al., 2022). Conversely, poor sleep quality is frequently reported by individuals with depression, complicating the understanding of the directional relationship between sleep disturbances and mental health symptoms (Edge, 2010; Riemann et al., 2020; Pearson et al., 2023). This bidirectional relationship between sleep disturbances and depression suggests that other factors may play a critical role in shaping both sleep patterns and mental health outcomes.

Health behaviors and socioeconomic characteristics are increasingly recognized as pivotal factors that influence both sleep quality and mental health (Grandner et al., 2015). These factors, which include household income, employment status, physical activity, and diet (among others), profoundly shape individual sleep patterns and may exacerbate or mitigate mental health symptoms. Despite understanding the important role of sleep duration in influencing mental health characteristics (Zhang et al., 2024; Lee et al., 2024; Nielson et al., 2023), further research is needed to explore how environmental, behavioral, and other sleep-related factors impact self-reported mental health. Understanding these interactions is crucial for identifying modifiable health behaviors that may present valuable opportunities for developing targeted interventions to improve depressive symptom severity. Elucidating such mechanisms will enable us to understand which components of sleep phenotype contribute to depression and provide us with a comprehensive overview of the influence of sleep health on mental health. Therefore, the aim of this paper is to investigate associations between sleep characteristics (i.e., regularity, duration) and self-reported depression severity considering relevant demographic, health behavior and socioeconomic characteristics in a nationally representative U.S. Sample using data from the National Health and Nutrition Examination Survey (NHANES) 2011–2014.

2. Methods

2.1. Study sample

The NHANES is a cross-sectional, nationally representative health and nutrition survey designed to assess the health and nutritional status of adults and children in the U.S. through a combination of interviews, physical examinations, and laboratory tests (Chen et al., 2018). The NHANES survey is administered by the National Center for Health Statistics at the Centers for Disease Control and Prevention, and the survey uses a complex, multistage probability sampling design to ensure that its data are representative of the civilian, non-institutionalized U.S. population (Johnson et al., 2013). This study includes two cycles of NHANES data (2011–2012, 2013–2014), which are the two NHANES cycles where physical activity monitors were applied and actigraphy data was collected for objective sleep assessment (National Center for Health Statistics, 2012; National Center for Health Statistics, 2014a). Of the 15,179 participants included in these two NHANES cycles, subjects 18 years of age and older with self-reported depression severity instrument data, and no psychotropic medication use were considered for analysis. The final study sample included 7297 participants (see Fig. 1).

2.2. Demographic variables

Participants age and sex were obtained from the NHANES Demographic Variables Questionnaire, and body mass index (BMI) from examination data (Body Measures). Race/ethnicity was determined from NHANES Demographics variable 'RIDRETH3' and included 'Non-Hispanic White', 'Non-Hispanic Black', 'Non-Hispanic Asian', 'Multi-Racial' and 'Mexican American' and 'Other Hispanic' categories were combined to a recoded variable 'Mexican American/Other Hispanic', and other categories were unchanged.

2.3. Socioeconomic characteristics

Income/Poverty Ratio: The income/poverty ratio was obtained from NHANES variable 'INDFMPIR - ratio of family income to poverty' and recoded where 0–1.30 = 'lowest', 1.31–1.85 = 'middle', and 1.86-max = 'highest' based from cut off points consistent with those used to determine eligibility of food assistance programs and other analyses of National data (Nord, 2010).

Current Employment: Current employment was determined from the NHANES variable 'OCD150 - Type of work done last week', where an answer of 'Working at a job or business' was coded as 'yes' (currently working) and all other answers were coded as 'no' (not currently working). Full or part-time work was not specified in the model.

2.4. Health behavior variables

Sedentary Time: Sedentary behaviors on a typical day were derived from the Physical Activity Survey (PAQ_H). Patients were asked to approximate how many minutes they spent sitting on a typical day (not including sleeping) and sedentary time was analyzed as a continuous variable of average minutes/day.

Diet Quality: The Healthy Eating Index-2015 (HEI-2015) was used for diet quality assessment. Participant nutrition and dietary intake was obtained from 24-h dietary recalls. The first recall was performed in person by research staff on the first day that actigraphy data were

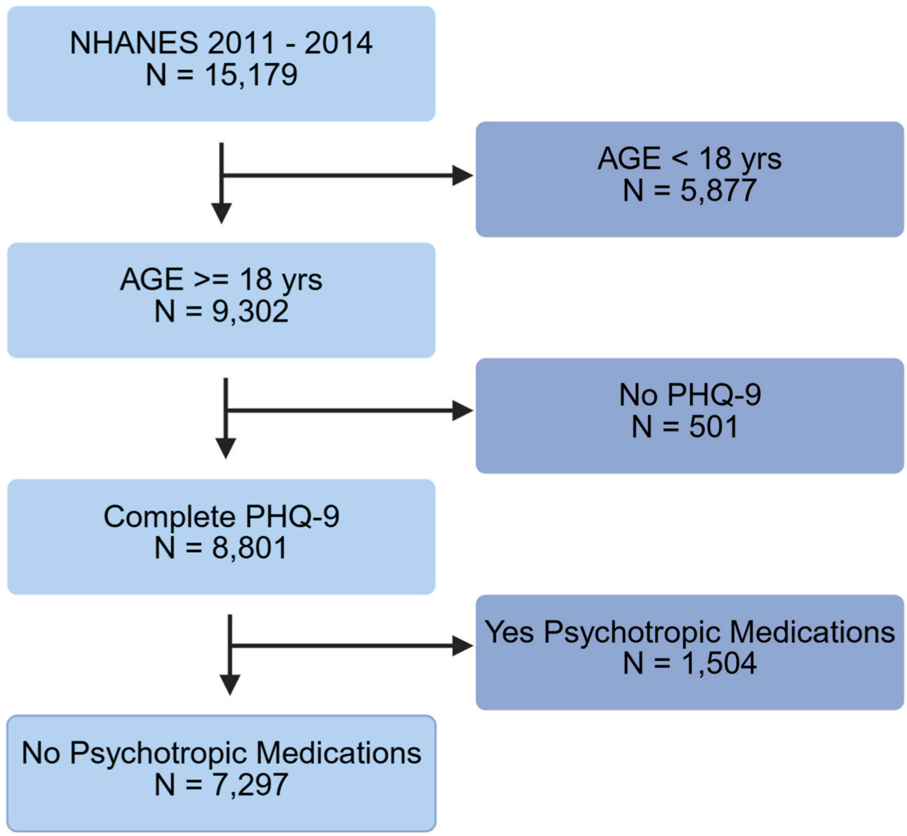

Fig. 1. Flow Chart of Study Cohort Filtering
Legend. Flow chart of participant filtering for eligibility for current study. Eligible participants from NHANES cycles 2011-2 and 2013–2014. Participants less than 18 years of age and those without PHQ-9 completed questionnaire information excluded from current study. Additional filtering excluded any participant on psychotropic classified medications with a final sample size of 7297. **Abbreviations**. PHQ-9: Patient Health Questionnaire (9-item). Created in BioRender. Maki, K. (2025) https://BioRender.com/c0dnv93.

collected during the medical examination visit, and the second recall was collected via telephone (Ahluwalia et al., 2016). A HEI-2015 per person score was calculated from the two 24-h recalls (Krebs-Smith et al., 2018). The updated HEI-2015 was used due to its inclusion of added sugars in total score calculation, and presence in recent health guidelines that also measure sleep as a health predictor component (Lloyd-Jones et al., 2022; Krebs-Smith et al., 2018).

***Cannabis Use in Previous* 14 Days:** Cannabis use in the past 14 days was quantified using variables from the Drug Use Survey (DUQ_H). All responses from the questions inquiring about the last time the participant used marijuana or hashish were recorded to days and if days $\leq$ 14, Active cannabis use = 'Yes'; if last use >14 days, Active cannabis use = 'No'. A period of 14 days was selected to correspond with the time in which symptoms of depression are evaluated in the PHQ-9.

***Current Tobacco Smoking*:** Active smoking status was quantified using variables from the Smoking - Cigarette Use Survey (SMQ_H). If patients had not smoked at least 100 cigarettes in life and/or answered they do not currently smoke cigarettes, Smoking = 'No'; if SMQ040 = 'Every day' or 'Some days', Smoking = 'Yes'.

2.5. *Psychotropic medication use*

Previous research demonstrates that self-reported mental health outcome measures are influenced from active psychotropic medication use (Busgang et al., 2022; Valles-Colomer et al., 2019), and relationships between sleep and mental health symptom severity may be confounded by these medications. Therefore, psychotropic medications (i.e., antidepressant, antimanic, and anxiolytic medication classes) were classified according to Lexicon Plus®, and participants reporting psychotropic medication use were excluded from the current analysis. See **Supplemental Methods** for medication classes included in our classification of psychotropic medications and respective coding syntax.

2.6. *Self-reported depression severity*

Symptoms of depression were quantified using the Patient Health Questionnaire (PHQ-9), which is a nine-item screening instrument that asked questions about the frequency of symptoms of depression over the past 14 days (Kroenke et al., 2001). PHQ-9 data was collected in participants aged 12 years and older, but as scores are restricted in participants aged 12–17, participants aged 18 and older were included in this present analysis. Additionally, participants requiring a proxy did not have the PHQ-9 questionnaire performed due to the sensitive nature of the questions.

Each item on the measure is rated on a 4-point scale (0 = 'Not at all'; 1 = 'Several days'; 2 = 'More than half the days'; and 3 = 'Nearly every day'), and the total score can range from 0 to 27, with higher scores indicating greater severity of depressive symptoms. Depression severity was evaluated using both continuous values and categorical grouping of depression severity levels to 'none' (scores 0–4), 'mild depression' (scores 5–9), 'moderate depression' (scores 10–14), 'moderately severe depression' (scores 15–19), and 'severe depression' (scores 20–27) (Kroenke et al., 2001).

2.7. *Subjective sleep variables*

Subjective measures of sleep were obtained from the Sleep Disorders Questionnaire using the following variables: 'SLD010H - How much sleep do you usually get on weekdays or workdays (hours)?', 'SLQ050 - Ever told doctor had trouble sleeping?', and 'SLQ060 - Ever told by doctor have sleep disorder?'. Of note, SLD010H instructs respondents to quantify hours of sleep at night on weekdays or workdays only; thus, daytime sleep behaviors, along with differences in sleep patterns from weekdays to the weekend (or workdays to non-workdays) were not considered.

2.8. Objective sleep variables

For NHANES 2011–2014, participants were asked to wear a physical activity monitor (ActiGraph model GT3X+, manufactured by ActiGraph, Pensacola, FL) on their wrist. The physical activity monitor was placed on the examination day in the NHANES Mobile Examination Center. Patients were instructed to keep wearing the device all day and night for seven full days (midnight to midnight) and remove it on the morning of the ninth day. The monitor continuously recorded triaxial accelerometry at 80 Hz sampling intervals, and monitor-independent movement summary units were used for accelerometer data processing (John et al., 2019). For detailed data collection, processing, quality control, and participant status characterization procedures, please see (National Center for Health Statistics, 2012; National Center for Health Statistics, 2014a; John et al., 2019). In brief, raw accelerometry data were compiled and underwent quality review/annotation, and monitor-independent movement summary units were subsequently independently calculated. An open-source machine learning algorithm was used for prediction of wake, sleep, or non-wear status for each minute using three-step process. First, prediction values and confidence intervals were calculated over each 30-s epoch from the monitor-independent movement summary units, and then in a second pass, minimum durations and predictive confidence values were considered in the periods before and after each segment undergoing evaluation (National Center for Health Statistics, 2012; National Center for Health Statistics, 2014a). Finally, longer periods were scanned to specifically consider orientation changes characteristic of physiologic sleep to generate a final determination of sleep, wake, or non-wear during each corresponding minute when data met duration and quality thresholds (National Center for Health Statistics, 2012; National Center for Health Statistics, 2014a). Actigraphy data were retained for our objective sleep analysis only for participants who provided at least seven valid monitoring days, with no more than one of those days containing two or more hours of invalid (excluded) epochs.

Sleep Regularity Index: Objective sleep data were collected and assessed using actigraphy data from the activity watch monitor as above. Raw actigraphy files named as 'physical activity monitor' were downloaded from the 2011–2012 and 2013–2014 NHANES cycles. The SRI was calculated using a script in the JMP version 16 statistical discovery software (version 16, Cary, NC) adapted from a previously published SRI python script (https://github.com/mengelhard/sri). (Phillips et al., 2017) The SRI is described as the average percent that a person is either asleep or awake at the same time in a 24-h period over a given interval of time (i.e., days, weeks or months). For the current analysis, a respondent's actigraphy data was included if the wearable device produced data for the entirety of seven 24-h days. A respondent was not included in the analysis if there was more than one day with two or more hours of 'excluded' data in line with previous recommendations for valid SRI calculation (Lunsford-Avery et al., 2018). Excluded data can result from a watch malfunction or non-wear. Epochs for this device are recorded as 1-min intervals with a total of 1440 epochs for each 24-h period. Actigraphy data were considered starting at 21:31 on Day 1 (examination day in the NHANES Mobile Examination Center) and were evaluated through 21:30 on Day 8 for a goal of 7 replicates of 24-h complete actigraphy data. After filtering for relevant actigraphy data, a total of 2830 respondents were excluded from the analysis of objective sleep parameters including SRI.

Day and Night Sleep Duration: Objective sleep duration was calculated using the day interval as data collected between 9:31 a.m.–9:30 p.m. and night intervals from 9:31 p.m.–9:30 a.m. Predicted sleep state values were summarized with day sleep duration including sleep that occurred during 9:30–21:29, and night sleep duration including sleep that occurred during 21:30–9:29, and hours of sleep per day or night, respectively were averaged across the seven 24-h periods of data to generate one mean value per participant.

2.9. Statistical analyses

Analyses were performed in SAS, SPSS and JMP (v16.0; SAS Headquarters, Cary, NC). Complex survey procedures with four-year sample weights were used in SAS to account for the NHANES complex sample design. Means, proportions, and standard errors (SE) were used to describe the overall sample and depression severity groups (from 'proc surverymeans' and 'proc surveyfreq' procedures). The SAS survey procedures 'Surveyreg' and the 'SurveyCorrCov' macro were used for descriptive, bivariate, and regression analyses to assess the association between depression, sleep-associated variables, patient specific variables, and health behavior variables (https://github.com/DavidRNelson/-surveycorrcov-sas-macro) (Nelson et al., 2020). Backward selection with $p < .1$ was used to choose variables for the final model. Sensitivity analyses using interaction terms on the fully adjusted survey-weighted model were conducted to evaluate interactions between SRI and significant predictors hypothesized to influence both SRI and depression including sex, family income/poverty ratio, current smoking and cannabis use within the past 14 days. A p-value less than 0.05 was considered statistically significant.

3. Results

This study sample included adults 18 years of age and older (n = 7297) and was 51.9 % female with a mean age of 45.08 ± 0.61 years (Table 1). A small proportion of the participants (17.2 ± 0.89 %) were current smokers and reported cannabis use in the past 14 days (11.4 ± 0.73 %). Participants reported an average of 6.59 ± 0.09 h per day of sedentary time, and their average diet quality score (assessed by HEI-2015) was 54.53 ± 0.34. Additionally, most participants both worked in the last week and were in the highest tier ratio (>185 %) of family income to poverty (62.24 % and 64.33 %, respectively). A comparison of the study sample (n = 7297) *vs.* participants not included in objective sleep analyses due to missing or incomplete data (n = 2395) was performed (Supplemental Table S1). Participants without objective sleep analyses were younger (40.83 ± 0.79 *vs.* 45.08 ± 0.79, $p < .001$), have worked in the past week (66.11 ± 1.64 % *vs.* 62.46 ± 1.19, $p = .016$), and had lower HEI scores (53.51 ± 0.46 *vs.* 54.53 ± 0.34, $p = .002$).

3.1. Objective and subjective sleep bivariate relationships with SRI

Objective sleep measurements indicated that participants slept an average of 6.70 ± 0.03 h/night, an average of 0.99 ± 0.03 h/day, and had an SRI of 61.79 ± 0.48 over the seven days of physical activity monitoring. Subjective sleep duration during the work week was estimated at 6.92 ± 0.02 h/night, which was significantly positively correlated with objective sleep/night (r = 0.23, $p < .0001$). Objective daytime sleep strongly impacted SRI scores (Fig. 2), where higher average sleep time during the day was significantly associated with lower SRI scores (r = −0.70, $p < .0001$). Although relationships between objective and subjective nighttime sleep with SRI were also significant, the positive associations between SRI and sleep at night were not as strong as daytime sleep (objective night sleep r = 0.19, $p < .0001$; subjective night sleep r = 0.08, $p < .001$).

Table 1
Demographics, sleep profiles, and health behaviors of study population.

Sample Size	
Unweighted	7297
Weighted	179,889,515
Demographics	**Mean or Percent (Std Error of Mean or Percent)**
Age (years)	45.08 (0.61)
BMI (kg/m^2)	28.63 (0.18)
Number Missing	65
Sex	
Female (%)	51.89 (0.79)
Male (%)	48.81 (0.79)
Race/Ethnicity (%)	
Non-Hispanic White (%)	62.91 (2.58)
Non-Hispanic Black (%)	12.60 (1.58)
Non-Hispanic Asian (%)	5.80 (0.65)
Mexican American/Other Hispanic (%)	16.27 (1.88)
Other Race – Including Multi-Racial (%)	2.42 (0.37)
Socioeconomic Characteristics	
Family Income to Poverty Ratio (%)	
Lowest (<130 %)	24.99 (1.81)
Middle (131 %–185 %)	9.88 (0.67)
Highest (>185 %)	65.12 (2.22)
Number Missing	537
Worked in Last Week (%)	
Yes	62.46 (1.19)
No	37.54 (1.19)
Number Missing	3
Objective Sleep Variables	
SRI	61.71 (0.50)
Avg. Day Sleep (hours)[¥]	0.99 (0.03)
Avg. Night Sleep (hours)[¥]	6.70 (0.03)
Number Missing	2395
Subjective Sleep Variables®	
Total Night Sleep (hours)	6.92 (0.02)
Number Missing	6
Ever Trouble Sleeping (%)	
Yes	19.65 (0.92)
No	80.35 (0.92)
Ever Sleep Disorder (%)	
Yes	6.36 (0.41)
No	93.64 (0.41)
Number Missing	4
Subjective Depression Severity	
PHQ-9 Continuous	2.45 (0.10)
PHQ-9 Severity Categories (%)	
None	82.74 (0.92)
Mild	11.63 (0.53)
Moderate	3.60 (0.45)
Moderately Severe	1.41 (0.23)
Severe	0.63 (0.14)
Health Behavior Variables	
HEI	54.53 (0.34)
Sedentary Time (min.)	395.29 (5.18)
Number Missing	3
Sedentary Time (hrs.)	6.59 (0.09)
Number Missing	3
Currently Smoking - Yes (%)	17.20 (0.89)
Number Missing	234
Cannabis Use in Past 14 Days - Yes (%)	11.39 (0.73)
Number Missing	2140

Legend. Continuous variables are displayed using mean (standard error), and categorical variables are displayed as the percent of the respective group (standard error of the percent). [¥]Hours of sleep categorized to the day and night periods, respectively, were averaged over seven days of actigraphy wear for objective average day sleep and objective average night sleep. ®For subjective sleep characterization, participants were asked to estimate how many hours of sleep they usually obtain at night during weekdays or workdays for subjective total night sleep, along with if they ever told a doctor they had trouble sleeping or if ever told they had a sleep disorder by a doctor. **Abbreviations**. Avg: Average, BMI: Body Mass Index, HEI: Healthy Eating Index, SE: Standard Error of the Mean, SRI: Sleep Regularity Index.

Table 2
Factors influencing depression severity: Sleep phenotype, demographics, and health behaviors.

	β (SE)	*p*-value	*95 % C.I. LL*	*UL*
Sex: Female	0.84 (0.20)	< .001	0.44	1.25
BMI (kg/m^2)	0.08 (0.02)	< .001	0.04	0.11
Family Income to Poverty Ratio				
Highest	−0.74 (0.28)	.014	−1.31	−0.17
Lowest	0.21 (0.34)	.534	−0.47	0.90
No work in the last week	0.70 (0.23)	.005	0.23	1.17
No Trouble Sleeping	−1.55 (0.31)	< .001	−2.18	−0.92
Total Subjective Sleep (hrs)	−0.22 (0.08)	.014	−0.39	−0.05
SRI	−0.02 (0.01)	.003	−0.04	−0.01
Cannabis Use in Past 14 days	1.32 (0.47)	.008	0.38	2.27
Currently Smoking	0.82 (0.26)	.003	0.29	1.35
HEI	−0.01 (0.01)	.211	−0.02	0.004

Table 2. Complex regression models with sample weights were performed (n = 2923). After holding significant or clinically relevant predictors constant, SRI (β = −0.02, *p* = .0026) and average total subjective sleep time in hours (β = −0.22, *p* = .014) remained significant predictors and negatively associated with PHQ-9. Reference Values - Sex: Male; Family Income to Poverty Ratio: Middle; Work in the last week: Yes; Trouble Sleeping: Yes; Cannabis Use in Past 14 days: No; Currently Smoking: Not Currently Smoking. Abbreviations. BMI: Body Mass Index, HEI: Healthy Eating Index, SE: Standard Error of the Mean, SRI: Sleep Regularity Index.

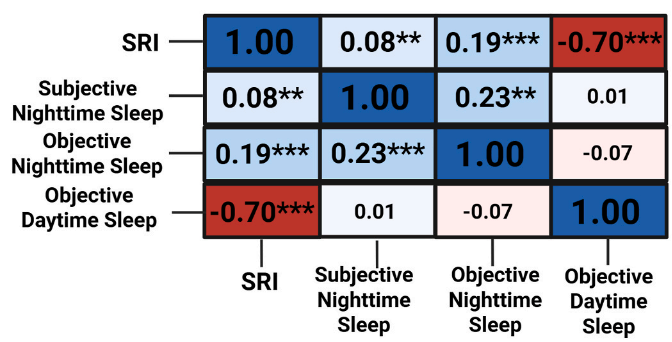

Fig. 2. Association Between Subjective and Objective Sleep Variables
Legend. In this study sample, complex survey-based Pearson correlations show that the sleep regularity index (SRI) is strongly negatively correlated with average daytime sleep, while its associations with subjective and objective nighttime sleep are positive but less pronounced. (**$p < .001$, ***$p < .0001$) Created in BioRender. Maki, K. (2025) https://BioRender.com/c0dnv93.

3.2. *The influence of sleep, health behaviors and socioeconomic variables with depression*

Severity of depression (average PHQ-9) scores were significantly different by sex (female 2.87 ± 0.13; male 2.06 ± 0.11; $p < .0001$), income to poverty ratio (highest: 1.93 ± 0.1; middle: 2.99 ± 0.19; lowest: 3.55 ± 0.19; $p < .0001$), and whether the participant worked in the last week (yes: 2.18 ± 0.1; no: 2.92 ± 0.14; $p < .0001$). Participants who reported more severe levels of depression had higher BMI ($r = 0.12$, $p < .0001$), and lower diet quality (HEI-2015; $r = -0.12$, $p < .0001$). Higher self-reported depression severity scores (PHQ-9) were also associated with shorter subjective and objective night sleep duration ($r = -0.15$, $p < .0001$ and $r = -0.07$, $p = .003$, respectively), and lower SRI scores ($r = -0.18$, $p < .0001$).

Complex regression models were performed, and after adjusting for relevant predictors, both SRI ($\beta = -0.02$, $p = .003$) and subjective nighttime sleep ($\beta = -0.22$, $p = .014$) remained significant predictors of self-reported depression severity via PHQ-9. Working status (participants who reported not working in the last week) was associated with higher depression ($\beta = 0.70$, $p = .005$), and while an income/poverty ratio in the highest group (over 185 % of Federal Poverty Line) was associated with lower depression (β = −0.74, p = .014); there were no differences between subjects in the middle (130–184 %) versus lowest (below 130 %) income/poverty ratio groups (β = 0.21, p = .534). Current tobacco and cannabis use were both predictors of higher depression severity (β = 0.82, p = .003; β = 1.32, p = .008, respectively). However, HEI-2015 scores were not significant predictors of self-reported depression severity (β = −0.01, p = .211). In sensitivity analyses, the interaction between SRI × gender was significant (Supplemental Fig. S1), indicating that among females each one-unit increase in SRI corresponded to a 0.028-point reduction in self-reported depression severity (β = −0.028, p = .043). Interactions between SRI and other tested variables were not significant including recent cannabis use (p = .578), family income/poverty ratio (p = .191), recent cannabis use (p = .578), or current smoking (p = .097).

4. Discussion

In this study, we explored the influence of sleep characteristics, such as sleep regularity and duration, on self-reported depression severity, while accounting for relevant demographic, socioeconomic and health behavior covariates. In a nationally representative sample of U.S. adults, we demonstrate that multiple factors, including sleep health, working status, income/poverty ratio, and active tobacco and cannabis use, influence depression severity. For example, indicators of sleep time and quality are significant predictors of self-reported depression severity including sleep regularity and subjective nighttime sleep. After controlling for all relevant variables, not currently working was associated with higher depression levels, while a higher income/poverty ratio was linked to lower depression levels. Current tobacco and cannabis use were also significant predictors of higher depression severity. These results extend existing research supporting relationships between sleep and mental health, highlighting the importance of including health behaviors and patient-specific factors when evaluating depression risk.

This analysis supports and contributes to the current literature on the associations between both objective and subjective sleep indices and mental health behaviors, particularly regarding the link between sleep regularity and depression. Notably, our results are consistent with one of the pioneer validation studies of the SRI which found that higher sleep irregularity was associated with elevated depressive symptom severity, along with other mental health symptoms such as increased perceived stress (Lunsford-Avery et al., 2018). Our analysis highlights the importance of considering multiple sleep components of sleep hygiene (i.e., day and nighttime duration and sleep regularity), in relation to depression. Additionally, a recent study has shown a strong association between sleep irregularity and symptoms of depression and anxiety among women (Swanson et al., 2023). In our analysis, women reported higher depression severity than men overall, and the significant female × SRI interaction demonstrated that women with lower SRI scores experienced higher depressive symptoms compared to men with similarly low SRI scores in alignment with these prior results. This suggests that although women may experience more severe depression, there is also a stronger relationship between sleep regularity and depression severity in women than in men. Therefore, women may experience greater reductions in depressive symptoms from sleep timing interventions, which highlights the importance of developing gender-specific sleep treatments for depression alongside other health behavior interventions, although our results should be further tested in validation and interventional studies.

This analysis further emphasizes the importance of evaluating and quantifying various health behaviors when exploring relationships between sleep and depressive symptoms. Previous research based on NHANES survey data has shown that both tobacco and cannabis use are associated with depression (Gorfinkel et al., 2020; Wu et al., 2023). Our current study supports these findings, revealing a positive relationship between active cannabis use in the prior 14 days and PHQ-9 scores. While cannabis use has been linked to higher levels of depression (Langlois et al., 2021), as well as alterations in sleep architecture during active use and periods of abstinence and/or withdrawal, self-reported depression severity has been identified as a mediator between cannabis use and poor sleep quality (Maple et al., 2016). This suggests a potential bidirectional relationship between sleep quality and depression severity. Furthermore, the endocannabinoid system, which plays a crucial role in regulating mood, sleep, and stress responses, has been implicated in both sleep quality and depression (Graczyk et al., 2021; Babson et al., 2017). However, due to the complex interactions between cannabis use, endocannabinoid signaling, and mental health, the relationship between these factors and their impact on sleep and depression warrants further investigation. Although we could not control for alcohol use in our present study, previous work by our group showed a relationship in people with alcohol use disorder (AUD) who recently completed inpatient treatment between SRI scores and relapse status (Barb et al., 2022). Moreover, another study from our group demonstrated a relationship of lower SRI scores with excessive daytime napping in people with AUD during inpatient treatment (Brooks et al., 2020). In this study sample, we also noted a strong inverse correlation between average daytime sleep and SRI, which underscores that napping behavior may be a major driver of sleep irregularity. However, the SRI is a multidimensional construct which is calculated as the probability of being in the same sleep or wake state at any two time-points 24 h apart. Therefore, in addition to timing, frequency and duration of daytime naps, SRI also captures variability in night-to-night sleep and wake times, shifts in the midpoint of the main sleep period, and fragmentation and wake within sleep episodes (Phillips et al., 2017; Lunsford-Avery et al., 2018; Fischer et al., 2021). Relying on daytime sleep alone therefore risks misclassifying individuals who keep highly irregular sleep schedules but rarely nap (leading to lower SRI scores) or have highly regulated nap and sleep schedules (leading to higher SRI scores). Future studies testing self-reported measures that combine questions on daytime sleep and napping behaviors with items on sleep- and wake-time variability may provide insight to the extent daytime napping correlates across different patient and occupational populations (i.e., shift workers). Building on our observation that lower SRI scores track with self-reported depression severity, future studies should replicate these analyses in diverse clinical and community cohorts to determine how much SRI contributes to mental health across patient populations.

The association between patient-specific factors, such as current work status, and depression has been noted to be complex and may depend on one's community or other psychological factors. For example, many studies have reported the protective benefits of employment on an individual's mental health and unstable work contributing to higher depression severity (Oh et al., 2022; Li and Chu, 2024). Other research has linked occupational hazards, such as employee burnout, to increased subjective stress and depression (Kottler et al., 2024; Ryan et al., 2023). Nevertheless, although these data only captured work status over the previous week, our findings support previous research and the relationships between employment and depressive symptoms such that, participants who reported no work in the previous week had higher depressive symptoms when all other factors were held constant.

Several strengths of our study enabled us to gather important data, including both objective and subjective assessments of sleep, and a comprehensive nationally representative database with clinically relevant variables, such as PHQ-9, health behaviors, and socioeconomic variables. However, there are limitations that are important to acknowledge. First, although prior research from our group demonstrated associations with the SRI in various clinical measures and alcohol use related variables in people with AUD (Barb et al., 2022), we did not include alcohol use in this analysis. We were unable to include this information in our analysis as the timeframe of the alcohol related surveys cover intake over the previous 12 months, and therefore would not be concordant with the timeframe captured in the current study. Second, patient-reported depression severity and actigraphy measures were not evaluated over the same timeframe. Actigraphy watches were placed during the in-person assessment and monitored for the following seven days of sleep and wake, while the PHQ-9 questionnaire assessed self-reported depression severity in the 14 days *preceding* the examination. We therefore had to assume that sleep behaviors in the post-visit week resembled sleep during the two-week period before the clinical assessment when depression severity was assessed. Such temporal mismatch may misclassify exposure or outcome variables and weaken the observed within-person associations. In addition, the cross-sectional design prevents causal inference in terms of whether irregular sleep contributes to mood disturbance or whether depression severity impacts sleep patterns (i.e., people with higher depression severity experience greater sleep irregularity and daytime napping secondary to their symptom presentation). Longitudinal studies that capture sleep and mood concurrently are needed to validate our findings and clarify directionality. Until such evidence is available, any recommendations must be considered hypothesis-generating and used to inform future clinically relevant research probing relationships between sleep and mental health.

Third, limitations inherent to actigraphy must be considered. Actigraphy estimates sleep based on movement, which may lead to misclassification, particularly in individuals who experience prolonged periods of inactivity while awake. Additionally, best practices for sleep regularity assessment recommend using sleep diaries alongside actigraphy to enhance accuracy (Lunsford-Avery et al., 2018). However, NHANES did not include subjective daily sleep logs to accompany actigraphy measures, limiting our ability to validate objective sleep regularity measurements outside of the comprehensive information on data quality review and open-source prediction algorithms published on the NHANES website (National Center for Health Statistics, 2014a; National Center for Health Statistics, 2014b). The timeframe of actigraphy collection in the NHANES sample was limited to 7–9 days and some data loss (i.e., individual respondents were excluded) was unavoidable due to respondents not wearing the watch devices for extended periods of time. This limited the total sample size with an adequate amount of physical activity monitor data meeting quality thresholds to be assessed for objective sleep measures and SRI. A comparison of respondents with versus without useable actigraphy revealed differences across groups: non-included participants were younger, more likely to be employed, and had slightly poorer diet quality. This pattern suggests a potential selection bias, whereby groups with greater competing time demands or unhealthy lifestyle behaviors were under-represented in the objective sleep analyses, possibly leading to conservative estimates of associations between sleep and mental health. Because these characteristics may also influence willingness or ability to wear actigraphy devices, our findings underscore the need for dedicated feasibility work. Future studies should explicitly assess actigraphy acceptability and adherence among younger, full-time workers, and adapt monitoring protocols (e.g., flexible wear schedules, real-time adherence prompts) to ensure these groups are adequately captured.

Finally, the self-reported sleep duration variable in NHANES was limited in scope. Due to the question wording (i.e., 'How much sleep do you usually get at night on weekdays or workdays?'), participants only commented on average nighttime sleep on weekdays or workdays, which does not account for factors that may influence SRI across the entire week. For example, daytime napping behaviors or extended sleep on weekends to compensate for decreased weekday sleep due to school-related or occupational factors may have resulted in an underestimation of perceived average sleep duration. Furthermore, as NHANES only inquired about night sleep and did not assess daytime sleep, participants with increased hours of sleep during the day due to shift work or other factors may have further underestimated total sleep duration, suggesting future validation of objective and subjective sleep variables should consider subjective evaluation of daytime and weekend sleep behaviors. Despite these limitations, our study identified significant associations between lower sleep regularity, shorter sleep duration, and increased depression severity, even after adjusting for key health behaviors and socioeconomic factors. These findings highlight the importance of sleep consistency in mental health and suggest that future research investigating the efficacy of interventions targeting sleep regularity may be beneficial for mitigating depression risk.

5. Conclusions

In this nationally representative samples of U.S. adults, lower SRI and shorter reported nighttime sleep duration remained significantly associated with increased self-reported depression severity, even after adjusting for clinically relevant factors. Given the strong correlation between average daytime sleep and SRI, daytime sleep patterns may serve as a pragmatic, although partial, proxy for assessing sleep regularity in the absence of actigraphy. Future studies are needed to test the sensitivity and specificity of relationships between daytime napping and SRI across clinical and occupational populations to determine its generalizability. Additionally, women had stronger relationships between SRI and depression severity and sleep hygiene represents a modifiable risk factor that could be targeted in managing depression severity in women. Given SRI was an independent predictor of depression severity, our results highlight the potential importance of sleep regularity in promoting mental health in both women and men and highlight the need for continued research on behavioral interventions aimed at improving sleep consistency as a non-pharmacologic approach to mitigating depression symptoms. In addition to optimizing sleep, targeting health behaviors such as smoking cessation and decreasing cannabis use will aid in the ongoing management of depressive symptoms and should be considered as complementary lifestyle strategies in mental health interventions across patient populations.

CRediT authorship contribution statement

Katherine A. Maki: Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization. **Li Yang:** Writing – review & editing, Methodology, Formal analysis. **Nicole Farmer:** Writing – review & editing, Validation. **Shreya Papneja:** Writing – review & editing, Visualization. **Gwenyth R. Wallen:** Writing – review & editing, Supervision. **Jennifer J. Barb:** Writing – review & editing, Methodology, Formal analysis, Data curation.

Patient consent statement

N/A. The NHANES datasets used in this analysis are publicly available and deidentified.

Authors' information

The contributions of the NIH authors were made as part of their official duties as NIH federal employees, are in compliance with agency policy requirements, and are considered Works of the United States Government. However, the findings and conclusions presented in this paper are those of the authors and do not necessarily reflect the views of the NIH or the U.S. Department of Health and Human Services.

Ethics approval statement

This study did not undergo ethics review as the NHANES datasets used in this analysis are publicly available and deidentified.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.nbscr.2025.100133.

Data availability

The raw data downloaded from the NHANES datasets and calculated variables used in this analysis have been deposited in Figshare and are freely accessible at DOI: 10.6084/m9.figshare.29573621

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