Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Non-linear association of Social Jetlag with Depressive Symptoms Mediating Suicidal Ideation: Heterogeneity by Age and Sex

Keke Yao
Shandong Daizhuang Hospital
Fei Zhao
Xiyuan Hospital Jining Hospital, China Academy of Chinese Medical Sciences
Zhenzhen Yang
Shandong Daizhuang Hospital
Zhonggang Wang
Shandong Daizhuang Hospital
Fuping Sun
FupingS03250@163.com
Shandong Daizhuang Hospital
Jie Yang
National Center for Mental Disorders, The Second Xiangya, National Clinical Research Center for Mental Disorders, Hospital of Central South University

Research Article

Keywords: social jetlag, depressive symptoms, suicidal ideation, non-linear association, mediation analysis, NHANES

Posted Date: August 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10734112/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Objectives

This study examined the nonlinear associations between social jetlag (SJL), depressive symptoms, and suicidal ideation. It also tested whether inflammatory markers and depressive symptoms mediated these associations. Stratified analyses by age and sex were performed.

Methods

Data came from 5,838 adults in the 2017–2020 National Health and Nutrition Examination Survey. Restricted cubic splines were used to model nonlinear relationships. Mediation analyses assessed the roles of an inflammatory burden index (CRP and neutrophil-to-lymphocyte ratio) and depressive symptoms. All analyses were stratified by age group and sex.

Results

A near U-shaped association emerged. Zero SJL corresponded to the highest depressive symptom scores. Mild-to-moderate SJL (> 0 to < 2 hours) was linked to lower scores, whereas severe SJL was linked to elevated scores. This pattern was strongest in young adults (20–39 years). Among women, moderate SJL was associated with a 65% reduction in the odds of suicidal ideation, compared with no SJL. Mediation analyses showed that depressive symptoms accounted for 25.2% of the SJL–suicidal ideation association. The inflammatory burden index did not mediate this association.

Conclusions

Mild-to-moderate SJL may have certain beneficial associations with mental health outcomes in specific subgroups. The overall SJL–mental health relationship is nonlinear. The mediating pathway operates primarily through depressive symptoms, not systemic inflammation.

What was known

Social jetlag is associated with depressive symptoms, a well-established risk factor for suicidal ideation. However, the mediating role of depressive symptoms in the relationship between social jetlag and suicidal ideation remains unclear.

What this study adds

Using nationally representative data, this study identifies a non-linear association between social jetlag and suicidal ideation, which is mediated by depressive symptoms. Furthermore, the findings reveal

significant heterogeneity across age and sex groups, offering novel, subgroup-specific evidence to inform targeted sleep interventions and suicide prevention strategies.

1. Introduction

Social jetlag (SJL) refers to the misalignment between an individual's internal biological clock (driven by endogenous circadian rhythms) and socially imposed sleep-wake schedules (e.g., work or school timetables). It is commonly quantified as the absolute difference in sleep midpoint between free days and workdays. In today's non-stop society, SJL is extremely common, with a substantial proportion of individuals experiencing significant social jetlag. For instance, among Japanese adolescents, nearly half (49.6%) reported SJL ≥ 1 hour and 17.1% reported SJL ≥ 2 hours [1]; in a sample of Chinese college students, over 20% experienced SJL ≥ 1 hour [2]; and among Icelandic adolescents, 71% exhibited moderate-to-severe SJL [3]. Extensive epidemiological research has linked SJL to a range of adverse health outcomes, including metabolic dysfunction, cardiovascular disease, and obesity [4,5]. Notably, growing attention has been directed toward the relationship between SJL and mental health outcomes, particularly depressive symptoms.

Accumulating evidence indicates a stable, albeit modest, positive association between SJL and depressive symptoms across diverse populations. A recent systematic review and meta-analysis of observational studies among young people (aged 10–24 years) found a statistically significant but modest positive correlation between SJL and depressive symptoms, with high SJL (≥ 2 hours) associated with 44% higher odds of depressive symptoms [6]. Large-scale population-based studies have further corroborated these findings: in the Korean working population, individuals with SJL > 2 hours had an 86% higher odds of depressive symptoms compared to those with minimal SJL [7]; among Chinese adolescents, SJL ≥ 2 hours was associated with a 51% increased risk of depression [8]; and among Japanese non-shift workers, SJL ≥2hours was linked to a 114% increased likelihood of depressive symptoms [9] Moreover, a study of Chinese college students revealed a non-linear (J-shaped or U-shaped) relationship between SJL and depressive symptoms, where SJL exceeding 1.2 hours markedly increased depression risk, whereas lower levels of SJL were not significantly associated with depression [10]. These findings suggest that the adverse effects of SJL may be dose-dependent, with mild degrees of SJL perhaps not uniformly harmful.

Beyond depressive symptoms, emerging evidence suggests that SJL may also be linked to suicidal ideation and related behaviors. A large cross-sectional study of Chinese adolescents (n = 39,731) identified SJL as a significant mediator in the association between problematic internet use and suicidal ideation, with the mediation effect being slightly larger in females than in males [11]. A prospective study of UK adults further demonstrated that evening chronotype, a condition closely related to SJL, was associated with increased future suicide intent, an effect mediated by feelings of defeat and entrapment [12]. Additionally, research among college students found that absolute SJL (the discrepancy between weekday and weekend sleep schedules) was uniquely linked to recent non-suicidal self-injury, suggesting that sleep timing inconsistency may be a more relevant risk factor than insomnia itself [13]. However,

nationally representative data on the direct association between SJL and suicidal ideation remain scarce. Most existing research has focused on adolescents or college students, with only one small longitudinal sample of UK adults (n = 187) covering a broader age range, yet lacking representative coverage of the full adult age spectrum [12]. Moreover, the potential moderating roles of age and sex in this relationship have not been adequately investigated, although sex differences in the mediating pathway have been noted in adolescent samples [11].

Although depressive symptoms are widely recognized as a proximal risk factor for suicidal ideation, few studies have explicitly tested whether they mediate the pathway between SJL and suicidal ideation. A study conducted in Mexico demonstrated that depressive symptoms mediated the relationship between circadian preference (morningness/eveningness) and suicidal ideation [14]; however, this mediational pathway has not yet been examined using SJL as the exposure in a nationally representative sample of adults. Meanwhile, circadian disruption is known to activate inflammatory responses [15], and existing research has shown that inflammatory markers, sleep disturbances, and depression are pairwise correlated. Specifically, elevated levels of systemic inflammatory markers, such as C-reactive protein (CRP) and the neutrophil-to-lymphocyte ratio (NLR), have been found to partially mediate the association between sleep disturbances and depression, albeit with a modest effect size [16]. Nevertheless, whether an inflammatory burden index constructed from these biomarkers mediates the pathway from SJL to suicidal ideation remains untested. Therefore, elucidating whether SJL influences suicidal ideation through depressive symptoms or systemic inflammation is critical for understanding the role of circadian misalignment in the chain of suicide risk.

To address these gaps, the present study will use nationally representative adult data from the National Health and Nutrition Examination Survey (NHANES) 2017–2020. Our objectives are threefold: (1) to characterize the shape (linear vs. non-linear) of the associations between SJL and both depressive symptoms and suicidal ideation; (2) to test the mediating role of depressive symptoms in the SJL-suicidal ideation relationship; and (3) to examine whether an inflammatory burden index serves as a biological mediator of this pathway, while also evaluating age and sex heterogeneity across all associations. The findings will provide empirical evidence for how circadian misalignment affects mental health and offer clues for population-level prevention and intervention strategies.

2. Methods

All procedures of NHANES were approved by the National Center for Health Statistics Research Ethics Committee, and written informed consent was given by each participant before participation. It was carried in compliance with the principles of the Declaration of Helsinki.

2.1 Study Design and Data Source

This study analyzed data from the 2017–2020 pre-pandemic cycle of the NHANES, a nationally representative survey of the United States. All NHANES data are publicly available and can be freely accessed at:https://wwwn.cdc.gov/nchs/nhanes/. From 15,560 initial participants, we excluded 6,328

individuals younger than 20 years, 87 pregnant women, and 3,307 individuals with missing data on SJL, depressive symptoms, suicidal ideation, or inflammatory biomarkers, resulting in a final analytic sample of 5,838 participants (**Figure 1**).

2.2 Variables

2.2.1 Social Jetlag (SJL)

SJL was calculated as the absolute difference in mid-sleep time between free days and workdays: SJL = |mid-sleep on free days − mid-sleep on workdays|, expressed in hours. Mid-sleep time was calculated as: bedtime + (wake time − bedtime) / 2. For participants whose wake time crossed midnight (i.e., wake time < bedtime), 12 hours was added to the wake time to ensure valid calculation [17,18]. Based on existing literature [7,19] and the distribution of study participants, participants were categorized into four groups: No SJL (= 0 h), mild SJL (0 to 1 h), moderate SJL (≥1 to 2 h), and severe SJL (≥2 h).

2.2.2 Depressive Symptoms and Suicidal Ideation

Depressive symptoms were assessed using the Patient Health Questionnaire-8 (PHQ-8), which comprises the first eight items of the PHQ-9, excluding the suicidal ideation item [20]. The PHQ-8 assesses symptom frequency over the past two weeks using a standardized 0–24 scoring system, with higher scores indicating greater depressive symptom severity. Suicidal ideation was assessed using the ninth item of the PHQ-9: "Over the last 2 weeks, how often have you been bothered by thoughts that you would be better off dead or of hurting yourself in some way?" Responses were dichotomized into presence (several days, more than half the days, or nearly every day) versus absence (not at all). The PHQ-8 was as valuable as the PHQ-9 in detecting cases of major depression [21].

Inflammatory Biomarkers

The inflammatory burden index (IBI) is a straightforward and reproducible composite marker of inflammation that provides a more comprehensive evaluation of systemic inflammatory load and immune imbalance than individual biomarkers [22]. It is calculated as the product of the NLR and CRP: IBI = CRP (mg/dL) × NLR, where NLR is defined as the absolute neutrophil count divided by the absolute lymphocyte count. Neutrophil and lymphocyte counts were obtained from an automated complete blood count, and CRP levels were measured using a high-sensitivity assay. To normalize their distributions before analysis, both IBI and CRP were natural log-transformed.

2.3 Covariates

Demographic information collected included age, gender, race, education level, and poverty-to-income ratio (PIR). Lifestyle factors included smoking status and physical activity. Medical conditions included hypertension, diabetes, coronary heart disease, stroke, chronic obstructive pulmonary disease, and cancer. Body mass index (BMI) was calculated using the standard formula of weight in kilograms divided by height in meters squared.

The study categorized race into five groups: Non-Hispanic White, Non-Hispanic Black, Mexican American, Other Hispanic, and other races. Educational level was stratified into five levels: <9th grade, 9–11th grade, High school graduate, Some college, and College graduate or above. Smoking status was classified into three categories based on lifetime consumption: never smoker (<100 lifetime cigarettes), former smoker (≥100 lifetime cigarettes but not currently smoking), and current smoker. Comorbidity burden was assessed as a count variable (range: 0–6) summing the presence of six physician-diagnosed chronic conditions: coronary heart disease, stroke, chronic obstructive pulmonary disease, cancer, hypertension, and diabetes.

2.4 Statistical Analysis

All analyses accounted for the complex multistage survey design of NHANES using appropriate weights (WTMECPRP), stratum (SDMVSTRA), and primary sampling unit (SDMVPSU) variables. Weighted means and proportions were calculated to describe sample characteristics. The shape of the association between continuous SJL and both PHQ-8 and suicidal ideation was examined using restricted cubic splines with three knots (0, 0.5, and 3 hours). Weighted linear regression and weighted logistic regression were used to estimate associations between SJL categories and PHQ-8 and suicidal ideation, respectively, with No SJL as the primary reference group. All models were adjusted for age, sex, race/ethnicity, BMI, smoking status, and comorbidity count.

Mediation analyses tested two parallel pathways linking SJL to suicidal ideation: an inflammatory pathway (SJL → IBI → suicidal ideation) and a psychopathological pathway (SJL → PHQ-8 → suicidal ideation). Bootstrap resampling (1,000 iterations) was used to estimate 95% CIs for the psychopathological pathway, given the non-linear exposure-mediator relationship identified in RCS analysis. Sensitivity analyses substituted CRP for IBI, tested an additional pathway (SJL → IBI → PHQ-8), and used mild SJL (0 to 1 h) as the alternative reference group. Stratified analyses by age group (20–39, 40–59, ≥60 years) and sex were conducted. Two-sided $p < 0.05$ was considered statistically significant, and $p = 0.05–0.10$ was interpreted as suggestive evidence.

3. Results

3.1 Characteristics of the participants

The study included 5,838 participants, representing approximately 169.4 million U.S. adults after sample weighting, of whom 3.7% (n = 218) reported suicidal ideation. Table 1 presents the baseline characteristics comparing participants with and without suicidal ideation. Significant differences were observed across several characteristics. Depressive symptoms (PHQ-8 score) were markedly higher in the suicidal ideation group compared to the non-suicidal group (mean 12.3 vs. 2.9, $p < 0.001$). Smoking status also differed significantly ($p < 0.001$), with a higher proportion of current smokers among those with suicidal ideation (29.8% vs. 16.4%) and a lower proportion of never smokers (42.7% vs. 57.9%). Participants with suicidal ideation had a greater comorbidity burden (mean 1.2 vs. 0.9, $p < 0.001$).

Race/ethnicity distribution showed significant variation (p = 0.017), with a higher representation of “other Hispanic” individuals in the suicidal ideation group (16.5%) and lower proportions of non-Hispanic Black and non-Hispanic White participants. SJL distribution also differed significantly between groups (p = 0.039); notably, the proportion of participants with No SJL was higher in the suicidal ideation group than in the non-suicidal group (47.7% vs. 38.8%). No statistically significant differences were found between the two groups for age (p = 0.279), sex (p = 0.434), body mass index (BMI; p = 0.057), or log-transformed inflammatory burden index (log-IBI; p = 0.129), although BMI was numerically higher in the suicidal ideation group (31.1 vs. 30.0).

Table 1
Characteristics of Study Participants by Suicidal Ideation Status

Characteristic	Suicidal Ideation			
	Overall N = 5,838[1]	No N = 5,620[1]	Yes N = 218[1]	p-value[2]
Age (years)	52.8 (17.3)	52.9 (17.3)	51.6 (17.6)	0.279
Sex				0.434
Male	2,870 (49.2%)	2,769 (49.3%)	101 (46.3%)	
Female	2,968 (50.8%)	2,851 (50.7%)	117 (53.7%)	
Race/Ethnicity				0.017
Mexican American	712 (12.2%)	682 (12.1%)	30 (13.8%)	
Other Hispanic	595 (10.2%)	559 (9.9%)	36 (16.5%)	
Non-Hispanic White	2,258 (38.7%)	2,180 (38.8%)	78 (35.8%)	
Non-Hispanic Black	1,347 (23.1%)	1,307 (23.3%)	40 (18.3%)	
Other	926 (15.9%)	892 (15.9%)	34 (15.6%)	
BMI (kg/m²)	30.1 (7.3)	30.0 (7.3)	31.1 (8.1)	0.057
Smoking Status				< 0.001
Never	3,346 (57.3%)	3,253 (57.9%)	93 (42.7%)	
Former	1,506 (25.8%)	1,446 (25.7%)	60 (27.5%)	
Current	984 (16.9%)	919 (16.4%)	65 (29.8%)	
Comorbidity Count	0.9 (1.0)	0.9 (1.0)	1.2 (1.3)	< 0.001
Social Jetlag				0.039
No (= 0)	2,284 (39.1%)	2,180 (38.8%)	104 (47.7%)	
Mild (> 0 to < 1 h)	1,428 (24.5%)	1,386 (24.7%)	42 (19.3%)	
Moderate (1 to < 2 h)	1,298 (22.2%)	1,258 (22.4%)	40 (18.3%)	
Severe (≥ 2 h)	828 (14.2%)	796 (14.2%)	32 (14.7%)	
PHQ-8 Score	3.3 (4.4)	2.9 (3.9)	12.3 (7.4)	< 0.001
Log-IBI	1.4 (1.3)	1.3 (1.3)	1.5 (1.3)	0.129

[2]Welch Two Sample t-test; Pearson's Chi-squared test

Characteristic	Suicidal Ideation			
	Overall	No	Yes	p-value[2]
	N = 5,838[1]	N = 5,620[1]	N = 218[1]	
[1]Mean (SD); n (%). Log-IBI: log-transformed Inflammatory Burden Index.				
[2]Welch Two Sample t-test; Pearson's Chi-squared test				

2.2 Non-linear Association between Social Jetlag and Mental Health Outcomes

Restricted cubic spline analysis revealed a significant non-linear association between continuous SJL and depressive symptoms (Wald F = 4.22, p = 0.039; Fig. 2A). The fitted curve exhibited an approximately U-shaped relationship: the highest PHQ-8 scores were observed in the No SJL (=0h). Predicted PHQ-8 scores decreased with mild to moderate SJL (>0 to < 2 h), followed by a slight increase at severe SJL (≥ 2 h). A similar declining non-linear trend was observed for suicidal ideation, although it did not reach conventional statistical significance. Specifically, the predicted log-odds of suicidal ideation were highest in the No SJL (0h), then gradually decreased as SJL increased from mild to moderate (>0 to < 2 hours), and subsequently entered a plateau phase when severe SJL (≥ 2 h) (Wald F = 3.19, p = 0.075; Fig. 2B). In contrast, no linear or non-linear association was found between SJL and the inflammatory burden index (Wald F = 0.70, p = 0.512).

3.3 Primary Analysis: SJL Categories and Mental Health Outcomes

Table 2 presents the associations between SJL categories and both depressive symptoms and suicidal ideation, using No SJL as the reference group. After adjusting for age, sex, race, BMI, smoking status, and comorbidity count, participants with mild SJL (> 0 to <1 h) exhibited significantly lower PHQ-8 scores (aβ = −0.60, 95% CI: −1.20 to − 0.04, p = 0.037), as did those with moderate SJL (aβ = −0.86, 95% CI: −1.54 to − 0.19, p = 0.017). The association for severe SJL was not statistically significant (aβ = −0.52, 95% CI: −1.14 to 0.10, p = 0.091). Regarding suicidal ideation, compared with the No SJL group, participants with moderate SJL had 56% lower odds of reporting suicidal ideation (aOR = 0.44, 95% CI: 0.25 to 0.77, p = 0.008). Mild SJL was associated with a suggestive 43% reduction in the odds of suicidal ideation (aOR = 0.57, 95% CI: 0.32 to 1.04, p = 0.066). The odds of suicidal ideation in the severe SJL group did not differ significantly from those in the No SJL group (aOR = 0.71, 95% CI: 0.39 to 1.30, p = 0.254). Furthermore, in a sensitivity analysis using mild SJL (0–1 h) as the reference group, No SJL was associated with a trend toward increased odds of suicidal ideation (aOR = 1.74, 95% CI: 0.96–3.16, p = 0.066), while moderate and severe SJL did not differ significantly from mild SJL (**Table S1**).

Table 2
Association between Social Jetlag Categories and Mental Health Outcomes (Reference: No SJL)

Characteristic	PHQ-8 (Depressive Symptoms)			Suicidal Ideation		
	Adjusted β	95% CI	p-value	Adjusted OR	95% CI	p-value
Social Jetlag						
No (SJL = 0)	—	—	—	—	—	—
Mild (> 0 to < 1 h)	-0.60	-1.2, -0.04	0.037	0.57	0.32, 1.04	0.066
Moderate (1 to < 2 h)	-0.86	-1.5, -0.19	0.017	0.44	0.25, 0.77	0.008
Severe (≥ 2h)	-0.52	-1.1, 0.10	0.091	0.71	0.39, 1.30	0.254
Abbreviations: CI = Confidence Interval, OR = Odds Ratio Adjusted for age, sex, race/ethnicity, BMI, smoking status, and comorbidity count.						

3.4 Mediation Analysis

All analyses were adjusted for age, sex, race/ethnicity, BMI, smoking status, and comorbidity count. In the overall analysis, depressive symptoms (PHQ-8) showed a significant mediating effect, accounting for 25.2% of the total effect. In contrast, the IBI did not mediate the association (indirect effect = 0.000, 95% CI: −0.003 to 0.003). Sensitivity analysis substituting CRP for IBI yielded consistently null findings (indirect effect = 0.000, 95% CI: −0.002 to 0.002). An additional pathway testing whether IBI mediated the SJL–depression association was also non-significant (indirect effect = 0.000, 95% CI: −0.003 to 0.003); detailed path coefficients are presented in **Table S2**. As shown in Fig. 3, the mediation analysis further revealed that the indirect effect of SJL on suicidal ideation through depressive symptoms was significant (a×b = − 0.035; bootstrap 95% CI: −0.067, − 0.005), with a proportion mediated of 25.2%. This indirect pathway operated despite a non-significant direct effect (c' = −0.079, p = 0.226) and a non-significant total effect (c = − 0.141, p = 0.089). The a-path (SJL → depressive symptoms) was negative and borderline non-significant (a = − 0.115, p = 0.095), whereas the b-path (depressive symptoms → suicidal ideation) was strongly positive (b = 0.308, p < 0.001).

3.5 Stratified Analyses

Figure 4 present the associations between SJL categories and both depressive symptoms and suicidal ideation stratified by age-sex group.

Age-stratified analyses. For depressive symptoms, the protective association between non-No SJL and PHQ-8 was most pronounced in young adults aged 20–39 years. In this age group, moderate SJL was

significantly associated with lower PHQ-8 scores (Adjusted β = −1.19, 95% CI: −2.18 to − 0.18, p = 0.024), while mild (Adjusted β = −1.17, p = 0.054) and severe SJL (Adjusted β = −0.94, p = 0.057) approached significance. In middle-aged adults (40–59 years), mild and moderate SJL showed suggestive protective associations (Adjusted β = −0.70, p = 0.073 and Adjusted β = −0.82, p = 0.073, respectively), whereas severe SJL was not significant (p = 0.249). Among older adults (≥ 60 years), the protective effect was largely attenuated and severe SJL even showed a non-significant positive association (Adjusted β = +0.49, p = 0.285), indicating a clear age-dependent gradient (Fig. 4A). For suicidal ideation, the age-stratified pattern was broadly consistent, although statistical power was limited by the smaller number of events (Fig. 4B). Notably, moderate SJL was significantly associated with lower odds of suicidal ideation among older adults (aOR = 0.37, 95% CI: 0.15 to 0.87, p = 0.026), and mild SJL approached significance in young adults (aOR = 0.40, p = 0.058). Detailed stratified results, including all effect estimates and confidence intervals, are provided in **Table S3** in the supplementary material.

Sex-stratified analyses. For depressive symptoms, males exhibited a dose-response pattern: the protective association strengthened progressively from mild (Adjusted β = −0.61, p = 0.070) to moderate (Adjusted β = −0.76, p = 0.042) to severe SJL (Adjusted β = −0.85, p = 0.034). In contrast, females showed a threshold effect: moderate SJL was significantly protective (Adjusted β = −0.95, p = 0.022), but the protective effect disappeared entirely for severe SJL (Adjusted β = −0.12, p = 0.741) (Fig. 4C). This sex-specific pattern was even more pronounced for suicidal ideation (Fig. 4D). Moderate SJL was significantly protective only in females, with a 65% reduction in the odds of suicidal ideation (aOR = 0.35, 95% CI: 0.20 to 0.59, p < 0.001), representing the single strongest protective signal across all subgroup analyses. No significant associations were observed in males for suicidal ideation. Detailed stratified results, including all effect estimates and confidence intervals, are provided in **Table S4** in the supplementary material.

4. Discussion

This study, based on large-sample data from the 2017–2020 NHANES, systematically examined, for the first time in a nationally representative sample of U.S. adults, the nonlinear associations between SJL and both depressive symptoms and suicidal ideation, and further tested the mediating roles of depressive symptoms and inflammatory burden in these associations. Three main findings emerged. First, SJL showed a significant nonlinear association with depressive symptoms, with mild to moderate SJL (> 0 to < 2 hours) paradoxically related to lower levels of depressive symptoms and suicidal ideation. Second, this 'protective' association exhibited marked age and sex heterogeneity, with the effect being most pronounced in young adults, and moderate SJL showing a particularly strong protective effect against suicidal ideation in women. Third, depressive symptoms significantly mediated the association between SJL and suicidal ideation, with a proportion mediated of 25.2%, whereas the inflammatory burden index constructed based on CRP and NLR was not confirmed as a significant mediating pathway. Collectively, these findings reveal a nuanced, non-linear relationship between SJL and mental health, characterized by a paradoxical protective association of Mild and Moderate SJL that is particularly

pronounced in young adults and women, and identify depressive symptoms, rather than systemic inflammation, as the key mediator linking SJL to suicidal ideation.

The most intriguing finding of this study is that, compared with no SJL, mild to moderate SJL (> 0 to < 2 hours) was associated with lower levels of depressive symptoms and a lower risk of suicidal ideation, and the non-linear relationship between SJL and depressive symptoms was statistically confirmed by restricted cubic spline analysis. This pattern differs from the assumption that any degree of circadian misalignment is invariably detrimental; instead, it resembles the U-shaped relationships often reported in sleep research, that both short and long sleep durations predict higher depression risk [23,24,25]. The approximately U-shaped relationship pattern between SJL and mental health outcomes in this study suggests that the complete absence of SJL (i.e., identical sleep timing on workdays and free days) may not represent the most optimal sleep rhythm pattern; rather, moderate social rhythm variability might confer adaptive benefits at the physiological or psychological level for individuals.

Several mechanisms may explain why mild to moderate SJL appears protective. A national survey showed that weekend catch-up sleep was associated with a lower prevalence of depressive symptoms, particularly among individuals with short weekday sleep [26]. Meanwhile, Mild and Moderate SJL implies a certain degree of flexibility in sleep-wake rhythm. Existing studies support an association between sleep-wake schedule flexibility and psychological flexibility [27,28]. A cluster analysis of Japanese young adults identified sleep-wake rhythm problems as one of four major sleep types, and psychological inflexibility (particularly the “inflexible type”) had a stronger negative impact on mental health [29]. These findings suggest that rigid adherence to a sleep-wake schedule may reflect lower psychological flexibility, thereby exacerbating cognitive arousal and negative emotions. Furthermore, a certain degree of day-to-day variability in sleep timing is increasingly viewed as a normal, potentially adaptive human behavior that aids entrainment to fluctuating social demands, rather than an inherent pathology [30]. An alternative, non-causal explanation is that a “No SJL” state may not directly foster depression but instead reflect limited social engagement or a monotonous lifestyle, which themselves confer elevated depression risk.

Notably, although the nonlinear trend for suicidal ideation did not reach conventional statistical significance ($p = 0.075$), its dose–response pattern closely mirrored that of depressive symptoms. This concordance suggests that any protective association of mild SJL with suicidality may largely operate through reduced depressed mood, rather than through a direct effect. The attenuated significance likely reflects limited statistical power due to lower endorsement of suicidal ideation in the sample. Similarly, a study on Mexican adolescents found that the association between circadian preference and suicidal ideation among morning-shift students was significantly mediated by depressive symptoms and school-day sleep duration [14]. This also indirectly supports the indirect pathway of depressive symptoms between SJL and suicide risk.

Our age-stratified analyses revealed a gradient in the association between SJL and depressive symptoms: a protective effect strongest in young adults aged (20–39 years), attenuated in midlife (40–

59 years), and absent in older adults (≥ 60 years). A similar pattern emerged for suicidal ideation, with moderate SJL retaining a residual protective effect even in the oldest group. This contrasts with prior studies reporting positive associations between SJL and depression across ages [1,3,31]. For example, a meta-analysis indicated SJL > 2 h increased depression odds by 1.87-fold in adolescents (Lu et al., 2026). The discrepancy may reflect that our protective effect was limited to moderate SJL (1 to < 2 h), whereas most literature examines severe SJL (>2 h) and different study populations [1,32]. Additionally, younger adults may benefit from weekend catch-up sleep, while post-retirement flexibility dilutes any protective value in older adults [33].

Sex-stratified analyses revealed distinct profiles. In males, SJL showed a linear protective relationship with depressive symptoms; in females, protection was limited to moderate SJL and lost at severe levels. Notably, moderate SJL was associated with substantially reduced risk of suicidal ideation in females, the strongest protective signal across subgroups. This sex-divergent pattern may be explained by inherent differences in sleep physiology and circadian regulation between males and females. Women have a shorter circadian period and an earlier melatonin phase [34,35,36], making their circadian system more sensitive to timing shifts. Moreover, women show lower tolerance to sleep deprivation and faster accumulation of sleep pressure [37]; therefore, moderate weekend catch-up sleep (i.e., moderate SJL) may relieve weekday sleep debt and confer emotional benefits, whereas excessive SJL disrupts this fragile balance and abolishes protection. After puberty, females also have higher rates of insomnia and depression [38,39] and poorer subjective sleep quality [40], rendering them more susceptible to the mood effects of SJL. In contrast, men's longer circadian period and later sleep preference [41,42], together with relative resilience to sleep loss [37], may allow a linear protective response even at higher SJL levels. Notably, the strong protective effect of moderate SJL on suicidal ideation in females suggests that permitting modest weekend sleep flexibility could have clinical preventive value for this high-risk group. Future mechanistic studies should examine interactions between sex hormones and circadian systems to elucidate the neurobiological basis of these sex-specific associations.

In this study, depressive symptoms were established as a key mediator in the association between SJL and suicidal ideation, accounting for 25.2% of the total effect; although the direct path from SJL to depressive symptoms was only marginally significant, the bootstrap confidence interval for the indirect effect did not include zero, confirming the statistical reliability of this mediation. This finding aligns with prior evidence that depressive symptoms mediate the relationship between chronotype and suicidal ideation in university students [30,43], and extends this mediational pathway to SJL as an objective indicator of circadian misalignment. In marked contrast, neither IBI nor CRP emerged as significant mediators, suggesting that SJL may influence suicidal ideation not through systemic low-grade inflammation. A more plausible mechanism involves central neuroinflammatory pathways, whereby circadian disruption leads to hyperactivation of the hypothalamic–pituitary–adrenal axis and microglial activation; such inflammatory responses can upregulate the kynurenine pathway and reduce serotonin synthesis, processes that are not necessarily reflected in single peripheral biomarkers [44,45]. Future research incorporating comprehensive cytokine profiles and neuroimaging measures is warranted to directly examine the role of neuroinflammation in this relationship.

Several important limitations should be noted when interpreting the present findings. First, the cross-sectional design of this study precludes establishing a causal direction between SJL and depressive symptoms or suicidal ideation. Although we tested the indirect effect of depressive symptoms as a mediator, the possibility of reverse causality cannot be ruled out. Future longitudinal studies are essential to clarify the causal direction. Second, SJL was calculated based on participants' subjective recall of sleep timing on workdays and free days, which may introduce recall bias; future studies employing objective measures such as actigraphy to assess SJL would provide more reliable result. Third, IBI relies on peripheral blood markers, which are distal from central nervous system inflammatory processes. Therefore, the null mediation findings in this study do not fully exclude a potential role of inflammatory pathways. Future studies should incorporate a broader panel of cytokines and combine peripheral with central measures for comprehensive assessment.

Conclusion

This study uncovers a nuanced, non-linear relationship between SJL and mental health. We demonstrate that mild-to-moderate SJL is associated with reduced depressive symptoms and suicidal ideation, particularly among younger adults and women, suggesting a potential adaptive role for moderate sleep flexibility in mitigating psychological distress. Crucially, this protective association is mediated primarily through the alleviation of depressive symptoms rather than systemic inflammatory burden. Future longitudinal studies using objective measures of circadian alignment are warranted to establish causality and elucidate the neurobiological mechanisms underlying this association.

Declarations

Ethics approval and consent to participate

All procedures performed in this study were in accordance with the ethical standards of the National Center for Health Statistics (NCHS) Research Ethics Review Board, which approved the NHANES data collection protocols. Written informed consent was obtained from all participants (or their legal guardians for minors) prior to their involvement in the NHANES survey. This study involved secondary analysis of de-identified, publicly available data; therefore, additional institutional review board (IRB) approval was not required.

Consent for publication

Not applicable. This manuscript does not contain any individual person's data in any form (including individual details, images, or videos). All data analyzed are de-identified and publicly available.

Availability of data and materials

The datasets analyzed in this study are publicly available from the NHANES database. Data can be accessed at the official NHANES website: https://www.cdc.gov/nchs/nhanes/. All data used in this study

are freely available for download without restriction. The analytical methods and code used to generate the results are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was supported by the Natural Science Foundation of Shandong Province (Youth Fund) (Grant/Award Number: ZR2025QC1848Z).

Authors' contributions

Conceptualization: Fuping Sun, Jie Yang; **Data curation:** Fuping Sun, Jie Yang; **Formal analysis:** Fei Zhao; **Investigation:** Keke Yao; **Methodology:** Keke Yao, Zhenzhen Yang; **Supervision:** Fuping Sun, Jie Yang; **Validation:** Fei Zhao, Zhonggang Wang; **Visualization:** Keke Yao; **Writing-original draft:** Keke Yao, Jie Yang; **Writing-review & editing:** All authors.

Acknowledgements

The authors thank all participants of the NHANES program and the staff of the National Center for Health Statistics for making these publicly available datasets accessible.

References

1. Tamura, N. & Okamura, K. Longitudinal course and outcome of social jetlag in adolescents: A 1-year follow-up study of the adolescent sleep health epidemiological cohorts. J. Sleep Res. 33, e14042 (2024). doi:10.1111/jsr.14042
2. Feng, J., Meng, X., Wang, C. et al. Associations of social jetlag with depressive symptoms among adults in Southern China: a cross-sectional study. Chronobiol. Int. 40, 783–794 (2023). doi:10.1080/07420528.2023.2209179
3. Magnusdottir, S., Magnusdottir, I., Gunnlaugsdottir, A. K., Hilmisson, H., Hrolfsdottir, L. & Paed, A. E. E. M. Sleep duration and social jetlag in healthy adolescents. Association with anxiety, depression, and chronotype: a pilot study. Sleep Breath. 28, 1541–1551 (2024). doi:10.1007/s11325-024-03026-z
4. Rutters, F., Lemmens, S. G., Adam, T. C. et al. Is social jetlag associated with an adverse endocrine, behavioral, and cardiovascular risk profile? J. Biol. Rhythms 29, 377–383 (2014). doi:10.1177/0748730414550199
5. Wong, P. M., Hasler, B. P., Kamarck, T. W., Muldoon, M. F. & Manuck, S. B. Social Jetlag, Chronotype, and Cardiometabolic Risk. J. Clin. Endocrinol. Metab. 100, 4612–4620 (2015). doi:10.1210/jc.2015-2929

6. Sun, S., Yang, Y., Yu, F. et al. Social jetlag and depressive symptoms among young people: a systematic review and meta-analysis. BMC Psychiatry 25, 664 (2025). doi:10.1186/s12888-025-07066-x
7. Min, J., Jang, T. W., Lee, H. E., Cho, S. S. & Kang, M. Y. Social jetlag and risk of depression: Results from the Korea National Health and Nutrition Examination Survey. J. Affect. Disord. 323, 562–569 (2023). doi:10.1016/j.jad.2022.12.010
8. Zhang, Y., Fan, Y., Ma, Z., Wang, D. & Fan, F. Associations of social jetlag and insomnia symptoms with depressive symptoms among Chinese adolescents: A large population-based study. Sleep Med. 104, 98–104 (2023). doi:10.1016/j.sleep.2023.02.024
9. Islam, Z., Hu, H., Akter, S. et al. Social jetlag is associated with an increased likelihood of having depressive symptoms among the Japanese working population: the Furukawa Nutrition and Health Study. Sleep 43, zsz204 (2020). doi:10.1093/sleep/zsz204
10. Luo, J., Yang, J., Dai, T. et al. Non-linear relationship between social jetlag and depressive symptoms among Chinese college students. Sci. Rep. 15, 18317 (2025). doi:10.1038/s41598-025-03371-3
11. Zhang, Y., Wang, D., Ma, Z. et al. Problematic internet use and suicide ideation among Chinese adolescents: The indirect effects of insomnia, nightmares, and social jetlag. J. Affect. Disord. 344, 347–355 (2024). doi:10.1016/j.jad.2023.10.081
12. Rasmussen, S., Chandler, J. F., Russell, K. & Cramer, R. J. A prospective examination of sleep chronotype and future suicide intent among adults in the United Kingdom: A test of the integrated motivational volitional model of suicide. Sleep Med. 124, 84–90 (2024). doi:10.1016/j.sleep.2024.09.004
13. Tubbs, A. S., Hendershot, S., Ghani, S. B. et al. Social Jetlag and Other Aspects of Sleep Are Linked to Non-Suicidal Self-Injury Among College Students. Arch. Suicide Res. 27, 686–703 (2023). doi:10.1080/13811118.2022.2057262
14. Arrona-Palacios, A., Díaz-Morales, J. F., Parra-Robledo, Z. & Adan, A. Sleep and Depressive Symptoms in the Morningness/Eveningness-Suicidal Ideation Relationship Depend on School Shift in Mexican Adolescents. J. Clin. Med. 10, 4681 (2021). doi:10.3390/jcm10204681
15. Yang, D. F., Huang, W. C., Wu, C. W., Huang, C. Y., Yang, Y. S. H. & Tung, Y. T. Acute sleep deprivation exacerbates systemic inflammation and psychiatry disorders through gut microbiota dysbiosis and disruption of circadian rhythms. Microbiol. Res. 268, 127292 (2023). doi:10.1016/j.micres.2022.127292
16. Yin, J., Gong, R., Zhang, M. et al. Associations between sleep disturbance, inflammatory markers and depressive symptoms: Mediation analyses in a large NHANES community sample. Prog. Neuropsychopharmacol. Biol. Psychiatry 126, 110786 (2023). doi:10.1016/j.pnpbp.2023.110786
17. Roenneberg, T., Pilz, L. K., Zerbini, G. & Winnebeck, E. C. Chronotype and social jetlag: a (self-)critical review. Biology (Basel) 8, 54 (2019). doi:10.3390/biology8030054
18. Ghotbi, N., Rabenstein, A., Pilz, L. K., Rüther, T. & Roenneberg, T. Chronotype, Social Jetlag, and Nicotine Use. J. Biol. Rhythms 38, 392–406 (2023). doi:10.1177/07487304231177197

19. Baek, S. U., Lee, Y. M., Won, J. U. & Yoon, J. H. Association between social jetlag and anxiety symptoms: Findings from a nationally representative sample of the Korean working population. Sleep Med. 126, 300–306 (2025). doi:10.1016/j.sleep.2024.12.029
20. Kroenke, K., Strine, T. W., Spitzer, R. L. et al. The PHQ-8 as a measure of current depression in the general population. J. Affect. Disord. 114, 163–173 (2009). doi:10.1016/j.jad.2008.06.026
21. Shin, C., Lee, S. H., Han, K. M. et al. Comparison of the usefulness of the PHQ-8 and PHQ-9 for screening for major depressive disorder: analysis of psychiatric outpatient data. Psychiatry Investig. 16, 300–305 (2019). doi:10.30773/pi.2019.02.01
22. Xie, H., Ruan, G., Ge, Y. et al. Inflammatory burden as a prognostic biomarker for cancer. Clin. Nutr. 41, 1236–1243 (2022). doi:10.1016/j.clnu.2022.04.019
23. Dong, L., Xie, Y. & Zou, X. Association between sleep duration and depression in US adults: A cross-sectional study. J. Affect. Disord. 296, 183–188 (2022). doi:10.1016/j.jad.2021.09.075
24. Li, X. L., Wei, J., Zhang, X., Meng, Z. & Zhu, W. Relationship between night-sleep duration and risk for depression among middle-aged and older people: A dose-response meta-analysis. Front. Physiol. 14, 1085091 (2023). doi:10.3389/fphys.2023.1085091
25. Zhu, Y., Chen, F., Fang, X., Liang, N., Na, G. & Liu, Z. U-shaped association between sleep duration and depression among postmenopausal women: Evidence from a population-based study. J. Affect. Disord. 397, 120934 (2026). doi:10.1016/j.jad.2025.120934
26. Park, J. H., Moon, J. H., Kim, H. J. et al. Association between weekend catch-up sleep and the risk of depression among Korean middle-aged adults. Sleep Biol. Rhythms 21, 51–58 (2022). doi:10.1007/s41105-022-00415-3
27. Liu, Z., Xiao, Y., Ye, Y., Li, Y., He, Z. & Zhou, X. Longitudinal Association Between Depressive Symptoms and Sleep Problems in Adolescents Following a Natural Disaster: Understanding the Role of Psychological Inflexibility. Behav. Ther. 57, 188–201 (2026). doi:10.1016/j.beth.2025.08.003
28. Wang, J., Zhang, Q., Song, K. et al. The associations between stress perception, psychological flexibility, and sleep quality among people with type 2 diabetes mellitus: A cross-sectional survey. J. Psychiatr. Res. 192, 417–423 (2026). doi:10.1016/j.jpsychires.2025.10.058
29. Ishii, M., Hakoda, M. & Okajima, I. Impact of sleep and psychological flexibility on young adults' physical and mental well-being. Sci. Rep. 16, 12345 (2026). doi:10.1038/s41598-026-53737-4
30. Taillard, J., Sagaspe, P., Philip, P. & Bioulac, S. Sleep timing, chronotype and social jetlag: Impact on cognitive abilities and psychiatric disorders. Biochem. Pharmacol. 191, 114438 (2021). doi:10.1016/j.bcp.2021.114438
31. Lu, Y. A. & Tsai, P. S. Associations of Social Jetlag With Depression and Anxiety in Adolescents and Young People: A Systematic Review and Meta-Analysis. Depress. Anxiety 5542425 (2026). doi:10.1155/da/5542425
32. Li, M., Zhang, Y., Huang, M. et al. Prevalence, correlates, and mental health outcomes of social jetlag in Chinese school-age adolescents: A large-scale population-based study. Sleep Med. 119, 424–431 (2024). doi:10.1016/j.sleep.2024.05.039

33. Okajima, I., Komada, Y., Ito, W. & Inoue, Y. Sleep Debt and Social Jetlag Associated with Sleepiness, Mood, and Work Performance among Workers in Japan. Int. J. Environ. Res. Public Health 18, 2908 (2021). doi:10.3390/ijerph18062908
34. Wever, R. A. Sex differences in human circadian rhythms: intrinsic periods and sleep fractions. Experientia 40, 1226–1234 (1984). doi:10.1007/BF01946652
35. Duffy, J. F., Cain, S. W., Chang, A. M. et al. Sex difference in the near-24 hour intrinsic period of the human circadian timing system. Proc. Natl. Acad. Sci. U. S. A. 108, 15602–15608 (2011). doi:10.1073/pnas.1010666108
36. Cain, S. W., Dennison, C. F., Zeitzer, J. M. et al. Sex differences in phase angle of entrainment and melatonin amplitude in humans. J. Biol. Rhythms 25, 288–296 (2010). doi:10.1177/0748730410374943
37. Armitage, R. & Hoffmann, R. F. Sleep EEG, depression and gender. Sleep Med. Rev. 5, 237–246 (2001). doi:10.1053/smrv.2000.0144
38. Zhang, B. & Wing, Y. K. Sex differences in insomnia: a meta-analysis. Sleep 29, 85–93 (2006). doi:10.1093/sleep/29.1.85
39. Mong, J. A. & Cusmano, D. M. Sex differences in sleep: Impact of biological sex and sex steroids. Philos. Trans. R. Soc. Lond. B Biol. Sci. 371, 20150110 (2016). doi:10.1098/rstb.2015.0110
40. Baker, F. C., Yűksel, D. & de Zambotti, M. Sex Differences in Sleep. In Current Clinical Neurology 55–64 (Humana Press, Cham, 2020). doi:10.1007/978-3-030-40842-8_5
41. Roenneberg, T., Kuehnle, T., Pramstaller, P. P. et al. A marker for the end of adolescence. Curr. Biol. 14, R1038–R1039 (2004). doi:10.1016/j.cub.2004.11.039
42. Duarte, L. L., Menna-Barreto, L., Miguel, M. A. L. et al. Chronotype ontogeny related to gender. Braz. J. Med. Biol. Res. 47, 316–320 (2014). doi:10.1590/1414-431x20143001
43. Park, H., Lee, H. K. & Lee, K. Chronotype and suicide: The mediating effect of depressive symptoms. Psychiatry Res. 269, 316–320 (2018). doi:10.1016/j.psychres.2018.08.046
44. Irwin, M. R. & Opp, M. R. Sleep health: reciprocal regulation of sleep and innate immunity. Neuropsychopharmacology 42, 129–155 (2017). doi:10.1038/npp.2016.148
45. Won, E. & Kim, Y. K. Stress, the autonomic nervous system, and the immune-kynurenine pathway in the etiology of depression. Curr. Neuropharmacol. 14, 665–673 (2016). doi:10.2174/1570159X14666151208113006

Figures

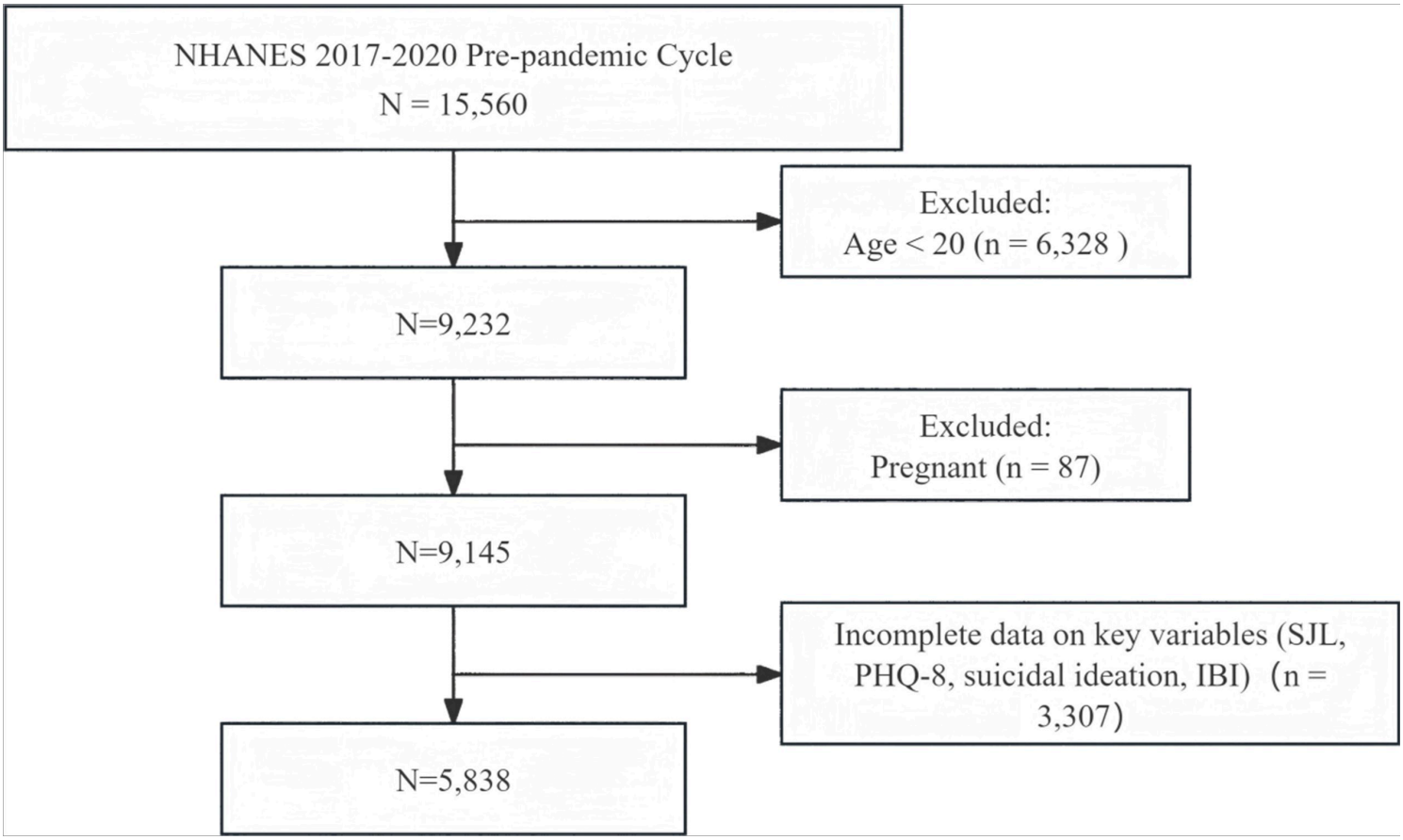


Figure 1

Flowchart of study sample selection.

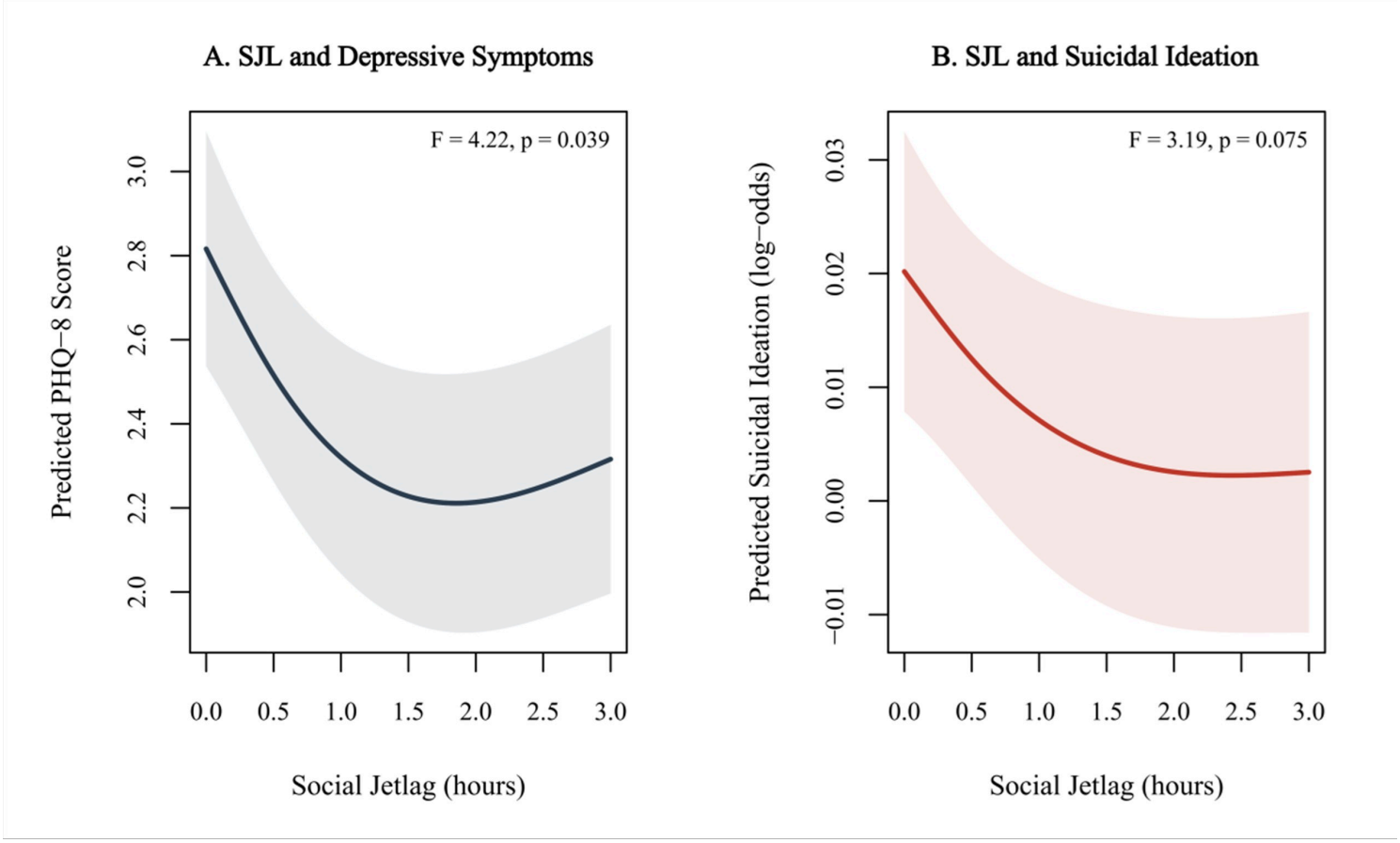


Figure 2

Non-linear association between social jetlag and depressive symptoms (A) and suicidal ideation (B) on restricted cubic spline regression models.

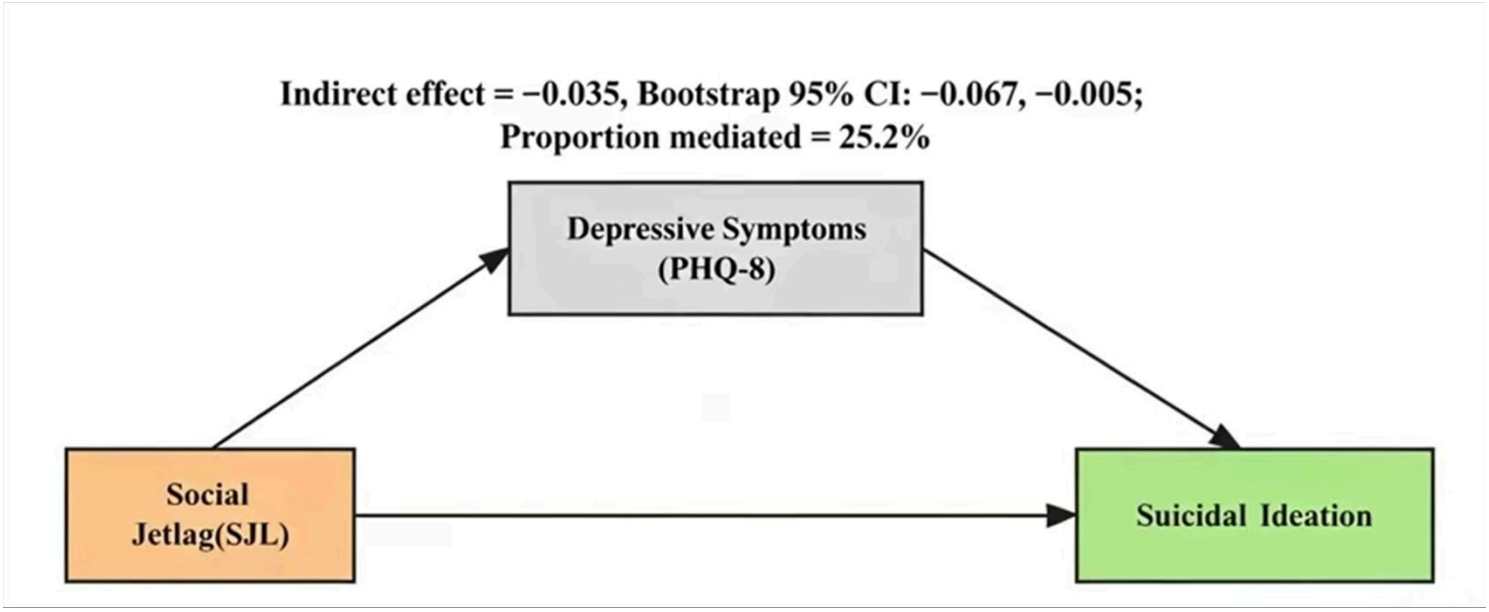


Figure 3

Mediation analysis of the Association between Social Jetlag and Suicidal Ideation

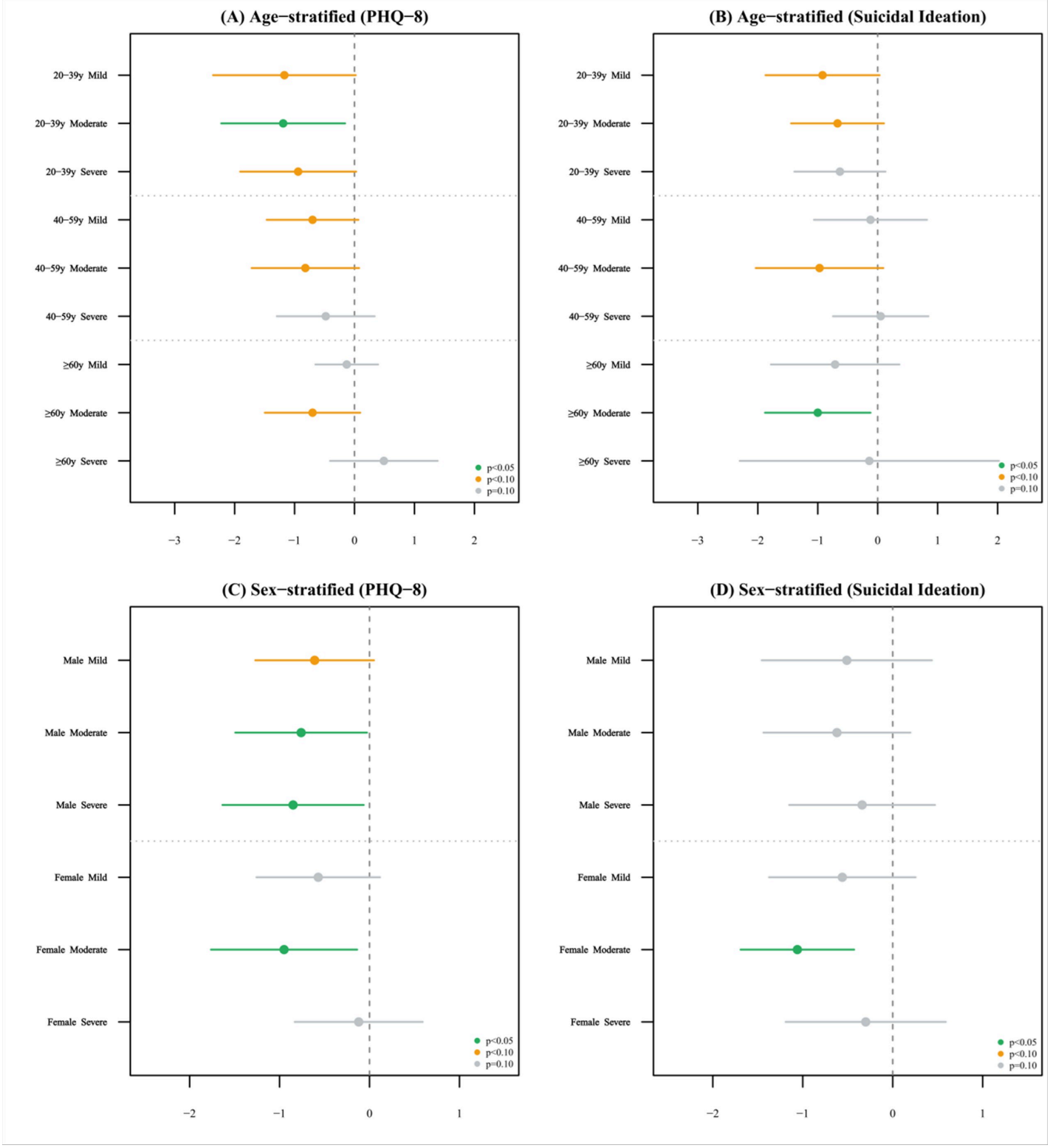


Figure 4

The associations between SJL categories and both depressive symptoms and suicidal ideation stratified by age-sex group.

(A-D) Stratified associations between social jetlag categories and mental health outcomes. (A) Age-stratified association with depressive symptoms (PHQ-8). (B) Age-stratified association with suicidal ideation. (C) Sex-stratified association with depressive symptoms (PHQ-8). (D) Sex-stratified association with suicidal ideation. Forest plots display adjusted β coefficients with 95% confidence intervals; green circles indicate $p < 0.05$, orange circles indicate $p < 0.10$, and gray circles indicate $p \geq 0.10$. Reference group: No social jetlag.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterialinfo.docx
- SupplementaryMaterial.doc
- STROBEchecklistcrosssectionalcxManuscriptYang.docx