The Princeton Journal of Interdisciplinary Research
ISSN 3069-8200

Investigating the Moderating Role of Sleep Quality to Depression and Loneliness After Stroke

Cunyi Xu (author)[1], Andrea Kusec (author)[2]

[1]Leicester Grammar School, Leicester, Leicestershire, United Kingdom

[2]University of Oxford, Oxford, Oxfordshire, United Kingdom

Abstract

Loneliness and depression occur frequently after stroke, and sleep difficulties often co-occur with both symptoms. This cross-sectional study used Health and Retirement Study Wave 15 data collected in 2020 and included 346 stroke survivors. Hierarchical linear regression models tested whether sleep difficulties moderated the association between depression and loneliness after adjustment for age, sex, race, income, education, and chronic disease burden. Higher depressive symptoms related to higher loneliness, and better sleep related to lower loneliness. The depression × sleep difficulties interaction was not significant, and no individual sleep indicator showed evidence of moderation. Younger age, fewer education years, greater chronic disease burden, and the "Other" racial group related to higher loneliness. These findings supported independent associations of depression and sleep difficulties with loneliness after stroke, but did not support moderation.

Keywords: depression, loneliness, sleep difficulties, stroke

Introduction

Stroke is a major global public health challenge that affects older populations. In 2021, approximately 11.9 million individuals experienced a new stroke worldwide, and an estimated 93.8 million were living with its long-term consequences (GBD 2021 Stroke Risk Factor Collaborators, 2024). Besides physical decline, stroke often leads to significant psychological sequelae like loneliness (C. Byrne et al., 2022). Loneliness represents an individual's perceived discrepancy between desired and actual social relationships. Loneliness after stroke is emerging as a critical issue, with consistent association with adverse psychological outcomes, such as anxiety, satisfaction with social roles and functional outcomes (Theeke et al., 2014). Loneliness is common among older adults more generally, affecting approximately 20–30% across many countries (Su et al., 2023). In a recent national survey, stroke survivors showed the highest loneliness prevalence, with 44% have significantly elevated levels of loneliness assessed by the 6-item De Jong Gierveld Loneliness Scale (C. Byrne et al., 2022). Loneliness levels have been shown to increase after stroke onset compared with pre-stroke levels in the Survey of Health, Aging, and Retirement in Europe and the Health and Retirement Study (HRS) (Willroth et al., 2024).

Post-stroke depression (PSD) is one of the most prevalent neuropsychiatric conditions, affecting nearly one-third of survivors in the first year following stroke (Chun et al., 2022; Dong et al., 2021). Depression and loneliness frequently co-occur after stroke (Elayoubi et al., 2023). Evidence across adult populations has demonstrated a robust positive correlation between loneliness and depression (Green et al., 2025) and a larger relationship in

stroke. In biennial post-stroke follow up assessments spanning from acute to 14 years post-stroke, depressive symptoms were higher in assessments when participants reported loneliness during the prior week than in waves when they did not report loneliness (Elayoubi et al., 2023). Despite their frequent coexistence, the underlying mechanisms connecting loneliness and depression after stroke remain poorly understood.

One potential way that depression and loneliness relate to each other is sleep. Sleep disturbances are highly prevalent following stroke, with a pooled prevalence of poor sleep quality of 53% in a meta-analysis of 3886 individuals (Luo et al., 2023). Sleep disturbances have also been shown to strongly influence emotional and social outcomes (Luo et al., 2023). Poor sleep quality, including insomnia, fragmented sleep, or non-restorative rest, is frequently observed in stroke survivors. Approximately half of patients experience insomnia during the acute post-stroke phase (Luo et al., 2023), and nearly one-third continue to suffer from chronic insomnia for months or years thereafter (Rissardo et al., 2025). Experimental studies show that even a single night of sleep deprivation can induce social withdrawal and heightened feelings of loneliness in non-stroke populations (Ben Simon & Walker, 2018). Jiang and colleagues reported that poor sleep quality amplified the association between fewer online social connections, a structural correlate of social isolation that could foster loneliness, and higher depressive symptoms, with this link evident among poor sleepers but not among good sleepers (Jiang et al., 2025). These results collectively indicate that sleep quality may play a crucial moderating role in the relationship between depression and loneliness post-stroke. However, no previous research examined whether and how sleep quality moderates

the association between depression and loneliness among stroke survivors. In stroke survivors, poor sleep quality may aggravate depressive symptoms and consequently hinder social interaction, thereby strengthening the association between depression and loneliness. Sleep loss has also been shown to weaken prefrontal control over amygdala reactivity, leading to a shift toward heightened threat sensitivity and reduced top down emotion regulation (Yoo et al., 2007). It is possible that these processes are also disrupted after stroke. Sleep quality may exacerbate the emotional impact of depression on loneliness, whereas good sleep may buffer against this effect, suggesting an interaction rather than a sequential process. Addressing this gap is clinically important, as identifying whether poor sleep interacts with post-stroke depression in loneliness outcomes could highlight sleep as a modifiable target for reducing loneliness. The present study aims to address this gap by testing the below hypothesis:

HA: Poor sleep quality moderates the relationship between depression and loneliness after stroke.

H0: Poor sleep quality does not moderate the relationship between depression and loneliness after stroke.

Methods

Data set and participants

Data for this study were obtained from the HRS, a freely accessible nationally

representative longitudinal survey of United States adults aged 50 years and older that was conducted biennially by the University of Michigan. The HRS (Health and Retirement Study) is sponsored by the National Institute on Aging (grant number NIA U01AG009740) and is conducted by the University of Michigan. The present cross-sectional analysis used wave 15 data collected in 2020 and was based on the HRS Longitudinal File 2022, latest release May 2025, version 1.

The analytic sample was restricted to wave 15 respondents with a self-reported history of stroke, defined by the indicator "r15stroke" equal to 1. Because the primary outcome measure of loneliness was derived from the Psychosocial and Lifestyle Questionnaire in the HRS data, the eligible population was limited to respondents who completed the below measures. Participants were excluded if data were missing in any analyzed variables.

Measures

Loneliness

Loneliness was assessed using the 11-item loneliness scale from HRS Psychosocial and Lifestyle Questionnaire, which was derived from the 20-item Revised UCLA Loneliness Scale. The loneliness measure followed the standard scoring for the 11-item loneliness scale from the HRS dataset. The scale score represented the mean of all 11 items after reverse coding the positively worded items, and the score was set to missing if more than five items were missing. Higher values indicated greater loneliness.

Depression

Depression was assessed using a modified version of the Center for Epidemiologic Studies Depression Scale (CESD; (Russell et al., 1980; Russell, 1996). In the HRS dataset, the CESD based index summed six negative indicators and the inverse of two positive indicators, where each indicator reflected whether a sentiment was experienced all or most of the time. In the present study, a depression score was constructed by applying the scoring approach but removing the two items that captured sleep and loneliness content to avoid collinearity. Specifically, the indicators "sleep is restless" and "felt alone" were excluded, while all remaining coding and reverse coding rules followed the approach. The resulting depression score ranged from 0 to 6, with higher values indicating a greater depressive symptom burden.

Sleep Difficulties

Sleep difficulties were operationalized as a composite score based on seven HRS sleep items. All items were summed without recoding, except for the "feeling rested" item, which was reverse coded so that higher values consistently reflected better sleep. The composite included three sleep disorder indicators, including having a sleep disorder in the current wave, ever having had a sleep disorder, and having had a sleep disorder since the last interview, and three insomnia symptom items assessing difficulties falling asleep, waking during the night, and waking too early. The insomnia symptom items used frequency-based response options, most of the time, sometimes, or rarely or never. The sleep difficulties score

was calculated as the sum of the seven indicators, yielding a total range of 2 to 14. Under this coding, higher scores indicated fewer sleep difficulties and greater perceived restfulness.

Covariates

Covariates were selected based on previous research demonstrating a link between these variables and loneliness included age in years, sex, race or ethnicity, household income, and years of education (Cohen-Mansfield et al., 2016; Hawkley et al., 2008). Sex was coded as male or female. Age was measured in years. Race was categorized as White or Caucasian, Black or African American, and Other, and indicator variables were created with White or Caucasian as the reference category. Income was included as a continuous measure of total household income in nominal dollars and reflected income received in the last calendar year, as provided in the HRS data. Education was measured as number of completed years of education. Chronic disease burden was constructed by summing six dichotomous conditions coded as yes or no, including high blood pressure, diabetes, heart disease, lung disease, cancer, and psychiatric disease. Higher scores indicated a greater chronic disease burden.

Statistical analysis

All analyses were conducted in R version 4.3.0. Statistical significance was set at $p < 0.05$ using two tailed tests. Descriptive statistics summarized sample characteristics. Distributions of continuous variables were examined using graphical methods and the Shapiro–Wilk test. Pairwise bivariate Pearson correlations were conducted among loneliness, depressive symptoms, sleep variables. A correlation heatmap was generated using the

'*corrplot*' package with non-significant correlations suppressed at the 0.05 level.

Hierarchical multiple linear regression evaluated whether sleep difficulties moderated the association between depressive symptoms and loneliness. In Model 1, loneliness was regressed on prespecified covariates including sex, age, race or ethnicity, household income, education years, and chronic conditions. In Model 2, depressive symptoms were added. In Model 3, the composite sleep difficulties score and the interaction term between depressive symptoms by sleep difficulties were added.

Additional exploratory models examined moderation by individual sleep indicators. Separate linear regression models tested interactions between depressive symptoms and trouble falling asleep, waking during the night, waking too early, and feeling rested. Each model included the same covariates used above. For the feeling rested item, the coding direction followed the analytic dataset used in modeling. Each individual sleep indicator model was first run without covariates and then with adjustment for covariates.

Model assumptions were evaluated using standard diagnostic plots. Linearity was assessed using residuals versus fitted value plots. Homoscedasticity was assessed using scale location plots. Residual distributions were assessed using quantile–quantile plots and residual histograms. Multicollinearity was assessed using variance inflation factors. Influential observations were evaluated using Cook's distance. Observations with Cook's distance greater than three times the mean Cook's distance were excluded, and models were refit after exclusion. Missing data were handled using a complete case approach. For the hierarchical

and exploratory linear regression models, complete case analysis was used. For correlation analyses, pairwise deletion was used so that each correlation coefficient was estimated using all available observations for that variable pair. Across all analyses, complete cases were used.

Results

Descriptive characteristics and unadjusted associations with loneliness

The sample included 346 participants (Table 1). Loneliness did not differ by Sex. The majority of participants were White/Caucasian (69.65%), followed by Black/African-American (22.83%) or Other Racial group (7.51%). The Other Racial Group showed the highest Loneliness scores.

Table 1

Sample characteristics and univariate associations with loneliness.

Variable	**Total *N*=346**	**Loneliness Mean (SD)**	***T*(*F*) value**	***p***
Age, years				
Mean (SD)	73.92 (10.30)			
Sex, n (%)			-0.51	0.615
1. Male	142 (41.04)	1.62 (0.44)		
2. Female	204 (58.96)	1.65 (0.47)		

Race, n (%)			4.38	0.013
1. White/Caucasian	241 (69.65)	1.62 (0.46)		
2. Black/African-American	79 (22.83)	1.61 (0.46)		
3. Other	26 (7.51)	1.89 (0.34)		
Education years, Year				
Mean (SD)	13.19 (2.74)			
Income, USD				
Mean (SD)	53,487.77 (52,252.58)			
Chronic Disease				
High Blood Pressure, n (%)			-0.88	0.381
1. Yes	281 (81.21)	1.65 (0.46)		
0. No	65 (18.79)	1.59 (0.43)		
Diabetes, n (%)			-0.66	0.512
1. Yes	125 (36.13)	1.66 (0.48)		
0. No	221 (63.87)	1.62 (0.44)		
Heart Disease, n (%)			-0.42	0.676
1. Yes	189 (54.62)	1.64 (0.48)		
0. No	157 (45.38)	1.62 (0.43)		
Lung Disease, n (%)			-3.01	0.003
1.Yes	62 (17.92)	1.81 (0.52)		
0. No	284 (82.08)	1.60 (0.43)		

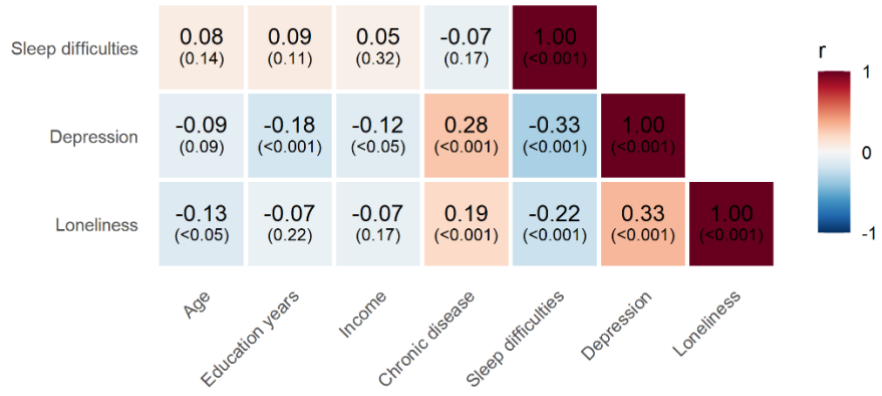
Cancer, n (%)			-0.05	0.958
1. Yes	84 (24.42)	1.63 (0.43)		
0. No	260 (75.58)	1.63 (0.47)		
Psychiatric Disease, n (%)			-5.16	< 0.001
1. Yes	113 (32.85)	1.82 (0.50)		
0. No	231 (67.15)	1.54 (0.40)		
Sleep Difficulties				
Mean (SD)	9.81 (2.13)			
Depression				
Mean (SD)	1.27 (1.72)			
Loneliness				
Mean (SD)	1.64 (0.46)			

Note: Binary variables were compared using independent samples t-tests, and variables with more than two categories were compared using one way ANOVA.

Figure 1 presents bivariate correlations among study variables. Sleep difficulties and depression showed the highest correlations to loneliness. Loneliness was also related to age and chronic disease burden.

Figure 1

Correlation heatmap of sleep difficulties, depression, loneliness, and covariates.



Note: Darker colors indicate stronger correlation values.

Hierarchical regression of loneliness and depression and differential moderation by sleep difficulties

The hierarchical regressions included *N*=316 participants (Table 2). Covariates alone explained 7.5% of the variance in loneliness (Model 1 adjusted $R^2 = 0.054$). Adding depression significantly improved model fit and increased explained variance to 20% (adjusted $R^2 = 0.179$; $\Delta R^2 = 0.125$). Adding sleep difficulties and the depression × sleep difficulties interaction further increased explained variance to 21.8% (adjusted $R^2 = 0.192$) and yielded an improvement over Model 2 ($\Delta R^2 = 0.018$).

Table 2

Hierarchical multiple linear regression models predicting loneliness

Predictor	Estimate (B)	Std. Error	t value	*p*-value
Model 1				

Sex	0.01	0.05	0.33	0.74
Age	-0.01	0.01	-2.20	0.02
Race-Black/African-American	-0.09	0.05	-1.71	0.09
Race-Other	0.20	0.10	2.07	0.04
Income	<0.01	<0.01	-0.17	0.87
Education Years	-0.02	0.01	-2.03	0.04
Chronic Disease	0.05	0.02	3.03	<0.01
Model 2				
Depression	0.11	0.01	7.987	<0.01
Model 3				
Sleep Difficulties	-0.03	0.01	-2.50	0.01
Depression × Sleep Difficulties	<0.01	<0.01	0.56	0.58

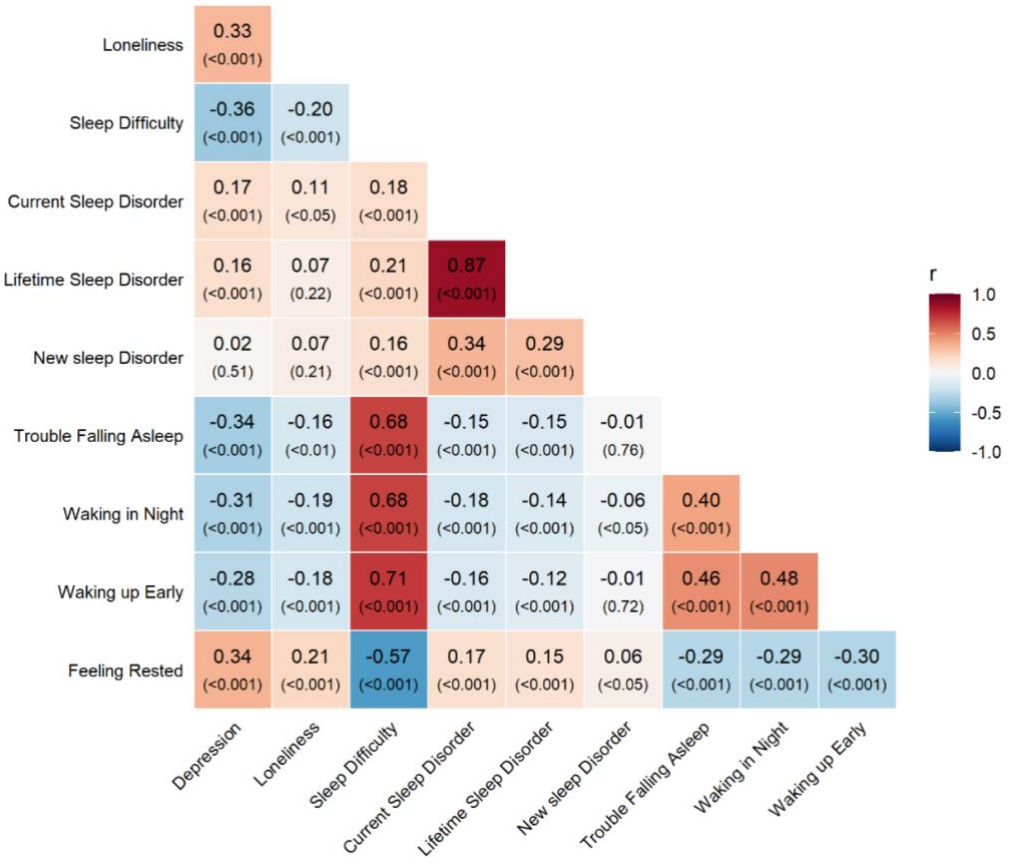
Exploratory Associations between sleep difficulties indicators and Loneliness

Bivariate correlations indicated small but varying associations between loneliness and individual sleep indicators (Figure 2). The composite sleep difficulties score showed a weak positive correlation with loneliness. Difficulties falling asleep, waking during the night, and waking too early showed weak negative correlations with loneliness. Feeling rested in the morning showed a small positive correlation with loneliness. Correlations between loneliness and having a sleep disorder in the current wave, ever having had a sleep disorder, and having

had a sleep disorder since the last interview were very small.

Figure 2

Correlation heatmap for sleep indicators, depression, and loneliness.



Note: Sleep items were defined as follows: Current Sleep Disorder, having a sleep disorder in the current wave; Lifetime Sleep Disorder, ever having had a sleep disorder; New Sleep Disorder, having had a sleep disorder since the last interview; Trouble Falling Asleep, difficulties falling asleep; Waking in Night, waking during the night; Waking up Early, waking too early; and Feeling Rested, feeling rested in the morning.

In unadjusted models exploring individual sleep indicators (Table 3), only waking too early and feeling rested in the morning were associated with greater loneliness. Across all indicators, depression × sleep interaction terms were not significant, providing no evidence that individual sleep indicators had moderating effects. In covariate adjusted models (Table 4), the previously significant associations for waking too early and feeling rested in the morning attenuated to non-significant or marginal levels, whereas waking during the night became significantly associated with lower loneliness. Interaction terms remained non-significant after adjustment.

Table 3

Sleep difficulties indicators in regression models predicting loneliness

Predictor	Estimate (B)	Std. Error	t value	*p*-value
Current Sleep Disorder	-0.05	0.07	-0.69	0.49
Depression × Current Sleep Disorder	0.05	0.03	1.44	0.15
Lifetime Sleep Disorder	-0.07	0.06	-1.21	0.23
Depression × Lifetime Sleep Disorder	0.02	0.03	0.65	0.52
New Sleep Disorder	0.12	0.22	0.53	0.59
Depression × New Sleep Disorder	0.03	0.09	0.32	0.75
Trouble Falling Asleep	-0.03	0.04	-0.73	0.47
Depression × Trouble Falling Asleep	0.02	0.02	0.95	0.34
Waking in Night	-0.06	0.03	-1.68	0.10

Depression × Waking in Night	-0.02	0.02	-0.79	0.43
Waking up Too Early	-0.09	0.04	-2.12	0.03
Depression × Waking up Too Early	0.01	0.02	0.62	0.54
Feeling Rested	0.10	0.04	2.55	0.01
Depression × Feeling Rested	<0.01	0.02	-0.24	0.81

Note: For each sleep item, an unadjusted linear regression model was fitted with loneliness as the dependent variable and depression, the sleep item, and their interaction term as predictors. Sleep items were defined as follows: Current Sleep Disorder, having a sleep disorder in the current wave; Lifetime Sleep Disorder, ever having had a sleep disorder; New Sleep Disorder, having had a sleep disorder since the last interview; Trouble Falling Asleep, difficulty falling asleep; Waking in Night, waking during the night; Waking up Early, waking too early; and Feeling Rested, feeling rested in the morning.

Table 4

Sleep difficulties indicators in regression models predicting loneliness with covariance correction

Predictor	Estimate (B)	Std. Error	t value	*p*-value
Current Sleep Disorder	<0.01	0.07	-0.01	0.99
Depression × Current Sleep Disorder	<0.01	0.03	-0.07	0.95
Lifetime Sleep Disorder	-0.06	0.06	-1.05	0.30
Depression × Lifetime Sleep Disorder	<0.01	0.02	0.06	0.96

New Sleep Disorder	0.18	0.20	0.87	0.39
Depression × New Sleep Disorder	0.02	0.09	0.24	0.81
Trouble Falling Asleep	-0.05	0.04	-1.46	0.15
Depression × Trouble Falling Asleep	0.03	0.02	1.40	0.16
Waking in Night	-0.07	0.03	-2.2	0.03
Depression × Waking in Night	-0.01	0.02	-0.54	0.59
Waking up Too Early	-0.07	0.04	-1.79	0.07
Depression × Waking up Too Early	0.02	0.02	1.11	0.27
Feeling Rested	0.07	0.04	1.92	0.06
Depression × Feeling Rested	<0.01	0.02	-0.08	0.93

Note: An adjusted linear regression model was fitted for each sleep item, with loneliness as the dependent variable and depressive symptoms, the sleep item, and their interaction term as predictors, while adjusting for sex, age, race, income, years of education, and chronic disease burden. Sleep items were defined as follows: Current Sleep Disorder, having a sleep disorder in the current wave; Lifetime Sleep Disorder, ever having had a sleep disorder; New Sleep Disorder, having had a sleep disorder since the last interview; Trouble Falling Asleep, difficulty falling asleep; Waking in Night, waking during the night; Waking up Early, waking too early; and Feeling Rested, feeling rested in the morning.

Discussion

In this cross-sectional analysis of older adults with stroke, higher depression related to

higher loneliness after adjustment for sociodemographic factors, and chronic disease burden. Sleep difficulties showed an independent association with loneliness in adjusted models, while the depression × sleep difficulties interaction did not reach statistical significance, indicating no moderating effect. In terms of relationships with covariates, older participants reported less loneliness. Participants in the "other race" category reported higher loneliness. Greater chronic disease burden showed a modest positive association with greater loneliness. In additional analyses of individual sleep indicators, small bivariate correlations were observed. Feeling rested showed a significant positive association with loneliness, though interaction terms were not significant. While waking up too early showed a significant negative association with loneliness, the corresponding interaction term was not significant. These results further supported a pattern of limited evidence for moderation.

Does Sleep Moderate Depression and Loneliness after Stroke?

The results here align with the reaffiliation motive (RAM) model. The RAM model conceptualizes a psychosocial model of loneliness that explains how social relationships are sought in response to perceived social isolation (Cacioppo et al., 2014). Loneliness, according to the RAM model, reflects how a person perceives and evaluates the adequacy of their social connections, rather than the objective size of their social network, and it therefore aligns closely with affective symptoms, with persistent loneliness leading to social withdrawal from usual activities. In our study, depressive symptom burden aligns with this pathway because it reflects elevated negative affect, which could further erode the perceived quality and availability of social ties. On this basis, sleep quality represented a candidate effect modifier

because sleep loss can impair emotion regulation and social functioning and thus strengthen the translation of depressive symptoms into loneliness (Ben Simon & Walker, 2018).

Several factors could explain why a sleep × depression interaction did not emerge. First, the moderation pattern reported by Jiang and colleagues (Jiang et al., 2025) addressed a different construct and measurement of loneliness; sleep quality moderated the longitudinal association between social connections and depressive symptoms in older adults, and the moderation appeared for online connections but not for in person connections, whereas the current analysis tested whether sleep indicators moderated the depression to self-reported loneliness association. Differences in how "social disconnection" was operationalized therefore could contribute to discrepant findings, because objective connection metrics and subjective loneliness capture related but non-identical processes. Thus, prior moderation evidence may not generalize to a depression–loneliness moderation hypothesis. Second, sample selection and missingness could attenuate moderation signals: restricting analyses to post-stroke participants with complete data on depression, loneliness, and sleep difficulties could introduce selection bias and range restriction, which may have reduced variability in key predictors. Third, heterogeneity in stroke timing and clinical severity within a large cohort could add noise if sleep problems, depression, and loneliness varied across recovery phases, thereby diluting effects that occur only in specific subgroups. Bayesian inference could clarify whether the result supported no moderation or whether the sample provided insufficient information to detect a small interaction (Dienes, 2014).

Even without evidence of a sleep × depression interaction, depressive symptom

burden related to loneliness after stroke, which supported a direct depression–loneliness pathway during recovery. In a three wave cross lagged panel study of stroke survivors assessed at baseline, 3 months, and 6 months poststroke, higher baseline Patient Health Questionnaire-9 depression scores predicted higher loneliness at 3 months after adjustment for baseline loneliness and social participation (Sun et al., 2026). Loneliness at 3 months also predicted higher depressive symptoms at 6 months, and depressive symptoms at 3 months predicted lower social participation at 6 months, which suggested a reinforcing cycle that linked negative affect, reduced engagement, and perceived social isolation (Luo, 2023). This longitudinal pattern aligned with the RAM framework because depressive symptoms could bias social appraisal and reduce approach motivation, thereby increasing perceived disconnection even when objective contact remained available. Taken together, these findings indicated that depression related processes contributed to loneliness after stroke, and they provided a rationale for examining sleep difficulties as an additional, potentially independent pathway to loneliness.

Sleep difficulties also showed an independent association with loneliness, which motivated examination of longitudinal and experimental evidence with loneliness as the outcome. In previous studies in stroke, sleep disturbance correlated with loneliness in stroke survivors within one year after stroke, which supported co-occurrence of these problems early after stroke (Theeke et al., 2014). In non-stroke populations, a systematic review and meta-analysis supported an association between loneliness and sleep disturbance, though the evidence base did not establish temporal ordering because most included studies used cross-

sectional designs (Griffin, Williams, Ravyts, et al., 2020). In experimental work, acute sleep loss increased social withdrawal and loneliness, which supported a causal effect of insufficient sleep on perceived isolation (Ben Simon & Walker, 2018). In an ecological momentary assessment study in late life, prior-night sleep quality and sleep disturbances related to the quality of next-day social encounters, and prior-night sleep strengthened the contemporaneous association between encounter quality and momentary loneliness (Zhou et al., 2025). In an intensive diary and wearable study under real-world stress exposure, sleep and loneliness or social connectedness showed bidirectional associations at trait and day-to-day levels, although some temporal paths varied across indices (Dworschak et al., 2024). Cross-lagged panel modeling in older Americans also indicated reciprocal prospective effects between sleep disturbance and loneliness across waves, although some lagged paths were not significant (Griffin, Williams, Mladen, et al., 2020). In the absence of stroke-specific longitudinal or interventional evidence on directionality and moderation, converging experimental and longitudinal findings in non-stroke populations suggest that poor sleep after stroke may heighten perceived social isolation and help sustain loneliness.

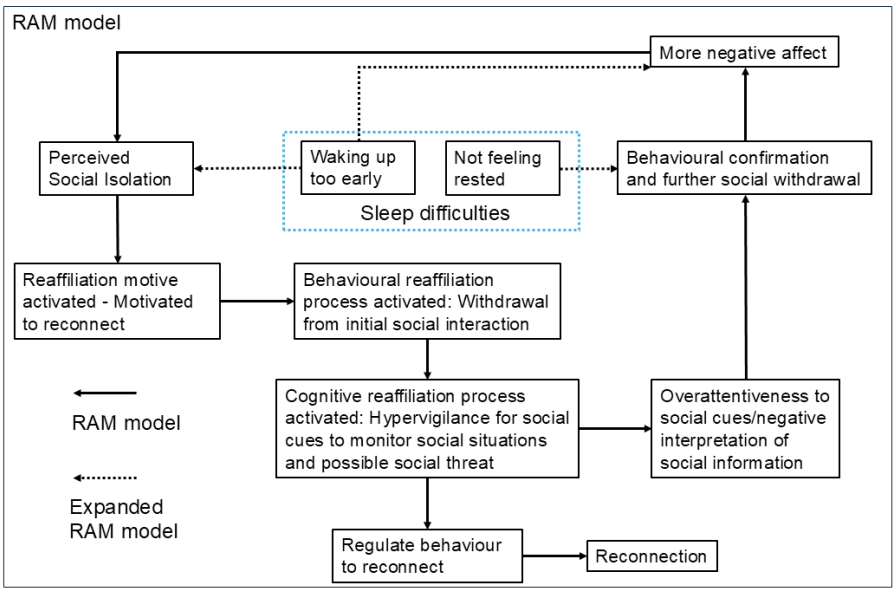
The Relationship of Different Types of Sleep Changes to Loneliness in Stroke

Despite a lack of evidence for moderation, frequently waking up too early and not feeling rested in the morning showed significant direct associations with loneliness. These findings were consistent with an HRS study in non-stroke populations (Qi et al., 2023), which reported early morning awakening and poor morning restfulness as two of the strongest sleep related correlates of loneliness in older adults. Qualitative stroke research has shown that

waking up too early may be particularly relevant because loneliness was often experienced most strongly at night (Yang et al., 2022), and early awakening increased the time spent awake and alone in the quiet hours before morning while others were asleep. Poor morning restfulness has been shown to relate to greater daytime fatigue and worse executive functioning, which could raise the perceived effort of initiating or sustaining social contact and favor withdrawal from social interaction (Tinajero et al., 2018). These individual associations suggest that post stroke sleep problems may contribute to loneliness by extending periods of solitary wakefulness and increasing daytime fatigue, promoting social withdrawal and reinforcing perceived social isolation as described in our adapted RAM model (Figure 3).

Figure 3

Expanded RAM model with sleep difficulties and depression.



Waking up too early increased time spent awake and alone during the night and early

morning, which could heighten perceived social isolation and increase negative effects. Not feeling rested reflected nonrestorative sleep and reduced daytime recovery, which could increase fatigue and reduce social initiative, thereby promoting behavioral withdrawal and strengthening behavioral confirmation of isolation.

Loneliness and Sociodemographic Factors after Stroke

The negative association between age and loneliness suggests that younger stroke survivors report greater loneliness. Stroke in younger or midlife adults often disrupts work and family roles (Aarnio et al., 2018; Westerlind et al., 2017), which widens the gap between expected social functioning and poststroke limitations and could intensify subjective loneliness. In addition to disruptions in work and family roles, social evaluative factors such as stigma and interpersonal sensitivity may be especially salient in young stroke. Qualitative data with stroke survivors indicated that stigma around loneliness and mental health discouraged disclosure and help seeking, which participants described as maintaining isolation and loneliness (Yang et al., 2022). In a separate cross sectional study of young and middle aged stroke survivors, perceived stigma was associated with higher loneliness, and interpersonal sensitivity partially mediated this association, with resilience moderating the mediated pathway (Huang et al., 2024). In younger individuals, stroke has been found to more readily undermine identity and social roles (Daniel et al., 2009), so loneliness could reflect not only reduced social contact but also reappraisals of self-efficacy and social belonging.

A protective association of education with loneliness was possible. Fewer years of education have been shown to reflect lower health literacy and less capacity to navigate rehabilitation services and community resources, which could reduce social participation and increase loneliness (Li et al., 2025). The positive association between chronic disease burden and loneliness supported a symptom and function pathway. Greater comorbidity likely increased fatigue, pain, and activity limitations, which reduce mobility and access to social activities and decrease social engagement. Heavier illness burden also could heighten perceived burden on others and reinforce stigma related concerns. Evidence in stroke and older adult populations shows similar links between chronic disease burden and social isolation (Li et al., 2025). Race findings required cautious interpretation because the "Other" race category was heterogeneous, subgroups were small, and residual confounding by unmeasured social determinants (e.g., neighborhood context, language and cultural barriers, differential access to supportive services) remained possible. Evidence in older adults suggests that racial or ethnic differences in loneliness are partly mediated by socioeconomic and contextual resources(Taylor et al., 2024).

Correlation versus Causation in Understanding Sleep and Loneliness after Stroke

In this study, sleep difficulties were associated with loneliness. However, to fully understand how sleep relates to loneliness and depression after stroke, different study designs are needed. In non-stroke individuals, a systematic review and meta-analysis (Griffin, Williams, Ravyts, et al., 2020) reported a moderate correlation between loneliness and self-reported sleep disturbance, and a cross-lagged model reported bidirectional associations

between loneliness and sleep disturbance(Griffin, Williams, Mladen, et al., 2020). In a controlled laboratory design, one night of sleep loss caused a neurobehavioral phenotype of social withdrawal and higher loneliness, and this phenotype was detectable to others, which also altered subsequent social approach tendencies (Ben Simon & Walker, 2018). Experimental sleep deprivation studies showed impaired facial emotion recognition, which may distort affective social cue appraisal and promote social withdrawal, consistent with RAM model pathways that link biased appraisal and withdrawal to persistent loneliness (van der Helm et al., 2010). Therefore, sleep difficulties could contribute to loneliness in post stroke individuals, but future stroke studies should establish temporal ordering with repeated assessments from early post stroke stages and should test causality by evaluating whether sleep focused interventions produced downstream reductions in loneliness in randomized designs.

Several other pathways may also link sleep difficulties with loneliness after stroke. Byrne and colleagues suggested that loneliness related difficulties after brain injury may involve impairments in executive functions, such as reduced energization (less ability to initiate and sustain effort) and weaker self-regulation (Christopher Byrne et al., 2022). Poor sleep may relate to these functions. As a result, a person may feel less able to initiate social contact, may tire quickly during interaction, and may avoid social situations. Another possible pathway may be sleep difficulties impair facial emotion recognition, which can make it harder to read others' feelings and respond appropriately (van der Helm et al., 2010). Together, these sleep related changes offered a testable account of how sleep difficulties may

contribute to loneliness after stroke. Future targeted studies that measure executive function, social cue processing, and social engagement are needed to evaluate these mechanisms.

Strengths and Limitations

To our knowledge, this is the first study to investigate the moderating role of sleep difficulties between depression and loneliness post-stroke. Several limitations restricted inference. First, the cross-sectional design did not support causal conclusions or temporal ordering between depression, sleep difficulties, and loneliness. Second, data comprised self-report measures, and measurement error may have biased associations. Third, the analysis used a single wave during 2020, which coincided with major social disruptions that may have altered loneliness and sleep. Fourth, the analysis did not use sampling weights, which could limit population representativeness.

Conclusion

Greater depressive symptom burden was associated with higher loneliness post-stroke. Sleep difficulties were independently associated with loneliness; however, no moderation of the depressive symptoms–loneliness association was observed. Waking too early and feeling rested may be particularly relevant to loneliness after stroke. Sleep quality interventions could reduce loneliness after stroke and could serve as a modifiable target in rehabilitation.

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Acknowledgments

We acknowledge the Cambridge Centre for International Research for providing the guidance and opportunity to conduct this research.