Current Psychology (2026) 45:104
https://doi.org/10.1007/s12144-025-08643-9

Why does my night seem so long? Dynamic reciprocal relationship between sleep health and rumination among college students

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Received: 6 February 2025 / Accepted: 28 October 2025 / Published online: 6 January 2026

Abstract
Sleep disturbances are prevalent within the global college student population, with rumination being a significant cognitive determinant of sleep health. Nonetheless, the reciprocal and dynamic relationship between these two factors has not been investigated. This study employed an intensive longitudinal design in which self-report data were collected over 21 days from 417 Chinese college students (76.0% women; M_{age} = 18.28 years, SD=0.90). Results of dynamic structural equation modeling (DSEM) revealed temporal stability in sleep quality, bedtime procrastination, and rumination. Poor sleep quality predicted subsequent rumination, and vice versa, creating a cycle of mutual exacerbation. Bedtime procrastination and rumination showed a similar bidirectional pattern. These findings provide the first longitudinal evidence of a dynamic, reciprocal cycle between rumination and sleep health among college students, revealing real-time mechanisms of mutual reinforcement. This study underscores the need for integrative interventions that concurrently address cognitive (rumination), behavioral (bedtime procrastination), and physiological (sleep quality) factors to effectively disrupt the self-reinforcing cycle.

Keywords Rumination · Sleep quality · Bedtime procrastination · Dynamic structural equation modeling

Introduction

Sleep health is a key indicator of an individual's physical and mental condition, as it plays a significant role in clearing the brain's metabolic waste (Lewis, 2021). Insufficient sleep not only exacerbates daytime fatigue but also poses risks for long-term health issues such as obesity, hypertension, and cardiovascular diseases (Kiss et al., 2024), and may even shorten the lifespan (Vaccaro et al., 2020). Based on an integration of 11 review papers in 30 countries, Chaput et al. (2020) concluded that 7 to 8 h of sleep per night is ideal for physical health, and this schedule is also associated with lower risk of depression.

Insomnia is prevalent among college students globally. For instance, a large-scale survey of 20,139 college students across 60 countries found that 11,597 participants (57.6%) scored above the clinical threshold for insomnia (Babicki et al., 2023). College students are in the transition phase from adolescence to early adulthood, a period when the lifestyle upheavals, such as increased independence in daily routines and a burgeoning social life, intersect with a mounting academic workload. This confluence often disrupts their sleep patterns (Chen & Chen, 2021). Furthermore, their cognitive and psychological development is not yet fully mature, making them more susceptible to the influence of rumination (Pedrelli et al., 2015).

Rumination has been identified as an individual difference associated with sleep problems in traditional longitudinal studies (e.g., Mazzer et al., 2019). In the current study, we use intensive longitudinal analyses, a cutting-edge method, to thoroughly examine the mutual longitudinal association between college students' rumination and sleep health. The aim is to provide new theoretical bases and practical guidance for improving the sleep health of college students.

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Rumination and general sleep health

Nolen-Hoeksema (1987) first proposed that rumination refers to the tendency of individuals to dwell persistently on negative life events, their underlying causes, and possible negative outcomes, while neglecting to contemplate strategies for improvement or problem-solving. This thinking pattern is associated with a higher risk of anxiety, depressive symptoms, and suicidal ideation (Le et al., 2025). Rumination can be a trait or state condition. Nolen-Hoeksema (1987) considered rumination to be a trait related to a depressive response style, and this aspect of rumination is typically measured in terms of self-belief information based on memory. On the other hand, state rumination is considered a temporary state of mind or a temporary coping mechanism (Whiteman & Mangels, 2016) and is measured in terms of immediate experiential information around the time of events.

Sleep health can be conceptualized as sleep quality and bedtime procrastination. The former reflects the depth, continuity, and restorative nature of sleep (Nelson et al., 2022), while the latter refers to the behavior of consciously delaying bedtime (Kroese et al., 2014). In a sample of 135 physically inactive undergraduate students, Zakaria et al. (2025) found that both rumination and bedtime procrastination were positively associated with poor sleep quality. Additionally, another study by You et al. (2021) revealed that rumination and bedtime procrastination not only separately mediated the relationship between internet addiction and poor sleep quality, but also played sequential mediating roles in this association.

Although these studies provided valuable insights into the relationships among rumination, bedtime procrastination, and sleep quality, there are potential limitations worth noting. First, both studies employed a cross-sectional design, which can only reveal correlations among these variables and test unidirectional associations. This approach fails to examine whether bidirectional influences exist between rumination and sleep health. Second, the studies focused on trait rumination, overlooking day-to-day fluctuations in rumination. Therefore, the present study aimed to examine rumination in relation to two key dimensions of sleep health—sleep quality and bedtime procrastination—at the state level.

Rumination and sleep quality

Harvey (2002) proposed the cognitive model of insomnia, which offers a new perspective for understanding the relationship between rumination and sleep quality. This model posits that when an individual perceives a threat to sleep or a lack of sleep, it will naturally trigger a series of negative cognitive responses. In response, the individual often adopts self-protective behaviors such as thought control, imagery control, and emotional suppression. At the same time, they may develop some misperceptions and false beliefs about sleep. Paradoxically, these seemingly "protective" behaviors and false beliefs actually work together to further exacerbate the symptoms of insomnia. As time goes by, the cumulative effect of these negative responses leads to severe sleep deprivation, which in turn greatly impairs the individual's normal daytime functions.

A meta-analysis of 55 studies involving 181,366 nonclinical adult participants demonstrated that higher rumination was correlated concurrently and longitudinally with poorer sleep quality, shorter total sleep duration, and longer sleep onset latency (Clancy et al., 2020). Furthermore, a longitudinal study of 1,219 community adults found that state rumination significantly predicted insomnia symptoms five months later (Olatunji et al., 2023). These findings suggest that state rumination is a potential risk factor for insomnia.

Previous studies have shown that poor sleep quality impairs cognitive functioning (Hudson et al., 2020). Additionally, individuals with sleep disorders often endorse irrational beliefs about sleep, which may contribute to increased daytime rumination about their sleep difficulties (Faccini et al., 2023). Taken together, the aforementioned series of research results clearly demonstrate that there may exist a complex and close interaction between rumination and sleep quality. In-depth exploration of this relationship is of great theoretical and practical significance for our comprehensive understanding of sleep health issues.

Rumination and bedtime procrastination

Bedtime procrastination represents a unique form of procrastination behavior, which is highly correlated with general procrastination and shares similar psychological mechanisms (Kroese et al., 2014). Gort et al. (2021) revealed that general procrastination positively predicted ruminative cognition. Therefore, it can be reasonably inferred that bedtime procrastination is also likely to aggravate an individual's rumination. This assumption aligns well with the goal-progress theory of rumination proposed by Martin and Tesser (2006). According to this theory, when individuals procrastinate and thus fail to reach their set goals, they become acutely aware of the disparity between their current situation and their ideal state. This awareness then prompts them to ruminate on the root causes of this gap.

Interestingly, the relationship between bedtime procrastination and rumination is not unidirectional. Rumination can also exacerbate bedtime procrastination (Hill et al., 2023). Sirois and Pychyl (2013) proposed a theoretical framework in which sleep-related rumination induces cognitive biases, causing individuals to downplay the long-term benefits of regular sleep (e.g., sustained energy and mental wellness)

as insufficient for alleviating immediate negative emotions. This emotional misattribution prioritizes short-term affect regulation over long-term health, thereby reinforcing tendencies toward bedtime procrastination. Some empirical studies have confirmed this inference. For example, in a 14-day experience sampling study involving 521 young adults (M_{age} = 24.6 years), rumination was found to be a significant positive predictor of bedtime procrastination (Carlson & Williams, 2024). Taken together, this body of evidence suggests a bidirectional association between rumination and bedtime procrastination, indicating that these two constructs may form a self-reinforcing cycle.

Intensive longitudinal analysis of bidirectional influences

The research to date suggests that there are bidirectional influences between rumination and sleep health. However, these mutual influences have not been examined within the same study. Additionally, most studies have used cross-sectional designs, making it difficult to ascertain the dynamic interactive relationship between rumination and sleep health (Slavish et al., 2018). The recently emerging intensive longitudinal design has provided an effective strategy for addressing these problems. Compared to cross-sectional research designs, intensive longitudinal designs are characterized by short and frequent measurement intervals. This approach allows researchers to explore complex patterns of individual change and analyze the dynamic relationships among various variables within individuals (Wright & Woods, 2020).

Dynamic structural equation modeling (DSEM) is helpful for analyzing intensive longitudinal data. This modeling procedure integrates the advantages of various modeling approaches including Multilevel Modeling (MLM), Time-Series Modeling (TSM), and Structural Equation Modeling (SEM). It enables dynamic analysis of latent variables, reveals the effects of the variables on themselves (autoregressive paths) and on each other (cross-lagged paths), and takes a more comprehensive consideration of influencing factors, leading to more accurate results (Hamaker et al., 2018). Many psychological studies focus on theories and hypotheses that are centered on intra-individual processes, yet their data analysis fundamentally explores inter-individual relationships, which may lead to biased conclusions. DSEM can conveniently incorporate features from intensive longitudinal data into the model (such as considering dynamic trends and cyclical changes), allowing not only for the analysis of how variables change over time but also for the dynamic changes in relationships between variables over time (Hamaker et al., 2018).

Although DSEM is a relatively recent technique, it has been applied in Western studies to analyze depression-sleep cycles among individuals with bipolar disorder (Lewis et al., 2023); however, its application to college student populations remains underexplored, especially in non-Western cultural contexts. Given that Chinese college students are immersed in a high-pressure academic environment—exemplified by the "involution" phenomenon of intense competition—they represent a stress-sensitive population (Yi et al., 2022) and offer unique insights for global youth research.

The current study

In this intensive longitudinal study, we tested the bidirectional relationship between college students' sleep health and rumination using dynamic structural equation modeling (DSEM). Drawing upon the cognitive model of insomnia, goal-progress theory, the theoretical framework proposed by Sirois and Pychyl (2013), and relevant empirical research, we propose the following hypotheses:

- Hypothesis 1 There will be a mutually exacerbating longitudinal relationship between rumination and poor sleep quality.
- Hypothesis 2 There will be a mutually exacerbating longitudinal relationship between rumination and bedtime procrastination.

Methods

Participants and procedure

The participants were 417 full-time undergraduate students (72.4% freshmen, 27.6% sophomores) from a university in Hunan Province, China (76.0% women; aged from 15 to 23 years, M=18.28, SD=0.90). Most students, 77.9% (n=325), had one or more siblings, and 52.0% (n=217) reported their place of residence as rural.

Psychology graduate students who received specialized training distributed a link to questionnaires on sleep quality, bedtime procrastination, and rumination on the online *Sojump* platform every evening for 21 consecutive days. Sample collection occurred from November 11, 2023, to December 1, 2023. This time frame was chosen to minimize the impact of special academic periods (e.g., early-semester adaptation or end-of-semester exam preparation) and major holidays. It covers a typical mid-semester phase, during which college students' daily routines—including academic tasks, social activities, and sleep schedules—are generally more stable. This approach ensures the capture of authentic and representative daily fluctuations in rumination and sleep health, thus enhancing the validity of

the longitudinal trend analysis. The questionnaire content was the same each day, but the order of items was random. It took about one minute to fill out the questionnaire. After data collection was completed, research assistants reviewed the data to ensure its validity. The screening criteria for valid questionnaires, developed for intensive longitudinal daily diary data to exclude inattentive or invalid responses, included three key aspects: (1) Filling time threshold: Questionnaires with a completion time of less than 10 s were excluded, as this duration is too brief for careful completion (e.g., random clicking); (2) Response consistency check: Questionnaires with identical ratings for all 6 items were excluded, as this suggests a lack of thoughtful engagement; (3) Duplicate submission filtering: Questionnaire links were tied to participants' unique student IDs, ensuring only one valid response per person per day was retained, and duplicates were removed to avoid redundancy. The study was approved by the Research Ethics Committee of the corresponding author's university. All participants provided their written consent to participate, and were told they had the right to withdraw at any time. Each participant received a reward of 20 yuan RMB at the end of the study.

Measures

Sleep quality

The Pittsburgh Sleep Quality Index (PSQI) is a commonly used 18-item self-report questionnaire for assessing sleep quality over the past month (Buysse et al., 1989). To alleviate the burden of daily assessments in the current study, two items adapted from the original PSQI were used to assess sleep quality in the current study, namely "Due to poor sleep last night, I feel sleepy today" and "Due to poor sleep last night, I find it hard to concentrate today." Each item was rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), with higher scores indicating poorer sleep quality. In this study, the within-person reliability of the scale (according to Cranford et al., 2006) was 0.98.

Bedtime procrastination

The Bedtime Procrastination Scale (BPS) developed by Kroese et al. (2014) consists of 9 self-report items. To align with the study's demands of daily data collection, the scale was modified by reducing the number of items and revising their wording. The two items with the highest relevance to the construct were selected for adaptation, specifically "I went to bed later than I had intended tonight" and "I went to bed early tonight if I had to get up early tomorrow morning." Each item is rated on a 5-point Likert scale, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). After reverse-scoring the second item, the average score was calculated, with higher scores indicating a greater tendency for bedtime procrastination. In this study, the within-person reliability of the scale (according to Cranford et al., 2006) was 0.97.

State rumination

The Brief State Rumination Inventory (BSRI), developed by Marchetti et al. (2018), is a self-report measure of an individual's repetitive thinking about negative experiences at a specific moment. The BSRI comprises 8 items, using a 100 mm Visual Analog Scale (VAS) for scoring, with the range from 0 (*strongly disagree*) to 100 (*strongly agree*). To adapt to the burden of daily assessments in this study, adjustments were made to the number of items, their wording, and scoring methods. The two items with the highest factor loadings in Marchetti et al.'s (2018) report were selected, namely "Right now, I am thinking: 'Why can't I handle things better?'" and "Right now, it is hard for me to shut off negative thoughts about myself." Each item was rated on a five-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*). The within-person reliability of the adapted scale (according to Cranford et al., 2006) was 0.98.

Data analyses

The data were analyzed with SPSS 23.0 and Mplus 8.6. Given that daily observations were nested within individuals, the variables were decomposed into potential within-individual components and between-individual components, which were then lagged to account for the effects of previous observations on subsequent outcomes (Hamaker et al., 2018).

First, a null model without any predictor variables was constructed to estimate the means, within- and between-variances, and intraclass correlations (ICCs). Then, a multilevel cross-lagged path model was established using DSEM to explore the bidirectional relations between rumination and sleep quality (Fig. 1), and between rumination and bedtime procrastination (Fig. 2), respectively.

Results

Descriptive statistics and correlation analysis

Table 1 presents the means, within- and between-variances, intraclass correlation coefficients (ICC), and the within- and

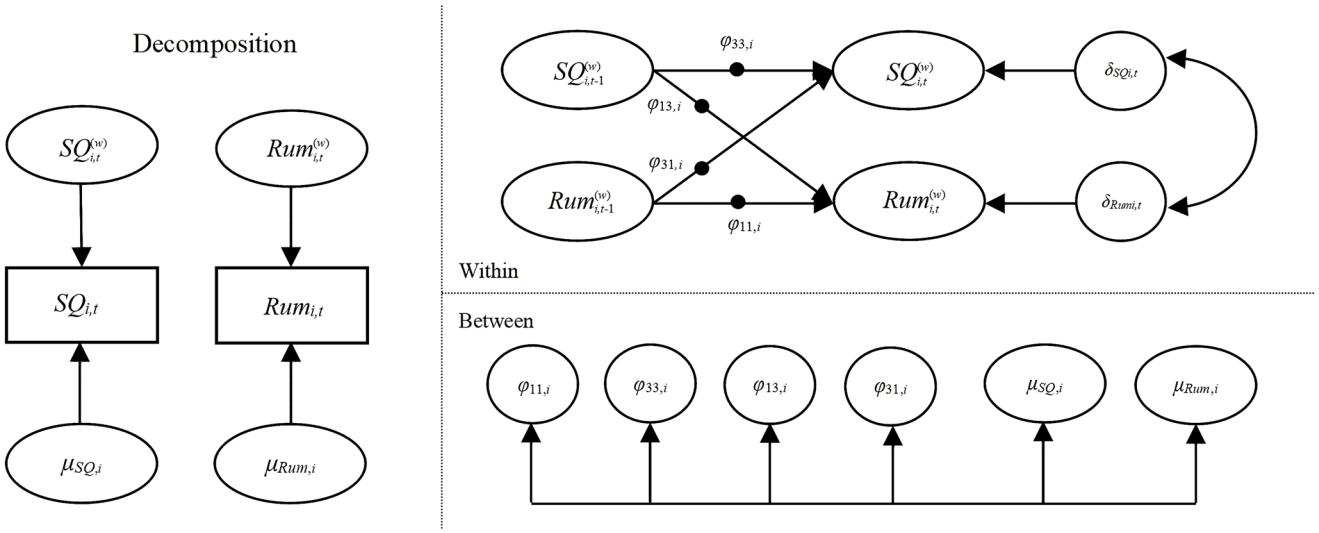

Fig. 1 Dynamic Structural Equation Model (DSEM) for Sleep Quality and Rumination. *Note*. SQ= Sleep Quality; Rum = Rumination. Black dots indicate person-specific autoregressive and cross-lagged effects. Left part contains the decomposition into within-person (time-varying) and between-person (time-invariant) components. Top right contains the within-person level model, which is a cross-lagged panel model. Bottom right contains the between-person level model, which includes the between-person components from the decomposition, as well as all the random effects of the model, corresponding to the solid black circles in the within-person level model

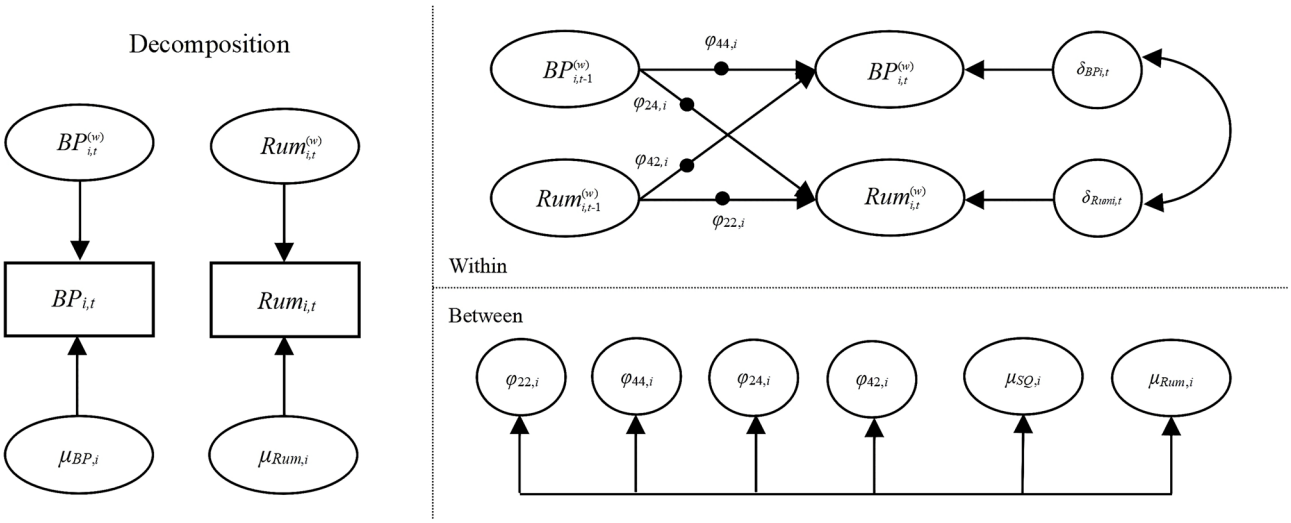

Fig. 2 Dynamic Structural Equation Model (DSEM) for Bedtime Procrastination and Rumination. *Note*. BP= Bedtime Procrastination; Rum = Rumination. Black dots indicate person-specific autoregressive and cross-lagged effects. Left part contains the decomposition into within-person (time-varying) and between-person (time-invariant) components. Top right contains the within-person level model, which is a cross-lagged panel model. Bottom right contains the between-person level model, which includes the between-person components from the decomposition, as well as all the random effects of the model, corresponding to the solid black circles in the within-person level model

between-correlations among rumination, sleep quality, and bedtime procrastination. The results revealed that the ICC for rumination, sleep quality, and bedtime procrastination was 0.54, 0.39, and 0.46, respectively, indicating that at least 39% of the variance was explained by the differences between individuals.

The results of within-person correlation analysis showed that rumination was significantly correlated with sleep quality (r=0.21) and bedtime procrastination (r=0.13), indicating that the higher the level of rumination the participants had that day, the lower their sleep quality and the more severe their bedtime procrastination on the same day. Similarly, the results of the between-person correlation analysis showed that rumination was positively correlated with sleep quality (r=0.69) and bedtime procrastination (r=0.51), indicating that participants with higher rumination tended to have poorer sleep quality and more severe bedtime procrastination.

Table 1 Descriptive statistics and intraclass correlation coefficients (ICC) for rumination, sleep quality, and bedtime procrastination

Variable	Mean	Variance		ICC	Correlations		
		Within-person	Between-person		Rumination	SQ	BP
Rumination	2.59	0.43	0.52	0.54	—	0.69	0.51
SQ	2.80	0.71	0.46	0.39	0.21	—	—
BP	3.15	0.61	0.53	0.46	0.13	—	—

Note. $n = 417$. ICC = Intraclass correlation. Between-person correlations are presented above the diagonal, and within-person correlations are presented below the diagonal. All the correlations were significant at $p < 0.001$. Data were collected over 21 consecutive days using a daily diary design. The DSEM model decomposes variance into within-person (daily fluctuations) and between-person (individual differences) components

Dynamic bidirectional relations between rumination and sleep quality

DSEM was used to investigate the reciprocal relationship between rumination and sleep quality. The unstandardized and standardized estimates and their 95% credible intervals (CI) for fixed and random effects are shown in Table 2. An effect is statistically significant when the CI does not include 0. The autoregressive effect of sleep quality ($\varphi_{33} = 0.157$, 95% CI = [0.129, 0.185]) was significant, indicating that current sleep quality could significantly predict the sleep quality on the next day. Furthermore, the autoregressive effect of rumination ($\varphi_{11} = 0.216$, 95% CI = [0.189, 0.246]) was descriptively stronger than that of sleep quality, suggesting that rumination had a relatively higher persistence or "inertia" compared to sleep quality.

More importantly, the cross-lagged effects between rumination and sleep quality were also significant. Higher rumination predicted a decline in sleep quality the following day ($\varphi_{31} = 0.056$, 95% CI = [0.028, 0.082]), which in turn predicted increased rumination the next day ($\varphi_{13} = 0.041$, 95% CI = [0.016, 0.065]). Thus, there was a self-perpetuating loop between rumination and sleep quality (non-standardized feedback effect [FE] = 0.002, 95% CI = [0.001, 0.005]; standardized feedback effect [FE] = 0.002), with a medium feedback effect (Luo et al., 2024). Moreover, the random variance in autoregressive and cross-lagged effects indicated significant individual differences in the bidirectional relations between rumination and sleep quality.

Dynamic bidirectional relations between rumination and bedtime procrastination

Table 3 presents the parameter estimates for the unstandardized and standardized bidirectional relations between rumination and bedtime procrastination. The findings revealed significant autoregressive effects for both rumination ($\varphi_{22} = 0.214$, 95% CI = [0.187, 0.242]) and bedtime

Table 2 Results of parameter Estimation from the dynamic structural equation model for rumination and sleep quality

	Unstandardized estimates			Standardized estimates		
	b	*SD*[a]	95% CI	*β*	*SD*	95% CI [b]
Fixed effects						
Autoregressive effects						
Rumination→Rumination	0.216	0.018	[0.182, 0.252]	0.216	0.015	[0.189, 0.246]
SQ→SQ	0.157	0.017	[0.125, 0.190]	0.157	0.014	[0.129, 0.185]
Cross-lagged effects						
Rumination→SQ	0.070	0.019	[0.034, 0.106]	0.056	0.013	[0.028, 0.082]
SQ→Rumination	0.032	0.011	[0.010, 0.054]	0.041	0.013	[0.016, 0.065]
FE	0.002	0.001	[0.001, 0.005]	0.002		
Random variances						
Autoregressive effects						
Rumination→Rumination	0.038	0.007	[0.026, 0.054]			
SQ→SQ	0.034	0.007	[0.022, 0.050]			
Cross-lagged effects						
Rumination→SQ	0.023	0.008	[0.011, 0.040]			
SQ→Rumination	0.010	0.003	[0.005, 0.018]			

Note. $n = 417$. [a]*SD* stands for the standard deviation of the posterior distribution. [b] CI stands for credible interval. SQ = Sleep Quality. DIC = 39691.785. Data were collected over 21 consecutive days using a daily diary design. The DSEM model decomposes variance into within-person (daily fluctuations) and between-person (individual differences) components. The model estimates both autoregressive effects (temporal stability of each variable) and cross-lagged effects (lagged influence between variables across days), allowing for examination of bidirectional dynamics (e.g., rumination at day *t*–1 predicting sleep quality at day *t*)

Table 3 Results of parameter Estimation from the dynamic structural equation model for rumination and bedtime procrastination

	Unstandardized estimates			Standardized estimates		
	b	*SD*[a]	95% CI	*β*	*SD*	95% CI [b]
Fixed effects						
Autoregressive effects						
Rumination→Rumination	0.214	0.017	[0.179, 0.247]	0.214	0.014	[0.187, 0.242]
BP→BP	0.200	0.018	[0.165, 0.236]	0.200	0.014	[0.172, 0.229]
Cross-lagged effects						
Rumination→BP	0.042	0.017	[0.009, 0.076]	0.038	0.013	[0.012, 0.063]
BP→Rumination	0.027	0.013	[0.002, 0.052]	0.033	0.013	[0.008, 0.061]
FE	0.001	0.001	[0.001, 0.003]	0.001		
Random variances						
Autoregressive effects						
Rumination→Rumination	0.040	0.007	[0.027, 0.056]			
BP→BP	0.049	0.008	[0.036, 0.067]			
Cross-lagged effects						
Rumination→BP	0.021	0.007	[0.009, 0.037]			
BP→Rumination	0.014	0.004	[0.007, 0.023]			

Note. $n = 417$. [a]*SD* stands for the standard deviation of the posterior distribution. [b] CI stands for credible interval. BP = Bedtime Procrastination. DIC = 38458.825. Data were collected over 21 consecutive days using a daily diary design. The DSEM model decomposes variance into within-person (daily fluctuations) and between-person (individual differences) components. The model estimates both autoregressive effects (temporal stability of each variable) and cross-lagged effects (lagged influence between variables across days), allowing for examination of bidirectional dynamics (e.g., rumination at day *t*–1 predicting bedtime procrastination at day *t*)

procrastination ($\varphi_{44} = 0.200$, 95% CI = [0.172, 0.229]), indicating their moderate carryover effects: when people had higher/lower.

levels of rumination and bedtime procrastination at a particular moment, they would also have higher/lower levels of rumination and bedtime procrastination the next day.

Additionally, there were significant cross-lagged effects between rumination and bedtime procrastination. Specifically, individuals who experienced more rumination reported more bedtime procrastination the next day ($\varphi_{42} = 0.038$, 95% CI = [0.012, 0.063]), in turn reported more rumination the day after that ($\varphi_{24} = 0.033$, 95% CI = [0.008, 0.061]). This indicated that there was also a self-sustaining loop between rumination and bedtime procrastination (non-standardized feedback effect [FE] = 0.001, 95% CI = [0.001, 0.003]; standardized feedback effect [FE] = 0.001), with a medium feedback effect (Luo et al., 2024). Furthermore, the bidirectional relations between rumination and bedtime procrastination exhibited significant individual variability.

Discussion

This study examined sleep health through two key lenses: sleep quality—a fundamental indicator of sleep depth and restorative function (Nelson et al., 2022)—and bedtime procrastination—a behavioral tendency that disrupts sleep onset regularity (Kroese et al., 2014). We used the recently developed modeling method of dynamic structural equation modeling (DSEM) to examine the dynamic bidirectional relations between sleep health and rumination. The results indicated that there were significant carryover effects for sleep quality, bedtime procrastination, and rumination. More crucially, there was a dynamic vicious cycle between sleep health and rumination, indicating that low levels of sleep health (i.e., poor sleep quality and high bedtime procrastination) might exacerbate subsequent rumination, and vice versa. These results provide strong support for Hypotheses 1 and 2, which posited mutually reinforcing longitudinal relationships between rumination and sleep quality, as well as between rumination and bedtime procrastination. Additionally, this study provides novel cross-cultural evidence to the international discourse on the relationship between rumination and sleep health, specifically within the unique, high-academic-pressure context of Chinese college students. These findings help to validate the cross-cultural applicability of existing theoretical frameworks, extending their relevance beyond Western cultural settings.

First, this study revealed a reciprocal relationship between rumination and sleep quality at the within-person level. Specifically, individuals with higher levels of rumination tended to report poorer sleep quality the following

day, and vice versa. This bidirectional association supported the results of a longitudinal resting-state fMRI study of 373 Chinese university students (Yang & Lei, 2025). According to the perseverative cognition hypothesis (Brosschot et al., 2006), rumination induces sustained psychophysiological arousal, which depletes cognitive resources and disrupts sleep homeostasis in both the short and long term. This disruption creates a reciprocal feedback loop, as sleep deprivation impairs daytime attentional control (Baker et al., 2015), increases the frequency of negative thought intrusions, and further intensifies rumination (Galbiati et al., 2018).

Furthermore, we found a reciprocal relationship between rumination and bedtime procrastination. Specifically, individuals with higher rumination were more likely to exhibit bedtime procrastination over time; conversely, individuals with higher levels of bedtime procrastination reported higher rumination subsequently. This finding is consistent with the theoretical framework of the "rumination-negative emotion-maladaptive behavior cycle" proposed by Lyubomirsky and Tkach (2003). In this cycle, rumination exacerbates negative emotions, which subsequently give rise to a series of cognitive and behavioral impairments—including increased negative thinking, diminished problem-solving ability, reduced motivation and behavioral inhibition, and impaired cognitive functioning. These difficulties result in a lack of motivation to initiate action, thereby fostering procrastination (Ciobotaru et al., 2024). In turn, procrastination reinforces negative emotional states and further deepens rumination, forming a self-perpetuating and escalating feedback loop (Gort et al., 2021).

Compared to previous studies that primarily examined the unidirectional effect of rumination on bedtime procrastination (Carlson & Williams, 2024; Flores et al., 2023), the present study conducted a more fine-grained analysis using daily diary data, capturing the dynamic, temporal evolution of rumination and bedtime procrastination over time. This approach enabled us, for the first time, to comprehensively uncover the complex bidirectional longitudinal relationship between the two variables.

Limitations, future directions, and implications

Several limitations of our study should be acknowledged. First, the assessment of sleep quality relied solely on questionnaire methods without combining objective physiological indicators. There are inconsistencies between subjective sleep quality measured by self-report questionnaires and objective sleep quality measured by activity recorders (Cudney et al., 2022). Specifically, self-report questionnaires often focus on individuals' perceived experiences during sleep, such as how easily they fell asleep, whether they woke up frequently during the night, and how rested they felt upon waking. Activity recorders measure aspects like the actual duration of sleep, the number of sleep cycles, and the level of physical movement during sleep, which are more objectively observable physiological data. They might be measuring different things. Future research should combine subjective reports with objective measurement tools such as activity recorders to improve the objectivity and accuracy of the findings.

Second, all the participants in this study were students recruited from a university in China. Therefore, it remains to be explored whether the.

findings will generalize to other populations or cultures. Finally, the underlying mechanisms between rumination and sleep health have not been thoroughly explored. Future research could employ experimental designs to further investigate the causal relationship between rumination and sleep health, as well as potential mediating (e.g., negative affect; You et al., 2023) and moderating (e.g., neuroticism; Slavish et al., 2018) variables in the association, to provide a deeper understanding and new treatment approaches.

This study utilized DSEM to disclose a dynamic bidirectional relationship between rumination and sleep health, highlighting the significance of considering both in interventions for enhancing physical and mental well-being. Given the mutually exacerbating cycle between rumination and sleep health, merely focusing on sleep health might be insufficient to alleviate related symptoms.

Regarding interventions for rumination, previous research has demonstrated that cognitive restructuring techniques can assist adults in identifying and modifying negative thought patterns (Langenecker et al., 2024). However, the specific impact of these strategies on the relationship between rumination and sleep health among college students remains to be further explored. Our findings suggest that future interventions should place greater emphasis on disrupting the vicious cycle between rumination and sleep health. For instance, cognitive-behavioral therapies that simultaneously target both rumination and sleep problems might yield more favorable outcomes. In terms of improving sleep health to alleviate rumination, behavioral treatment techniques (e.g., stimulus control therapy, sleep restriction therapy) can be employed to address sleep problems like difficulty falling asleep or maintaining sleep, thereby reducing rumination caused by sleep issues (Sharma & Andrade, 2012). Future research could further evaluate the long-term efficacy of these interventions in the college student population and explore how to personalize them based on individual differences.

Currently, it remains uncertain whether there have been studies that simultaneously intervened in rumination and sleep problems. Nevertheless, the results of this study provide a theoretical foundation for future research in this area. Future studies could further explore comprehensive

intervention measures to more effectively break the vicious cycle between rumination and sleep health and improve the physical and mental health of college students.

Author contributions H.G. conceived of the study, participated in its design and coordination, participated in the interpretation of the data, and helped up to draft the manuscript; S.L. conceived of the study, participated in its design and coordination and drafted the manuscript; Y.H. participated in the interpretation of the data and the revisions of the manuscript; J.F. performed the statistical analysis; Y.C. collected the data and participated in its design and coordination. All authors read and approved the final manuscript.

Funding This research was funded by grants from the post-funded projects of the National Social Science Fund of China (24FJKB012), the Humanities and Social Sciences Fund Project of the Ministry of Education (24YJA190003), and the Natural Science Foundation of Hunan Province (2025JJ50159).

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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