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# The Role of Sleep and Metacognition in Linking Stress to Self-Hate: A Dual- Analytic Study in University Students

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## Abstract

# Background

Stress-related mental health problems are highly prevalent among university students, yet the mechanisms through which stress gives rise to distinct affective outcomes remain poorly understood. Sleep disturbance represents a core transdiagnostic pathway through which stress may impair emotional functioning; however, the sequential roles of sleep quality and daytime sleepiness, as well as their interaction with metacognitive processes, remain unclear. Moreover, reliance on single analytic approaches may obscure outcome-specific vulnerabilities within the stress–sleep–mental health system.

# Methods

A total of 1,374 university students completed validated measures assessing perceived stress, sleep quality, daytime sleepiness, anhedonia, self-hate, and metacognition. We applied a dual-analytic framework that integrated regression-based chain and moderated mediation models with a Discrete Bayesian Network (DBN) to examine both linear associations and probabilistic dependencies among variables.

# Results

Perceived stress exerted significant indirect effects on both anhedonia and self-hate through poorer sleep quality and increased daytime sleepiness, with a markedly stronger indirect pathway for self-hate. Daytime sleepiness showed a substantially larger effect on self-hate than on anhedonia, and metacognition significantly moderated the association between sleepiness and self-hate, but not anhedonia. DBN analyses converged with regression findings, indicating that self-hate was probabilistically more sensitive than anhedonia to stress- and sleep-related disruptions.

# Conclusions

These findings identify self-hate as a particularly sleep- and cognition-sensitive outcome within the stress–sleep–mental health network. Integrating regression and Bayesian approaches clarifies distinct vulnerability pathways and highlights sleep-focused, cognition-informed interventions as promising targets for stress-related mental health problems in young adults.

## 1 Introduction

Mental health problems have become a major public health concern among young adults, with symptoms such as anhedonia and self-hate posing substantial threats to psychological well-being and

social functioning (Carvajal et al., 2021; Whitton et al., 2023). Anhedonia, defined as a diminished capacity to experience pleasure, undermines motivation and engagement in daily life (Watson et al., 2020). Self-hate reflects pervasive self-denigration and intense self-criticism and has been linked to increased vulnerability across a range of mental health disorders(Gazzillo et al., 2025; Lieberman et al., 2023). Although stress has been consistently identified as a key contributor to these symptoms(Shivakumara et al., 2023), the mechanisms through which stress influences specific mental health outcomes in young adults remain incompletely understood.

Stress is widely recognized as an important exogenous risk factor for mental health problems, exerting its effects through interconnected psychological and physiological pathways (Ghasemi et al., 2024; Pascoe et al., 2020). University students are particularly susceptible to stress due to academic demands, developmental transitions, and social pressures. Importantly, stress may not influence mental health directly; instead, sleep-related processes may play a critical mediating role, providing a theoretical framework for examining the stress–sleep–mental health relationship(Chai et al., 2025).

Sleep is a fundamental biological process essential for emotional and cognitive functioning. Accumulating evidence indicates that stress disrupts sleep quality, leading to difficulties in sleep initiation and maintenance, reduced sleep duration, as well as poorer subjective sleep experiences(Gardani et al., 2022). Impaired sleep, in turn, contributes to excessive daytime sleepiness, which has been associated with cognitive inefficiency, emotional dysregulation, and compromised social functioning(Guerrini Usubini et al., 2022; Soto et al., 2023). Among university students, compensatory behaviors such as daytime napping are common and may further disrupt circadian rhythms, thereby increasing psychological vulnerability(Rea et al., 2022). Consistent with this, circadian rhythm disruption has been directly linked to a higher prevalence of psychiatric disorders, including depression and anxiety (Yeom et al., 2024). These findings highlight the need to examine the combined roles of sleep quality and daytime sleepiness in linking stress to mental health outcomes.

Beyond sleep-related factors, individual differences in cognitive functioning may shape vulnerability to psychological distress. Metacognition refers to the capacity to monitor and regulate one's own cognitive processes(Belte et al., 2024). While higher metacognitive ability can facilitate adaptive coping under stress (Drigas et al., 2021), heightened self-monitoring may also amplify negative self-focused attention and self-critical thinking, particularly under conditions of impaired alertness such as excessive daytime sleepiness(Socci et al., 2024). Despite growing interest in metacognition in psychopathology research, its moderating role within the stress–sleep–mental health pathway remains insufficiently explored.

Against this backdrop, this study employed a chain mediation model to investigate whether perceived stress influences mental health outcomes—specifically anhedonia and self-hate—via sleep quality and daytime sleepiness. We further examined whether metacognitive beliefs moderate the association between daytime sleepiness and mental health. We hypothesized that (1) perceived stress would exert significant indirect effects on mental health through poorer sleep quality and heightened daytime sleepiness, and (2) metacognitive beliefs would amplify the detrimental impact of daytime sleepiness on

psychological functioning. Together, these findings aim to clarify the stress–sleep–mental health pathway and inform targeted mental health interventions in university populations.

# 2 Methods

# 2.1 Participants

A total of 1,374 undergraduate students participated in this study. Participants ranged in age from 18 to 25 years (682 males and 692 females). All participants provided informed consent prior to participation and completed the questionnaires anonymously. This study was approved by the Ethics Committee of Beijing Huilongguan Hospital.

# 2.2 Measures

### Perceived Stress

Perceived stress was assessed using the Perceived Stress Scale (PSS) (Lu et al., 2017). PSS is a widely used self-report questionnaire that assesses the degree to which individuals perceive their lives as unpredictable, uncontrollable, and overloaded, providing a global measure of perceived stress over the past month. The internal consistency of the scale was acceptable in the current sample (Cronbach's α = 0.741). Higher scores indicated greater perceived stress. The total score (X) was used in subsequent analyses.

### Sleep Quality and Daytime Sleepiness

Subjective sleep quality over the past month was measured using the Pittsburgh Sleep Quality Index (PSQI)(Tsai et al., 2005), which assesses various dimensions of sleep such as sleep latency, sleep duration, disturbances, use of sleep medication, and daytime dysfunction. In line with the PSQI structure, the assessment covered bedtime, wake time, sleep latency, sleep duration, frequency of awakenings, snoring or coughing, physical discomfort, and nightmares. All items reflected average experiences over the previous month. Higher scores indicated greater severity of sleep problems. The PSQI total score was used to index sleep quality (M1). The Epworth Sleepiness Scale (ESS) is a widely used self-report questionnaire designed to assess excessive daytime sleepiness in daily life. The Mandarin-Chinese version (CESS) has been validated, showing good internal consistency (Cronbach's α = 0.81), and sensitivity to clinical change, making it suitable for use in Chinese-speaking populations(Chen et al., 2002). According to standard cutoffs (0–9 = normal, 10–12 = mild, 13–15 = moderate, ≥ 16 = severe), we recoded ESS scores into four categories (1–4) to reflect the severity of daytime sleepiness (M2).

### Mental Health

Anhedonia (Y1) was assessed using the Snaith–Hamilton Pleasure Scale (SHAPS), a widely used self-report measure of hedonic capacity, with higher total scores indicating greater levels of anhedonia. The Chinese version of the SHAPS has demonstrated excellent internal consistency (Cronbach's α = 0.93)(Liu

et al., 2012). Self-hate (Y2) was assessed using the Self-Hate Scale (Jiaqi et al., 2023), which consists of seven items. Higher scores indicated greater levels of self-hate. The scale had good internal consistency, and the Cronbach's α was 0.945(Jiaqi et al., 2023).

### Metacognition

Metacognitive beliefs (W) were measured using the 30-item Metacognitions Questionnaire (MCQ-30)(Dai et al., 2018). Items were rated on a 4-point Likert scale, assessing aspects such as cognitive monitoring, beliefs about thought control, and metacognitive beliefs. The MCQ-30 showed excellent internal consistency in the present sample (Cronbach's α = 0.892).

## 2.3 Statistical Analyses

This study employed a cross-sectional design to test the chain mediation effect of sleep quality and daytime sleepiness on the relationship between stress and mental health, and to examine whether metacognition moderates the link between sleepiness and mental health outcomes.

### Descriptive Statistics

Descriptive analyses were conducted in SPSS 26.0 to compute means and standard deviations for all primary variables, including perceived stress, sleep quality, daytime sleepiness, anhedonia, self-hate, and metacognition. Demographic data (e.g., age, gender, educational level) were also summarized.

### Correlation Analyses

Correlation analyses were conducted to examine associations among perceived stress, sleep quality, daytime sleepiness, anhedonia, self-hate, and metacognition. Given the ordinal nature of the daytime sleepiness measure and deviations from normality, Spearman's rank-order correlation coefficients were used for correlations involving daytime sleepiness, whereas Pearson correlations were applied to associations between continuous variables. These preliminary analyses informed the subsequent mediation, moderation, and Bayesian network analyses.

### Mediation Analysis

Regression-based chain mediation models (Model 6 in Hayes' PROCESS macro) were used to test the indirect effects of perceived stress (X) on mental health outcomes (Y1, Y2) through sleep quality (M1) and daytime sleepiness (M2).

**Bayesian Network Analysis**: In addition to regression-based mediation models, a Discrete Bayesian Network (DBN) was employed as a complementary approach to investigate the probabilistic dependencies among perceived stress, sleep quality, daytime sleepiness, anhedonia, self-hate, and metacognition. This approach enables the examination of conditional dependencies and the estimation of posterior probabilities of mental health outcomes under varying levels of stress, offering a data-driven confirmation of the hypothesized pathways. All variables were first imputed for missing values using

median substitution and discretized into two quantile-based bins. The network structure was specified based on theoretical assumptions: stress influencing sleep quality, sleep quality influencing daytime sleepiness, and daytime sleepiness influencing both anhedonia and self-hate, with metacognition moderating self-hate. Conditional probability distributions (CPDs) were estimated using a Bayesian estimator with a BDeu prior and an equivalent sample size of 10. Inference was performed via variable elimination, and the network was visualized using NetworkX in Python.

### Moderated Mediation Analysis

Moderated mediation models (Model 14 in PROCESS) were employed to test whether metacognition (W) moderated the relationship between daytime sleepiness (M2) and mental health outcomes (Y1, Y2). All analyses were conducted using SPSS version 26.0.

## 3 Results

## 3.1 Descriptive Statistics of Demographic and Main Study Variables

Descriptive statistics for participants' demographic characteristics and key study variables—including perceived stress, daytime sleepiness, sleep quality, anhedonia, self-hate, and metacognition—are presented in Table 1.

Table 1
Descriptive Statistics for Demographic and Psychological Variables (N = 1,374)

| Variable | Mean (M) | Standard Deviation (SD) |
|---|---|---|
| Age | 19.60 | 2.74 |
| Gender (Male/Female) | 682/692 | – |
| Perceived stress | 21.32 | 10.80 |
| Daytime sleepiness | 1.85 | 0.74 |
| Sleep quality | 4.50 | 0.70 |
| Anhedonia | 22.30 | 8.69 |
| Self-hate | 14.04 | 9.64 |
| Metacognition | 57.46 | 16.93 |

## 3.2 Correlation Analysis Between Stress, Sleep, Mental Health, and Metacognition

Correlation analyses were conducted to examine the relationships among perceived stress, sleep quality, daytime sleepiness, mental health indicators (anhedonia and self-hate), and metacognition. The results, shown in Table 2, revealed significant positive correlations between perceived stress and all other variables, including daytime sleepiness ($r = 0.317$, $p < 0.001$), sleep quality ($r = 0.336$, $p < 0.001$), anhedonia ($r = 0.220$, $p < 0.001$), self-hate ($r = 0.385$, $p < 0.001$), and metacognition ($r = 0.365$, $p < 0.001$).

Daytime sleepiness was significantly correlated with sleep quality ($r = 0.455$, $p < 0.001$), anhedonia ($r = 0.093$, $p = 0.001$), self-hate ($r = 0.262$, $p < 0.001$), and metacognition ($r = 0.228$, $p < 0.001$). Sleep quality was significantly associated with anhedonia ($r = 0.230$, $p < 0.001$), self-hate ($r = 0.400$, $p < 0.001$), and metacognition ($r = 0.310$, $p < 0.001$).

Additionally, anhedonia was significantly correlated with self-hate ($r = 0.441$, $p < 0.001$) and metacognition ($r = 0.300$, $p < 0.001$). The strongest correlation was found between self-hate and metacognition ($r = 0.490$, $p < 0.001$).

Table 2
Pearson Correlations Among Key Study Variables

| Variable | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1. Perceived Stress | — | | | | | |
| 2. Sleep Quality | 0.336*** | — | | | | |
| 3. Daytime Sleepiness | 0.314*** | 0.426*** | — | | | |
| 4. Anhedonia | 0.220*** | 0.230*** | 0.121*** | — | | |
| 5. Self-hate | 0.385*** | 0.400*** | 0.254*** | 0.441*** | — | |
| 6. Metacognition | 0.365*** | 0.310*** | 0.225*** | 0.300*** | 0.490*** | — |

*Note: Values represent correlation coefficients. Spearman's rank-order correlations were used for associations involving daytime sleepiness to account for ordinal measurement and non-normality. ***p < 0.001 (two-tailed).*

# 3.3 Chain Mediation Analysis: Stress, Sleep, and Mental Health

A chain mediation model was conducted to examine whether sleep quality ($M_1$) and daytime sleepiness ($M_2$) jointly mediated the effect of perceived stress (X) on two mental health outcomes: anhedonia and self-hate (Y). The results indicated that the total effect of perceived stress on anhedonia was significant ($\beta = 0.18$, $SE = 0.02$, $t = 8.36$, $p < 0.001$), accounting for 4.8% of the variance ($R^2 = 0.048$). Similarly, perceived stress significantly predicted self-hate ($\beta = 0.34$, $SE = 0.02$, $t = 15.45$, $p < 0.001$), accounting for 14.8% of the variance ($R^2 = 0.148$). These findings indicate that higher levels of stress are associated with more severe anhedonia (Fig. 1) and self-hate (Fig. 2).

Path analysis of the chain mediation model revealed that perceived stress significantly predicted poorer sleep quality (β = 0.09, SE = 0.01, t = 12.46, p < 0.001), which in turn significantly predicted greater daytime sleepiness (β = 0.12, SE = 0.01, t = 17.86, p < 0.001). Furthermore, daytime sleepiness significantly predicted anhedonia (β = 1.10, SE = 0.32, t = 3.48, p = 0.001), although the proportion of variance explained was small ($R^2$ = 0.009) (Fig. 1). In contrast, the effect of daytime sleepiness on self-hate was stronger (β = 3.41, SE = 0.34, t = 10.04, p < 0.001), explaining 6.8% of the variance ($R^2$ = 0.068) (Fig. 2).

Mediation analysis confirmed that the indirect effects of stress on mental health outcomes through sleep-related variables were significant. For anhedonia, the chain mediation reflected a partial mediation model. The direct effect of stress remained significant after controlling for the mediators (β = 0.14, SE = 0.02, t = 6.10, p < 0.001), with an estimated indirect effect of β = 0.008, indicating a relatively small yet significant indirect effect through sleep quality and daytime sleepiness (Fig. 1).

For self-hate, the model similarly supported a partial mediation effect. The direct effect of stress remained significant after accounting for both mediators (β = 0.26, SE = 0.02, t = 10.98, p < 0.001), while the estimated indirect effect was β = 0.024, reflecting a stronger mediating role of sleep-related variables (Fig. 2).

## 3.4 Moderation by Metacognition: Interaction Between Daytime Sleepiness and Mental Health

Moderated mediation analyses were conducted to test whether metacognition moderated the effect of daytime sleepiness on mental health outcomes. No significant interaction was found between sleepiness and metacognition for anhedonia (β = 0.02, SE = 0.02, t = 1.04, p = 0.297) (see Fig. 1). However, the interaction effect was significant for self-hate (β = 0.05, SE = 0.02, t = 3.29, p = 0.001) (see Fig. 2).

Simple slope analyses revealed that for individuals with high metacognition (+ 1 SD), the impact of daytime sleepiness on self-hate was significantly stronger compared to those with low metacognition (− 1 SD), suggesting that individuals with heightened metacognitive awareness are more vulnerable to the emotional consequences of daytime dysfunction (see Fig. 3).

## 3.5 Bayesian Network Analysis

The DBN analysis revealed that high perceived stress occurred with a probability of 0.556, while low stress had a probability of 0.444. Sleep quality was clearly dependent on stress level: under high stress, the probability of poor sleep was 0.741 compared with 0.542 under low stress. Daytime sleepiness was influenced by sleep quality, with higher sleepiness more likely under poorer sleep (0.782 vs. 0.473).

Mental health outcomes were moderately sensitive to stress. The probability of elevated self-hate under high stress was 0.508, slightly higher than under low stress (0.498). Similarly, the probability of elevated anhedonia under high stress was 0.508, compared with 0.502 under low stress. These results indicate

that stress increases the likelihood of negative mental health outcomes, primarily through its impact on sleep and daytime sleepiness. Metacognition showed a near-even distribution (high: 0.514, low: 0.486) and influenced self-hate in combination with daytime sleepiness, consistent with the moderation hypothesis (Fig. 4). Although the absolute differences in posterior probabilities were modest, they reflect consistent directional shifts across the network and are meaningful in the context of probabilistic modeling rather than effect-size estimation.

# 4 Discussion

This study investigated the chain mediation effects of sleep quality and daytime sleepiness in the relationship between perceived stress and mental health outcomes—specifically anhedonia and self-hate—among university students, while also examining the moderating role of metacognition. Overall, the findings demonstrate that perceived stress exerts both direct and indirect effects on mental health through sleep-related pathways, thereby extending current conceptualizations of the stress–sleep–mental health framework and offering implications for intervention in student populations.

Consistent with prior research, significant positive correlations were observed among perceived stress, poorer sleep quality, increased daytime sleepiness, anhedonia, self-hate, and metacognition. These associations suggest that stress may impair emotional functioning partly by disrupting sleep continuity and daytime alertness(Komarov et al., 2020). The strong association between sleep quality and daytime sleepiness further supports the concept of sleep continuity, whereby nocturnal sleep disturbances translate into daytime dysfunction, subsequently increasing vulnerability to psychological distress (Howarth et al., 2024). Additionally, the substantial correlation between anhedonia and self-hate indicates that these affective symptoms may co-occur, reflecting overlapping yet partially distinct emotional processes.

The regression-based chain mediation analyses revealed differential pathways for anhedonia and self-hate. For anhedonia, although the indirect pathway via sleep quality and daytime sleepiness was statistically significant, the direct effect of stress remained substantial. This pattern suggests that anhedonia may be less sensitive to sleep-related mechanisms and more strongly influenced by neurobiological factors, such as dopaminergic dysfunction, which are not fully captured by behavioral sleep variables (Wang et al., 2021; Wieman et al., 2022). In contrast, the mediation pathway was more pronounced for self-hate, indicating that sleep disruption may play a more substantial role in translating stress into negative self-evaluative emotions.

To complement the regression-based findings, a DBN analysis was conducted to examine the probabilistic dependencies among stress, sleep, and mental health variables. The DBN results provided a convergent yet distinct perspective by modeling conditional probability structures, rather than linear effects. Specifically, high stress increased the probability of poor sleep quality, which in turn elevated the likelihood of daytime sleepiness. Daytime sleepiness probabilistically influenced both anhedonia and self-hate; however, the effect was more pronounced for self-hate. Posterior inference indicated that under high stress, the probability of self-hate increased more markedly than that of anhedonia. These

findings reinforce the chain mediation pathway identified in regression analyses while highlighting self-hate as a more stress- and sleep-sensitive outcome from a probabilistic standpoint. Importantly, the DBN offers an interpretable and data-driven framework that allows exploration of conditional relationships that cannot be directly captured by traditional regression approaches.

University students may be particularly vulnerable to these mechanisms due to lifestyle and contextual factors. Flexible schedules, academic pressure, and frequent bedtime delays may compromise nocturnal sleep while increasing reliance on daytime napping, thereby exacerbating sleep–wake instability (Chai & Lu, 2025; Schmidt et al., 2024). Insufficient nighttime sleep not only impairs physiological recovery but also increases daytime sleepiness, which may disrupt circadian rhythms and heighten emotional reactivity to stress, potentially exacerbating mental health problems (Meyer et al., 2024; Walker et al., 2020). Although daytime napping may temporarily compensate for sleep loss, excessive or irregular napping can further disturb biological rhythms and undermine restorative nocturnal sleep, suggesting that student lifestyle habits may have cumulative adverse effects on mental health (Blanchard et al., 2023).

The moderating role of metacognition further underscores the importance of individual differences in shaping vulnerability to sleep-related mental health outcomes. Consistent with both the moderated mediation and DBN findings, daytime sleepiness exerted a stronger negative effect on self-hate among individuals with higher levels of metacognition. Highly metacognitive individuals tend to engage in increased self-monitoring and reflective processing, which may heighten awareness of functional impairments and promote self-critical interpretations when daytime dysfunction occurs(Buck et al., 2020). In contrast, metacognition did not significantly moderate the relationship between daytime sleepiness and anhedonia, supporting the notion that anhedonia may be less dependent on cognitive appraisal processes and more closely tied to neurophysiological mechanisms.

From a theoretical perspective, this study elucidates a multi-level pathway through which stress influences mental health via sleep quality and daytime sleepiness, while also identifying self-hate as a particularly sensitive outcome shaped by cognitive vulnerability. The integration of regression-based mediation with DBN analysis strengthens confidence in the proposed mechanism by demonstrating consistency across complementary analytical frameworks. Clinically, these findings suggest that interventions targeting sleep quality may represent a critical target for reducing stress-related mental health problems in university students. Moreover, individuals with high metacognitive tendencies may benefit from tailored interventions that address maladaptive self-monitoring and self-critical thought patterns in the context of sleep disturbances.

Several limitations should be acknowledged. First, the cross-sectional design precludes causal inference, and longitudinal studies are needed to validate the proposed temporal pathways. Second, the sample consisted exclusively of university students, limiting the generalizability of the findings to other populations. Third, only metacognition was examined as a moderating factor; future research should incorporate additional psychological and contextual variables and consider multilevel or dynamic

modeling approaches. Despite these limitations, the present study contributes to a more nuanced understanding of the stress–sleep–mental health relationship and provides a foundation for future research and targeted intervention strategies.

## Declarations

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# Author Contribution Statement

Yanxia Kang: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Project administration. Weijie Song: Conceptualization, Writing - review & editing. Zhu Shi: Data curation, Writing - review & editing. Meng Qi: Data curation, Writing - review & editing. Jing-Xu Chen: Conceptualization, Methodology, Resources, Writing - review & editing, Supervision.

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# Conflict of Interest Statement

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

# Ethics statement

This study was approved by the Ethics Committee of Beijing Huilongguan Hospital. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

# Data Availability Statement

The data that support the findings of this study are available from the corresponding author, Jing-Xu Chen, upon reasonable request. The data are not publicly available due to privacy or ethical restrictions.

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# Figures

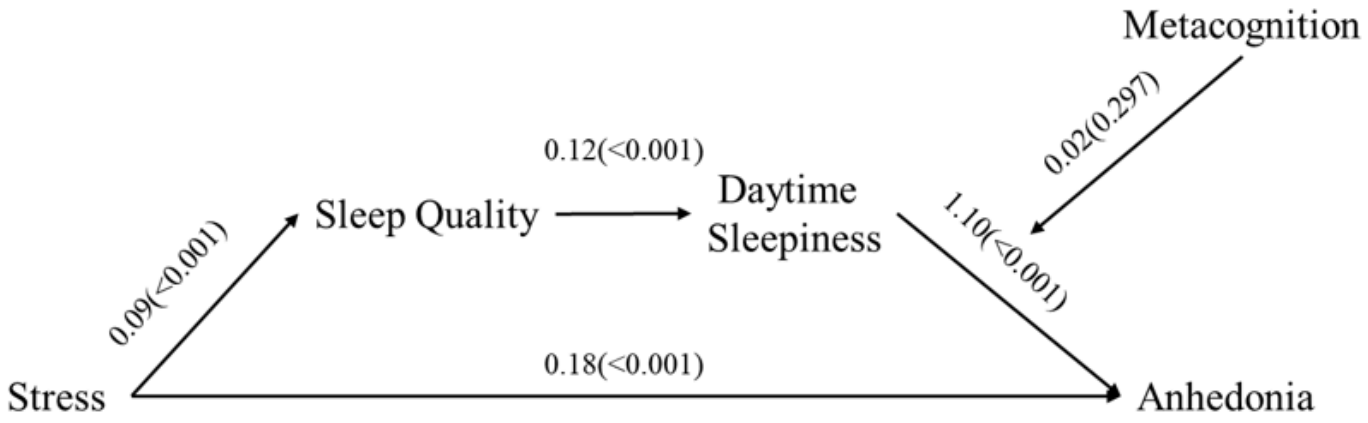



**Figure 1**

Chain Mediation Model of the Effect of Perceived Stress on anhedonia

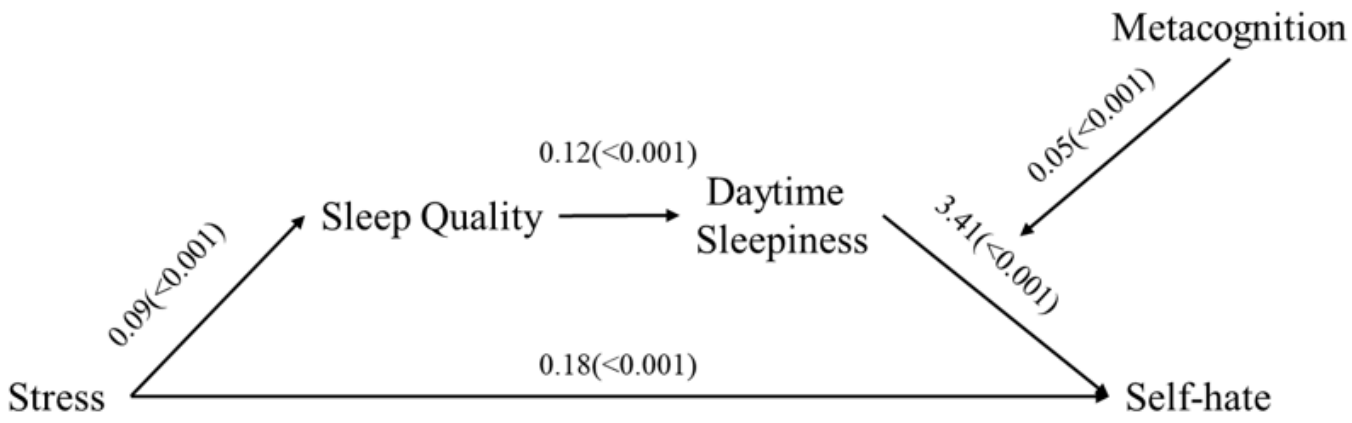



Figure 2

Chain Mediation Model of the Effect of Perceived Stress on self-hate

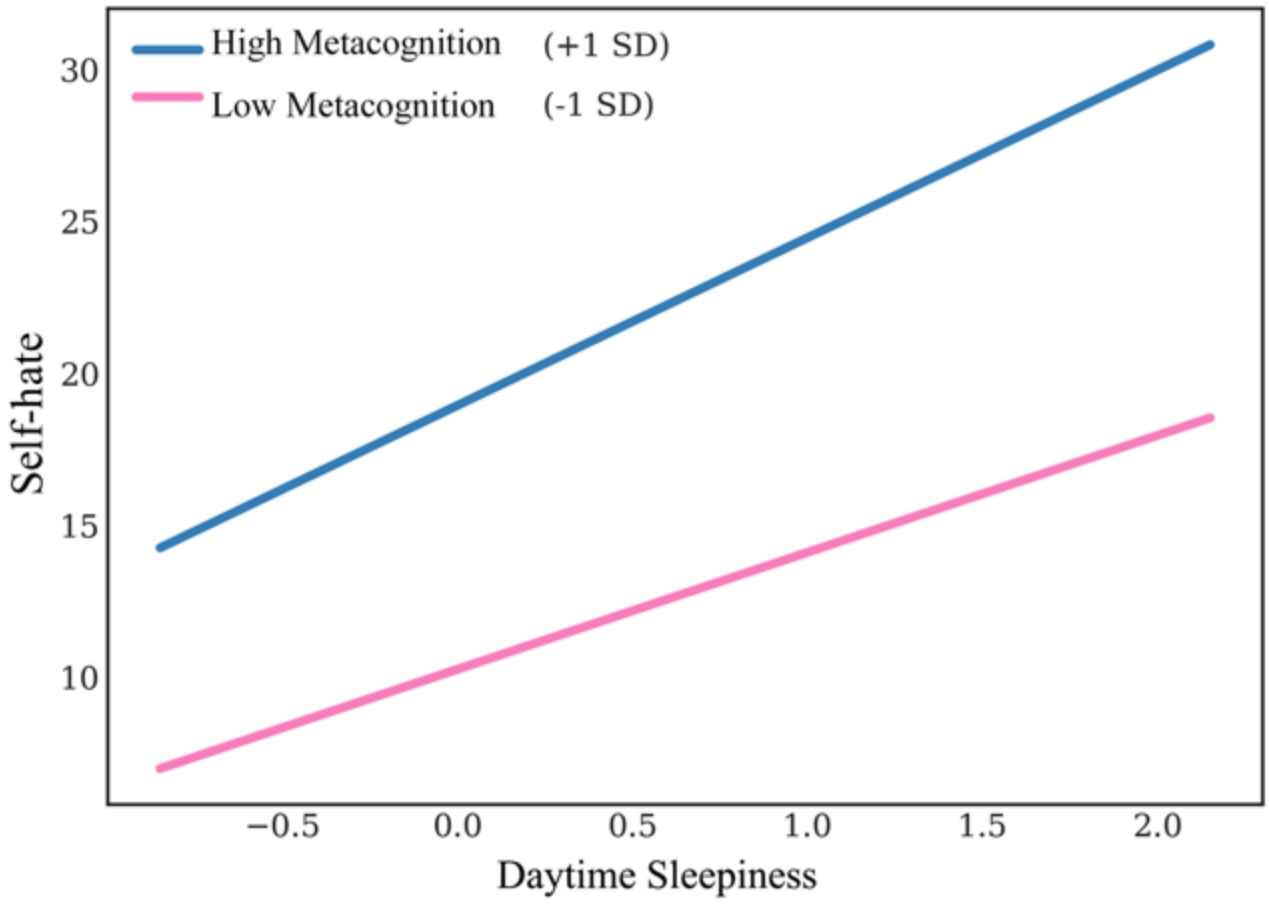



Figure 3

Moderating Effect of Metacognition on the Relationship Between Daytime Sleepiness and self-hate




## Figure 4

## Bayesian Network of Stress, Sleep, and Mental Health

*Note: Edges represent conditional dependencies; posterior probabilities are reported in the Results section.*