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ORIGINAL RESEARCH

The Mediating Role of Cognitive Reappraisal on Bedtime Procrastination and Sleep Quality in Higher Educational Context: A Three-Wave Longitudinal Study

Yuan Zhang[1], Shazia Rehman[2], Abdullah Addas[3,4], Mehmood Ahmad[5], Ayesha Khan[6]

[1]College of Art, Nanyang Vocational College of Agriculture, Nan Yang, Henan, 47300, People's Republic of China; [2]Department of Psychiatry, National Clinical Research Center for Mental Disorders, and National Center for Mental Disorders, The Second Xiangya Hospital of Central South University, Changsha, Hunan, 410011, People's Republic of China; [3]Department of Civil Engineering, College of Engineering, Prince Sattam Bin Abdulaziz University, Al-Kharj, 11942, Saudi Arabia; [4]Landscape Architecture Department, Faculty of Architecture and Planning, King Abdulaziz University, Jeddah, 21589, Saudi Arabia; [5]Department of Pharmacology and Toxicology, Faculty of Veterinary and Animal Sciences, The Islamia University of Bahawalpur, Bahawalpur, 63100, Pakistan; [6]Department of Applied Psychology, Faculty of Social Sciences, The Islamia University of Bahawalpur, Bahawalpur, 63100, Pakistan

Correspondence: Shazia Rehman, Department of Psychiatry, National Clinical Research Center for Mental Disorders, and National Center for Mental Disorders, The Second Xiangya Hospital of Central South University, Changsha, Hunan, 410011, People's Republic of China, Tel +86-13308429613, Email rehmanshazia.malik@gmail.com

Background: While bedtime procrastination is commonly associated with adverse outcomes such as poor sleep quality, the mechanisms mediating these effects remain underexplored. Grounded in the Self-Regulation Model of Behavior and the Transactional Model of Stress and Coping, this study examines the mediating role of cognitive reappraisal in the relationship between bedtime procrastination and sleep quality over time.

Methods: Employing a longitudinal design, the study examined the progression of bedtime procrastination, cognitive reappraisal, and sleep quality among university students at three distinct time points throughout an academic semester. Structural equation modeling and autoregressive time-lagged panel models were utilized to analyze the data, assessing both the direct effects and the mediating role of cognitive reappraisal over time.

Results: The results revealed that bedtime procrastination exhibited significant stability across time points (β = 0.619 to 0.658, p<0.001). Bedtime procrastination at earlier time points predicted poorer cognitive reappraisal (β= −0.169, p<0.05 to −0.215, p<0.01) and subsequent sleep quality (β=0.256, p<0.001). Additionally, cognitive reappraisal significantly mediated the relationship between bedtime procrastination and sleep quality (β= −0.359, Boot 95% CI: −0.51 to −0.234), emphasizing the role of emotional regulation strategies in sleep-related outcomes.

Conclusion: These findings underscored the impact of bedtime procrastination on sleep quality and highlight cognitive reappraisal as a key mediator. Interventions focusing on enhancing emotion regulation skills could mitigate the adverse effects of bedtime procrastination and improve sleep outcomes among university students.

Keywords: bedtime procrastination, cognitive reappraisal, sleep quality, longitudinal study, time-lagged panel model

Introduction

In university life, managing time and emotions effectively is essential for academic success and personal well-being.[1,2] Bedtime procrastination, a specific form, involves the intentional delay of sleep initiation without external constraints despite recognizing its negative consequences.[3,4] This behavior, often linked to activities like excessive social media use, gaming, or watching television, disrupts sleep schedules and negatively impacts sleep quality, cognitive functioning, and emotional regulation.[5–8] Although bedtime procrastination is common, its severity and long-term consequences are less understood, with mixed findings regarding its relationship to sleep parameters such as sleep duration, efficiency, and latency.[9,10] This issue is particularly concerning among university students, who face unique challenges such as academic pressures, social obligations, and lifestyle choices contributing to irregular sleep patterns.[11–13] While educational and

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societal pressures are widely acknowledged globally, in Pakistan, these challenges are compounded by sociocultural factors, including heightened family expectations,[14] cultural taboos surrounding mental health discussions,[15] and limited access to resources for stress management.[16] These factors influence students' sleep-related behaviors and may exacerbate tendencies toward bedtime procrastination. While interventions such as sleep hygiene education[17] and mindfulness training[18] have shown promise in improving general sleep quality, their effectiveness in addressing bedtime procrastination remains unclear. These gaps underscore the need for further research to explore culturally relevant interventions targeting bedtime procrastination and its impact on university students' well-being.

Cognitive reappraisal, a specific emotion regulation strategy, mitigates emotional responses by reinterpreting the significance of emotional events.[19] As a focused component of emotion regulation, cognitive reappraisal serves as an adaptive response, enabling individuals to shift their perception of emotional events actively, fostering psychological resilience, maintaining interpersonal relationships, and promoting mental health.[20] Previous research has highlighted the pivotal role of cognitive reappraisal in enhancing sleep quality and fostering positive emotional states.[21] Additionally, early cognitive behavioral therapy reduces negative emotions and maladaptive behaviors by transforming distorted cognitive frameworks and enhancing cognitive reappraisal skills.[22] This study specifically focuses on cognitive reappraisal, given its critical role in mitigating emotional distress and promoting psychological resilience. While emotion regulation encompasses a broader range of strategies, cognitive reappraisal is uniquely suited for exploring its impact on academic pressures, personal challenges, and sleep-related outcomes in university students.[20,21] Effective use of cognitive reappraisal may be particularly beneficial for this population in maintaining mental health and academic performance amidst stressful academic environments.

Sleep quality refers to an individual's subjective perception of their sleep, encompassing key dimensions such as sleep duration, latency (time taken to fall asleep), efficiency (time spent asleep while in bed), and disturbances during sleep.[23] It is crucial for overall health, impacting cognitive performance, emotion regulation, and quality of life.[24] Poor sleep quality is associated with impaired emotional functioning, reduced cognitive abilities, and an increased risk of psychopathologies such as anxiety and depression.[25,26] Notably, there is an overlap in the dysfunctions of brain structures and neurotransmitters that govern both the sleep-wake cycle and affective disorders.[27–29] Sleep quality among university students has been widely reported to be poor. It is influenced by various factors, including academic stress, lifestyle choices, and psychological factors, such as bedtime procrastination and emotion regulation strategies.[30,31] Good sleep quality is essential for cognitive functioning, emotional regulation, and overall health.[32] However, students frequently experience disrupted sleep patterns, affecting their academic performance, memory, decision-making abilities, and vulnerability to stress.[33–36]

The interplay among bedtime procrastination, sleep quality, and cognitive reappraisal is multifaceted and central to understanding student well-being. Bedtime procrastination disrupts sleep patterns by reducing sleep duration and quality and impairing cognitive functioning. Such impairments may hinder the ability to engage in adaptive emotion regulation strategies like cognitive reappraisal, leading to difficulties in managing stress and emotions. Over time, this creates a feedback loop where poor sleep quality and ineffective emotion regulation reinforce bedtime procrastination, further exacerbating emotional distress and sleep-related problems. Understanding these dynamics is critical for identifying intervention points to improve students' sleep health and emotional well-being.

This study is grounded in two complementary theoretical models: the Self-Regulation Model of Behavior[37] and the Transactional Model of Stress and Coping.[38] The Self-Regulation Model explains bedtime procrastination as a deficit in self-regulation, wherein individuals prioritize immediate gratification (eg, leisure activities) over long-term benefits, such as sufficient sleep.[39] Poor self-regulation in one domain can deplete resources needed for effective emotional and behavioral control in others, leading to heightened stress and diminished functionality.[40,41] On the other hand, the Transactional Model of Stress and Coping highlights cognitive reappraisal, an emotion regulation strategy, as a key mechanism in coping with stressors. This model posits that stress responses are shaped by how individuals appraise and reframe challenges.[42] Cognitive reappraisal can mitigate the emotional strain caused by bedtime procrastination and poor sleep quality, fostering more adaptive coping and reducing the likelihood of further procrastination.[43,44] Together, these models provide a robust framework for understanding how bedtime procrastination, cognitive reappraisal, and sleep quality influence well-being.

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Based on these theoretical foundations, the study hypothesizes:

Study Hypothesis 1: Bedtime procrastination negatively impacts sleep quality at subsequent time points, suggesting that regular delays in bedtime can degrade sleep quality over time.

Study Hypothesis 2: Cognitive reappraisal positively influences sleep quality, indicating that emotion regulation can enhance sleep outcomes despite stressors such as bedtime procrastination.

Study Hypothesis 3: Cognitive reappraisal mediates the relationship between bedtime procrastination and sleep quality, providing a pathway through which bedtime procrastination affects sleep quality via changes in emotional regulation strategies.

This longitudinal study enhances existing knowledge on bedtime procrastination, cognitive reappraisal, and sleep quality by exploring their dynamic interplay and potential causal associations over time, a perspective rarely examined in cross-sectional research. Using a three-wave longitudinal design and a cross-lagged panel model (CLPM), the study investigates how bedtime procrastination and cognitive reappraisal influence sleep quality, emphasizing the mediating role of cognitive reappraisal in mitigating the negative effects of procrastination on sleep. Conducted within Pakistani universities, this research addresses the unique sociocultural dynamics influencing academic pressures, sleep patterns, and emotional coping strategies, offering valuable insights for culturally tailored interventions.

Materials and Methods

Study Design and Participants

The present research employed a three-wave longitudinal design to assess temporal trends in bedtime procrastination, cognitive reappraisal, and sleep quality among university students across different levels of academic stress during the spring semester of 2023. Data were collected via convenience sampling from The Islamia University of Bahawalpur, Pakistan, where all students across various disciplines were invited to participate. The study was designed to capture how these psychological and behavioral constructs evolve over time in response to varying academic pressures.

Sampling and Eligibility Criteria

The target population consisted of all undergraduate and postgraduate students enrolled at The Islamia University of Bahawalpur in the spring semester of 2023. Eligibility criteria included:

(a) being an enrolled student in any discipline at the targeted University during the study period,
(b) willingness to participate in all three waves of data collection,
(c) age 18 years or older, and
(d) ability to understand and respond to survey items in English.

Students who were not available to participate in all three data collection waves or had medical conditions affecting their sleep or mental health were excluded from the study.

Data Collection Procedure

Data were collected at three distinct time points within the semester to capture variations in the constructs of interest under different levels of academic stress. The first period was the start of the semester (P_1), the second period (P_2) was immediately after the mid-term exam, and the third period (P_3) was two weeks before the final exams. The study employed a multi-pronged approach to maximize student recruitment, utilizing personalized Email invitations, social media campaigns, on-campus advertisements, classroom announcements, and student ambassadors. These strategies were designed to engage various disciplines and ensure high participation rates. Incentives and follow-up reminders further encouraged consistent involvement in the research. This multi-faceted recruitment approach ensured maximum reach and engagement with the student population, resulting in a robust sample size for the study. Each survey took approximately

15–20 minutes to complete. The same measures were administered at each time point to ensure consistency. Further details on the data selection and participant recruitment procedures are given in the Supplementary File 1: Additional information.

At baseline, 1912 participants completed the first wave of data collection. In the second phase, which took place immediately after the mid-term exams, 671 participants completed the survey. In the third phase, conducted two weeks before the final exams, 487 participants participated in the study. Across all three waves, 403 participants provided complete data, participating in each data collection phase, allowing for longitudinal analysis of the overlapping sample. Of these participants, 58.31% were females, and 41.69% were males, with an average age of 23.42. Further details on the socio-demographics of the study participants are presented in the Supplementary File 1: Additional analysis.

Measurement Scales

Bedtime Procrastination

The current study employed a 9-item scale Bedtime Procrastination Scale (BPS), initially devised by Kroese et al,[3] as a validated instrument to evaluate the propensity for bedtime procrastination. Participants' responses were captured using a 5-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree", where elevated scores signify a heightened inclination towards bedtime procrastination. The BPS reflects a universal construct of procrastinating bedtime despite the absence of external demands, making it relevant across diverse cultures, including Pakistan. While the scale has not yet been formally validated in the Pakistani context, it has been utilized in studies conducted with Pakistani university students, demonstrating its applicability and relevance to this population.[45–47] Cultural factors such as irregular sleep schedules and late-night habits among university students in Pakistan align with the behaviors captured by the BPS, further supporting its cultural relevance. The scale has been shown to have good reliability and validity in differentiating between high and low bedtime procrastinators, with an alpha value of 0.92 in its original version.[3,4,48]

Cognitive Reappraisal

The Cognitive Reappraisal Subscale derived from the Emotion Regulation Questionnaire (ERQ)[49] evaluates the propensity to modify one's cognitions to alter emotional experiences. This subscale comprises six items scored on a 7-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree". Higher scores on this subscale suggest a more frequent utilization of cognitive reappraisal as a strategy for emotion regulation. While the ERQ has been validated and widely used as a whole in studies conducted with Pakistani university students,[50–52] the Cognitive Reappraisal Subscale has not been independently validated in this context. However, as a well-established and psychometrically sound dimension of the ERQ, the subscale has demonstrated robust reliability and validity across diverse populations.[53–55] Given the universal nature of cognitive reappraisal as an emotion regulation strategy and its theoretical independence within the ERQ, its use in the current study is justified.

Sleep Quality

The Pittsburgh Sleep Quality Index (PSQI) is a widely adopted self-reported measure to evaluate sleep quality over one month.[56] This instrument encompasses multiple dimensions of sleep, such as duration, disturbances, latency, and daytime dysfunction. Responses are quantified on a 4-point Likert scale, with the cumulative score ranging from 0 to 21. A cumulative score >5 suggests suboptimal sleep quality. The PSQI demonstrates good internal consistency, as evidenced by a Cronbach's alpha value of 0.83, and exhibits robust test-retest reliability.[57–59] Although no formal validation of the PSQI (in English version) has been conducted within the Pakistani context, it has been employed in studies with Pakistani populations in its original English form, demonstrating its applicability and relevance.[46,60,61] The universal constructs assessed by the PSQI, such as sleep disturbances and daytime dysfunction, are relevant across diverse cultures, including Pakistan. Additionally, cultural practices and modern lifestyle factors in Pakistan, such as late-night screen use and socializing, align with the dimensions captured by the PSQI, ensuring its cultural appropriateness for the current study.

This study utilized the original English versions of the scales. As English is the official medium of instruction and academic communication in Pakistan, the target population (university students) was expected to comprehend the items easily. Bilingual experts reviewed each scale to ensure linguistic clarity and appropriateness for the Pakistani context. No modifications to the original scales were deemed necessary.

Analytical Approach

Data were analyzed using a series of statistical techniques to examine the temporal trends in bedtime procrastination, cognitive reappraisal, and sleep quality across three waves of data collection. Descriptive statistics and bivariate correlational analysis were performed for all study variables at each time point to summarize the data and describe the characteristics of the sample. Reliability and validity of the study variables were assessed at each time point to ensure consistency and accuracy of the measurements over time.[62–64] For the longitudinal analysis, the data were first assessed for missingness, and Little's MCAR test[65] was conducted to determine if the data were missing completely at random. Missing data were handled using Full Information Maximum Likelihood (FIML) estimation to ensure unbiased parameter estimates.[66] In addition, a post hoc power analysis was also conducted to evaluate the adequacy of statistical power in detecting meaningful effects given the sample size at the final wave (P3). Next, measurement invariance tests were performed to establish configural, metric, scalar, and residual invariance across the three-time points.[67,68] These tests were conducted to confirmed that the study constructs were measured equivalently over time. An autoregressive mediation model was employed to investigate bedtime procrastination's direct and indirect effects on sleep quality over time, with cognitive reappraisal as the mediator.[69] This approach allowed for estimating autoregressive effects (stability of each construct across time points) and cross-lagged effects (predictive effects of one construct on another over subsequent time points). Mediation effects were tested to determine whether cognitive reappraisal mediated the relationship between bedtime procrastination and sleep quality at different times. The model fit was assessed using standard fit indices, including the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR).[70] Indirect effects were estimated using bootstrapping techniques with 5000 resamples to calculate confidence intervals and determine the significance of the mediation pathways.[71] This method provided robust estimates of the indirect effects, allowing for a clearer understanding of how changes in bedtime procrastination influenced sleep quality via cognitive reappraisal over time. All analyses were performed using SPSS and Mplus software. Statistical significance was set at $p < 0.05$ for all tests.

Panel Attrition

In order to investigate whether systematic attrition of participants between the baseline (P_1) and follow-up data collection periods may have influenced the results, a comparative analysis was conducted between the baseline group (n=1912) and the overlapped group (n=403) of participants utilizing Students' t or χ^2 test. No statistically significant differences were observed between the two groups for demographic and study variables. Consequently, we can infer that any systematic dropout did not significantly affect the study results. The results are presented in Supplementary File 1: Additional analysis.

In addition, the FIML estimation was applied to account for missing data across the three waves. This method ensured that the findings remained unbiased despite participant attrition, providing robust parameter estimates and retaining the statistical rigor of the analysis. The use of FIML allows for a comprehensive analysis of the available data while minimizing the potential impact of missing data on study conclusions.[65,66]

Measurement Invariance Over Time

In an effort to examine the stability of measurement across temporal intervals, we designated one latent variable for each of the three-time points, corresponding respectively to the measures of bedtime procrastination, cognitive reappraisal, and sleep quality. Following the guidance of Geiser et al,[72] the relationships between indicators and factors, specifically factor loadings and intercepts, must remain consistent across measurements. To accommodate this requirement, we introduced factors specific to each indicator. The initial stage in assessing measurement invariance, termed configural invariance, involved verifying whether the included constructs maintain a consistent pattern of free and fixed loadings over time. This consistency suggests that underlying data support the association of indicators with the three latent factors, as it persists over time. Should configural invariance be confirmed, further constraints are applied for the subsequent evaluation stage, known as metric or weak invariance. This stage presupposes that each item contributes uniformly to the latent construct across time. We then proceeded to examine metric invariance by ensuring the equalization of factor loadings for the constructs across time. The ensuing stage, called scalar/strong invariance, involves ascertaining whether the mean differences in the latent construct entirely capture the mean differences in the shared variance of the items. Scalar invariance was evaluated by equalizing the item intercepts over time while maintaining the constraints in the metric invariance model.[73] The ultimate step in assessing measurement invariance, termed residual or strict invariance, involves making the residual variables equivalent over time. If residual invariance is validated, variations in the observed variables can solely be ascribed to variations in the latent variables' variances. To ascertain the preeminence of a more robust model, we followed the guidance of the Satorra-Bentler.[74] We posited that the model incorporating the most significant number of invariance constraints provided it maintains an acceptable fit and does not substantially worsen the estimate, represents the final model.[75] As the statistic for assessing model fit is sensitive to sample size, we compared the CFIs (<0.01) and RMSEAs (<0.015) of the models.[76,77]

Hypotheses Testing

Adhering to the guidance in the existing literature,[65] we utilized autoregressive time-lagged panel models for hypothesis testing. Initially, a baseline model ($M_{stability}$) was established, encapsulating the temporal stabilities of the three observed variables under investigation. In a subsequent phase ($M_{time\text{-}lagged}$), we incorporated time-lagged effects:

- Bedtime procrastination (P_1) → Cognitive reappraisal (P_2)
- Bedtime procrastination (P_2) → Cognitive reappraisal (P_3)
- Cognitive reappraisal (P_1) → Sleep quality (P_2)
- Cognitive reappraisal (P_2) → Sleep quality (P_3)
- Furthermore, a direct path from Bedtime procrastination (P_1) → Sleep quality (P_3) was integrated into the model. A significant path here would suggest partial mediation; its absence would indicate full mediation.[65]

Results

Convergent and Validity Analysis Results

Table 1 demonstrates the convergent and discriminant validity analysis outcomes, which showed good reliability and validity across all three time points (P_1,P_2, P_3) for each construct. Cronbach's alpha values for bedtime procrastination, cognitive reappraisal, and sleep quality were above 0.86, indicating high internal consistency for each construct. Composite reliability (CR) values were also high (0.79–0.89), further supporting the reliability of these scales. Average Variance Extracted (AVE) values range from 0.56 to 0.73, suggesting adequate convergent validity, as most are above the 0.50 threshold. This means the constructs explained a sufficient proportion of variance in their indicators.

Bivariate Correlation Analysis Results

Table 2 presents the findings from the bivariate correlations analysis, which revealed significant associations between bedtime procrastination, cognitive reappraisal, and sleep quality across time. Additionally, autoregressive effects indicated high stability for each construct over time, with strong positive correlations between the same constructs at

Table 1 Convergent and Discriminant Validity Analysis

	Cronbach's α	Composite Reliability	Average Variance Extracted
Bedtime procrastination (P_1)	0.91	0.88	0.73
Bedtime procrastination (P_2)	0.92	0.87	0.69
Bedtime procrastination (P_3)	0.92	0.86	0.71
Cognitive reappraisal (P_1)	0.88	0.86	0.58
Cognitive reappraisal (P_2)	0.90	0.89	0.61
Cognitive reappraisal (P_3)	0.89	0.88	0.63
Sleep quality (P_1)	0.88	0.86	0.59
Sleep quality (P_2)	0.86	0.79	0.56
Sleep quality (P_3)	0.89	0.87	0.71

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Table 2 Descriptive Estimates and Bivariate Correlation Analysis Over Three-Time Intervals

		1	2	3	4	5	6	7	8	9
1	Bedtime procrastination at P1	1								
2	Bedtime procrastination at P2	0.75***	1							
3	Bedtime procrastination at P3	0.76***	0.78***	1						
4	Cognitive reappraisal at P1	−0.25*	−0.29**	−0.33**	1					
5	Cognitive reappraisal at P2	−0.31**	−0.38***	−0.41***	0.65***	1				
6	Cognitive reappraisal at P3	−0.42***	−0.43***	−0.49***	0.68***	0.71***	1			
7	Sleep quality at P1	−0.49***	−0.58***	−0.61***	0.38***	0.38***	0.37***	1		
8	Sleep quality at P2	−0.53***	−0.61***	−0.67***	0.36***	0.33***	0.28**	0.65***	1	
9	Sleep quality at P3	−0.58***	−0.65***	−0.71***	0.35***	0.23**	0.20**	0.71***	0.69***	1
	Mean (SD)	24.56 (5.51)	27.82 (7.23)	32.16 (11.73)	23.34 (6.13)	20.53 (5.07)	18.14 (2.35)	4.4 (2.62)	6.1 (2.94)	12.7 (5.17)

Notes: *p<0.05. **p<0.01. ***p<0.001.
Abbreviations: SD, Standard deviation; P1, Baseline time; P2, Second phase; P3, third phase.

different time points (bedtime procrastination: P_1 to P_2 = 0.75, p<0.001; P_2 to P_3 = 0.78, p<0.001). Cross-lagged effects showed that bedtime procrastination was negatively associated with cognitive reappraisal and sleep quality over time (bedtime procrastination and sleep quality at P_1: −0.49, P_2: −0.61), while cognitive reappraisal was positively associated with sleep quality (P_1: 0.38, p<0.001; P_2: 0.33, p<0.001).

Measurement Invariance

Configural, Metric, Scalar, and Residual Invariance Models were tested for each construct over time, and outcomes are presented in Table 3. For bedtime procrastination, cognitive reappraisal, and sleep quality, all models (configural, metric, scalar, residual) demonstrated good fit indices (CFI ≈ 1.000 for bedtime procrastination and close to 0.98 for cognitive reappraisal and sleep quality; RMSEA ≈ 0.000–0.051), indicating that measurement invariance was achieved across time points. The changes in fit indices (ΔCFI and ΔRMSEA) are well within the acceptable ranges (ΔCFI < 0.01, ΔRMSEA < 0.015), confirming that the constructs were measured equivalently across time points. This allows for meaningful comparisons of the constructs across time in the longitudinal analysis.

Model Fit Analysis

Table 4 demonstrates the results of the comparison between the measurement model and the structural models. The measurement model showed adequate fit (CMIN/df = 1.34, RMSEA = 0.042, SRMR = 0.038, CFI = 0.98); however, the stability model (CMIN/df = 1.22, RMSEA = 0.039, SRMR = 0.037, CFI = 0.99) indicated an even better fit. The autoregressive mediation model (CMIN/df = 1.17, RMSEA = 0.040, SRMR = 0.038, CFI = 0.98) showed a slightly lower fit than the stability model but still meets the criteria for good model fit. The minor differences in ΔCFI (−0.01) and ΔRMSEA (0.001) between the stability model and the autoregressive mediation model suggested that the mediation model provides a plausible explanation of the data without a significant loss of model fit. This balance of fit and complexity, supported by AIC and BIC values, indicated that the model captures meaningful relationships while maintaining parsimony.

Cross-Lagged Panel Model Analysis with Mediation Effects

The CLPM results indicated the relationships among bedtime procrastination, cognitive reappraisal, and sleep quality over three time points (Figure 1). Significant autoregressive effects indicated stability within individuals over time for all three constructs. Cross-lagged effects showed that bedtime procrastination negatively impacts cognitive reappraisal and sleep quality, while cognitive reappraisal positively predicts sleep quality. Also, the autoregressive mediation model

Table 3 Measurement Invariance (Configural, Metric, Scalar, and Residual) Comparison for All Study Models Over Time

	Fit Indices					Model Comparison	
	CMIN/df	RMSEA	SRMR	CFI	TLI	CFI	RMSEA
Bedtime Procrastination							
Configural	1.29***	0.000	0.014	1.000	0.966		
Metric	1.23***	0.000	0.017	1.000	0.959	0.000[a]	0.000[a]
Scalar	1.27***	0.000	0.021	1.000	0.961	0.000[b]	0.000[b]
Residual	1.38*	0.000	0.023	1.000	0.967	0.000[c]	0.000[c]
Cognitive reappraisal							
Configural	1.56	0.035	0.029	0.991	0.962		
Metric	1.31**	0.041	0.031	0.989	0.959	−0.002[a]	0.006[a]
Scalar	1.28***	0.033	0.033	0.989	0.960	0.000[b]	−0.008[b]
Residual	1.21***	0.030	0.031	0.988	0.958	−0.001[c]	−0.003[c]
Sleep Quality							
Configural	1.51*	0.051	0.039	0.983	0.967		
Metric	1.35*	0.049	0.043	0.983	0.966	0.000[a]	−0.002[a]
Scalar	1.22***	0.044	0.045	0.982	0.962	−0.001[b]	−0.005[b]
Residual	1.15***	0.041	0.042	0.982	0.960	0.000[c]	−0.003[c]

Notes: As the chi-square statistic for assessing model fit is sensitive to sample size, we compared the CFIs (<0.01) and RMSEAs (<0.015) of the models.[76] [a]Comparison of metric invariance and configural invariance models. [b]Comparison of scalar invariance and metric invariance models. [c]Comparison of residual invariance and scalar invariance models. *p<0.05. **p<0.01. ***p<0.001.

Table 4 Model Fit Analysis

Models	Fit Indices					Model Comparison		AIC	BIC
	CMIN/df	RMSEA	SRMR	CFI	TLI	ΔCFI	ΔRMSEA		
Measurement Model	1.34*	0.042	0.038	0.98	0.97			1256.15	1368.72
Stability Model	1.22*	0.039	0.037	0.99	0.96			1135.82	1290.34
Autoregressive Mediation Model	1.17*	0.040	0.038	0.98	0.95	−0.01[a]	0.001[a]	1077.09	1241.58

Notes: *p<0.01. [a]Comparison of autoregressive mediation model and stability model. As the chi-square statistic for assessing model fit is sensitive to sample size, we compared the CFIs (<0.01) and RMSEAs (<0.015) of the models.[76]
Abbreviations: AIC, Akaike information criterion; BIC, Bayesian information criterion.

results supported that cognitive reappraisal partially mediates the relationship between bedtime procrastination and sleep quality over time (β=−0.359, Boot 95% CI: −0.51 to −0.234).

Post-Hoc Power Analysis for Detecting Significant Effects

To assess the statistical power to detect the autoregressive effects and cross-lagged effects in the CLPM, specifically for the influence of bedtime procrastination (P1) on cognitive reappraisal (P2) and cognitive reappraisal (P2) on sleep quality (P3), post hoc power analyses were conducted using Monte Carlo simulation studies in Mplus version 8.6.[78] To ensure the stability of the simulation results, 10,000 replications were performed with a random seed of 5000 for population draws.[78] Statistical power was determined by the proportion of replications in which the null hypothesis (that a parameter equals zero) was rejected at ($p < 0.05$). The results demonstrated sufficient statistical power (> 0.80) to detect medium-to-large effect sizes (f^2=0.02). Despite the reduced sample size at P3, these findings affirmed the robustness of the significant effects reported in the study.

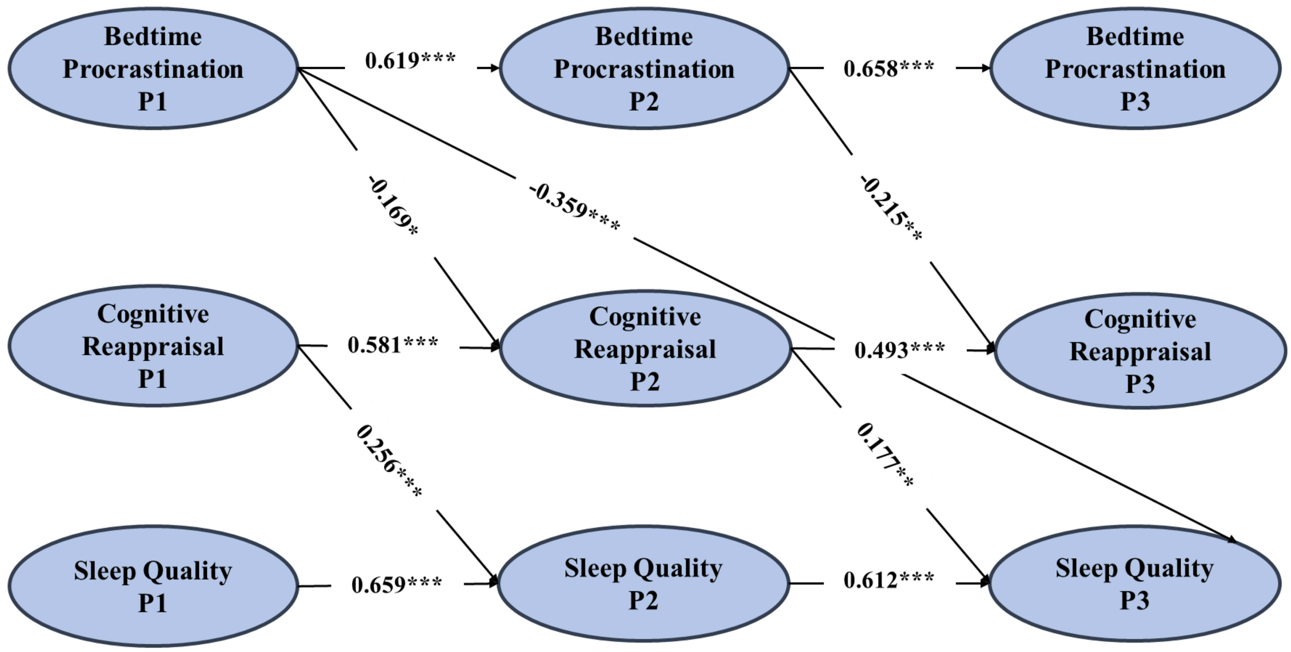

Figure 1 Autoregressive time-lagged panel models with mediation (*p<0.05, **p<0.01, ***p<0.001).

Discussion

This study provided novel insights into the longitudinal dynamics of bedtime procrastination, cognitive reappraisal, and sleep quality. Employing a three-wave design captured temporal fluctuations often overlooked in cross-sectional research. Additionally, the study introduces cognitive reappraisal as a mediator, offering a deeper understanding of its role in mitigating the adverse effects of bedtime procrastination on sleep quality. Finally, the research highlighted the significance of sociocultural factors in shaping these relationships, addressing a critical gap in the literature by focusing on Pakistani university students. These contributions underscored the potential for developing targeted interventions to enhance sleep hygiene and emotion regulation in culturally diverse academic settings.

First, the high autoregressive effects observed for bedtime procrastination, cognitive reappraisal, and sleep quality across the three time points indicate that these constructs are stable over time. The robust stability of bedtime procrastination, demonstrated by high correlations between adjacent time points, suggests that procrastinating going to bed is a persistent behavioral pattern. This is consistent with the literature on habitual behaviors, which often require targeted interventions to modify.[79] Similarly, cognitive reappraisal, an emotion regulation strategy, showed considerable stability over time. Prior research suggests that cognitive reappraisal is an established trait-like characteristic that is relatively stable within individuals, especially under conditions of repeated stress.[49,80–82] The stability of sleep quality is also noteworthy, indicating that students' sleep patterns are not prone to significant variation unless intervened upon or influenced by major life events or academic stressors. These findings highlight the importance of considering baseline tendencies when designing interventions to reduce bedtime procrastination and improve sleep quality.

In addition, the cross-lagged relationships between bedtime procrastination, cognitive reappraisal, and sleep quality provided interesting insights into the causal pathways between these constructs. The negative cross-lagged effects of bedtime procrastination on both cognitive reappraisal and sleep quality at each time point suggested that students who consistently delay bedtime are less likely to engage in effective cognitive regulation and are more likely to experience poor sleep quality. This aligns with prior studies that link procrastination with negative psychological and health outcomes, such as anxiety, stress, and poor sleep.[3,83–85] However, the present study adds a temporal dimension, demonstrating that these associations persist over time. The persistent negative effect of bedtime procrastination on sleep quality suggests a cumulative risk: the longer an individual engages in bedtime procrastination, the more significant

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the deterioration in their sleep quality. This finding supports theories emphasizing the long-term health consequences of poor self-regulation behaviors.[86]

Moreover, the mediation analysis provided compelling evidence that cognitive reappraisal mediates the relationship between bedtime procrastination and sleep quality. This finding is significant as it highlights a potential mechanism by which bedtime procrastination impacts sleep quality. The mediation suggested that bedtime procrastination may lead to reduced use of adaptive cognitive strategies, which in turn worsens sleep quality. This is consistent with the Self-Regulation Model, which posits that effective emotion regulation is key to managing stress and maintaining healthy routines.[87] Students who engage in bedtime procrastination may be caught in a vicious cycle where poor sleep impairs their ability to reappraise stressful situations, leading to further procrastination and poor sleep.[4,48,88,89] This cycle emphasizes the importance of targeting cognitive reappraisal skills in interventions. Teaching students how to reframe stressful situations and manage their time effectively could mitigate the adverse effects of bedtime procrastination on sleep quality, potentially improving overall well-being.

Interestingly, while the mediation effect was significant, the direct effect of bedtime procrastination on sleep quality remained substantial. This suggested that other factors might mediate or moderate this relationship besides cognitive reappraisal. Variables such as perceived stress, anxiety, or overall time management skills could influence how bedtime procrastination affects sleep quality. Future research could explore these factors to provide a more comprehensive understanding of the mechanisms linking procrastination behaviors and sleep outcomes.

While the study experienced a high attrition rate, several steps were taken to mitigate its potential impact. Attrition analysis confirmed that the final sample was representative of the initial cohort, reducing concerns about systematic bias. FIML estimation further ensured the robustness of parameter estimates despite missing data, and post hoc power analysis demonstrated sufficient statistical power to detect medium-to-large effects. Although the reduced sample size may limit the detection of smaller effects, the significant findings reported remain theoretically meaningful and robust.

Limitations and Future Directions

This study has several limitations that must be acknowledged. First, the sample was drawn from a single university, limiting the generalizability of the findings to other populations or settings. Future studies should include diverse samples across universities, cultural contexts, and age groups. Second, reliance on self-reported measures may introduce bias, and incorporating objective measures like actigraphy could enhance validity. Third, while cognitive reappraisal was examined as a mediator, other potential mediators or moderators, such as perceived stress or social support, were not included, which future research should address for a more comprehensive understanding. Fourth, the high attrition rate across three waves of data collection reduced the sample size at P3, potentially limiting the detection of smaller effects, despite attrition analysis confirming representativeness and the use of FIML estimation to address missing data. However, the assumption of data MCAR may not fully account for all patterns of missingness, emphasizing the need for better retention strategies. Fifth, while the structural equation modeling showed excellent fit indices, the potential for overfitting cannot be ruled out, and future research should use cross-validation to confirm robustness. Sixth, the scales used, while psychometrically sound globally and in Pakistani populations, lack formal validation within Pakistan's cultural and linguistic context, warranting further study. Seventh, academic stress levels, likely varying across the three-time points, were not directly assessed, potentially confounding the relationships studied. Including academic stress measures in future studies would clarify its influence. Finally, the short time frame of one academic semester limits insights into long-term effects, which could be better explored in multi-year longitudinal studies.

Implications

The findings have several important implications for interventions targeting sleep quality and emotional regulation in university students. Given the identified mediating role of cognitive reappraisal, interventions focusing on enhancing cognitive reappraisal skills could be particularly effective. Cognitive-behavioral therapy (CBT) and mindfulness-based interventions that teach adaptive cognitive strategies could help students manage stress and reduce bedtime procrastination. Additionally, educational programs and workshops that focus on improving time management skills, setting healthy bedtime routines, and coping with academic stress could mitigate the negative impact of bedtime procrastination on sleep quality. Universities could implement peer support groups and digital interventions, such as apps that provide reminders and motivation to adhere to a healthy sleep schedule, to encourage students to adopt healthier sleep behaviors. Furthermore, policy changes that promote a more balanced academic workload and provide resources for mental health support could help create an environment conducive to better sleep and overall well-being.

Conclusion

This longitudinal study highlighted the significant role of bedtime procrastination in predicting poor sleep quality over time and identified cognitive reappraisal as a critical mediator in this relationship. The findings suggested that bedtime procrastination is a stable behavioral pattern and a significant risk factor for deteriorating sleep quality among university students. Interventions aimed at enhancing cognitive reappraisal skills and reducing procrastination behaviors could be beneficial in improving sleep quality and overall mental health in this population. Future research should explore additional mediating and moderating factors to understand better the pathways linking bedtime procrastination and sleep quality. By addressing these factors, educational institutions and mental health professionals can better support the well-being of students.

Institutional Review Board Statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Review Committee of The Islamia University of Bahawalpur, Pakistan (Approval No. IUB/2022-R0967).

Data Sharing Statement

The raw data that support the findings of this study are available upon reasonable request from the authors (Mehmood Ahmad: mehmood.ahmad@iub.edu.pk and Ayesha Khan: ayeshakhan674@hotmail.com).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

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Disclosure

The authors report no conflicts of interest in this work.

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