JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Sleep Quality as a Predictor of Cognitive Performance in University Students: A Cross-Sectional Study

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Abstract
This cross-sectional study investigated sleep quality as a significant predictor of cognitive performance among university students (N=150). Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), while cognitive performance was measured through validated standardized tasks evaluating attention, working memory, processing speed, and executive function. Descriptive statistics revealed that 30.7% of students experienced poor sleep quality, while 50.7% exhibited fair sleep quality. Spearman's rank-order correlation analysis demonstrated significant negative associations between PSQI scores and all cognitive domains ($r = -0.521$ to -0.687, $p < 0.001$). Mann-Whitney U tests confirmed significant differences in cognitive performance between good and poor sleep groups (all $p < 0.001$). Multiple linear regression analysis ($R^2 = 0.587$, adjusted $R^2 = 0.567$) confirmed sleep quality as an independent predictor of cognitive outcomes after adjusting for demographic variables (age, gender, year of study) and lifestyle factors (exercise frequency, caffeine consumption). Effect size analysis revealed large practical significance for the sleep-cognition relationship (Cohen's d = 1.72-2.14). The intervention group (n=42) demonstrated clinically meaningful improvements in PSQI scores (10.2 ± 2.1 to 6.8 ± 1.9, $p < 0.001$) and cognitive performance following targeted sleep hygiene and stress management interventions. The findings underscore the critical importance of sleep quality in supporting cognitive functions essential for academic achievement and suggest the necessity for targeted, evidence-based interventions to enhance student well-being. Limitations included the cross-sectional design for the observational phase and potential recall bias in self-reported measures. The study recommends future longitudinal investigations with objective sleep measurement methods (actigraphy, polysomnography) to establish causality and evaluate long-term intervention efficacy.

Keywords: sleep quality, cognitive performance, university students, Pittsburgh Sleep Quality Index, statistical analysis, cross-sectional study, academic achievement, effect size, intervention outcomes

1. Introduction
1.1 Background and Context
Sleep is a fundamental physiological process essential for cognitive functioning, emotional regulation, memory consolidation, and overall well-being[1][2]. University students face unique challenges that frequently compromise sleep quality, including academic stress, irregular schedules, excessive screen time, social pressures, and part-time work commitments [3]. Recent epidemiological data indicate that 50-70% of university students report suboptimal sleep quality, contributing to significant academic and health consequences [2][4].
Poor sleep quality has been consistently and systematically linked to diminished cognitive performance across multiple domains, including deficits in attention span, memory consolidation, executive function, and problem-solving abilities[1][3]. Research demonstrates that sleep plays a critical role in memory consolidation through synaptic plasticity mechanisms, information processing optimization, and learning consolidation[2]. Sleep deprivation and fragmented sleep patterns have been shown to negatively impact

academic achievement, with correlational studies reporting reductions in GPA ranging from 0.2 to 0.5 points in students with poor sleep quality[4][5].

Despite the growing body of evidence, significant gaps remain in the literature regarding robust cross-sectional investigations examining sleep quality as a predictor of cognitive performance in diverse university populations, particularly within the Indian educational context. This study was designed to address this gap by systematically investigating the predictive relationship between sleep quality and cognitive performance among university students at Dayananda Sagar University, with the explicit goal of providing empirical evidence that could inform evidence-based institutional policies and targeted interventions to promote student well-being and academic success.

1.2 Statement of the Problem

University students frequently experience poor sleep quality due to multifactorial causes including academic demands, irregular lifestyle patterns, psychological stress, and environmental factors [1][3]. This compromised sleep leads to documented cognitive impairments such as reduced attention span, memory lapses, decreased processing speed, and diminished problem-solving abilities, ultimately affecting academic performance, mental health, and overall student well-being[2][4].

While previous studies have established correlational associations between sleep quality and cognitive performance in Western university populations, limited research has specifically examined sleep quality as a quantitative predictor of cognitive outcomes in Indian university students. Furthermore, most existing research lacks comprehensive statistical analysis including effect size calculations, multivariate regression modeling, and intervention outcome measurement. Addressing these gaps is deemed crucial for developing targeted, evidence-based interventions to improve sleep habits, enhance cognitive functioning, and optimize academic outcomes in this population[3][5].

1.3 Research Questions and Hypotheses

Research Questions:

1. What is the magnitude and statistical significance of the relationship between sleep quality (as measured by PSQI) and cognitive performance across multiple cognitive domains in university students?
2. Which specific dimensions of sleep quality (duration, efficiency, latency, disturbances, daytime dysfunction) demonstrate the strongest predictive associations with cognitive performance domains?
3. After controlling for demographic variables (age, gender, year of study) and lifestyle factors (exercise frequency, caffeine consumption), does sleep quality remain a significant independent predictor of cognitive outcomes?
4. What is the magnitude of intervention effects on sleep quality and cognitive performance following targeted sleep hygiene and stress management programs?

Hypotheses:

- **Primary Hypothesis (H_1):** Poor sleep quality will demonstrate a significant negative predictive relationship with cognitive performance across all domains examined, with PSQI scores showing negative correlation coefficients ($r < -0.40$) and statistical significance at $p < 0.01$ level.
- **Secondary Hypothesis (H_2):** Sleep quality will remain a statistically significant independent predictor of cognitive performance after adjusting for demographic and lifestyle covariates, as demonstrated through multiple linear regression analysis ($p < 0.05$).
- **Tertiary Hypothesis (H_3):** Executive function and attention will demonstrate stronger associations with sleep quality than processing speed, reflecting the greater vulnerability of frontal lobe-dependent functions to sleep deprivation.
- **Intervention Hypothesis (H_4):** Students receiving targeted sleep hygiene and stress management interventions will demonstrate clinically meaningful improvements in both sleep quality (Cohen's $d > 0.80$) and cognitive performance measures compared to baseline assessments.

1.4 Significance of the Study

This study is significant for multiple reasons. First, it provides empirical evidence with comprehensive statistical analysis on the predictive role of sleep quality in cognitive performance among university students in the Indian educational context. Second, the study incorporates advanced statistical techniques including effect size calculations, multivariate regression modeling, and pre-post intervention analysis, providing more rigorous evidence than previous cross-sectional investigations. Third, the findings are intended to inform the development of targeted, evidence-based institutional interventions, including sleep hygiene education programs, flexible academic scheduling aligned with chronotype diversity, stress management workshops incorporating mindfulness techniques, and campus-based sleep health awareness campaigns. Finally, the study contributes to the broader understanding of modifiable factors influencing academic success and student well-being in higher education settings.

1.5 Scope and Delimitations

The study focuses on university students aged 18-25 years enrolled in undergraduate and postgraduate programs, examining the relationship between sleep quality and cognitive performance at a single point in time through a cross-sectional observational design. The study captures a snapshot of sleep quality and cognitive functioning but does not explore longitudinal effects or establish causal relationships. The sample is delimited to students without diagnosed sleep disorders or medical conditions affecting sleep quality, thus limiting generalizability to the broader student population. Additionally, the study is geographically limited to Dayananda Sagar University, Bengaluru, and may not be representative of other universities with different institutional contexts, student demographics, or cultural factors.

2. Methodology

2.1 Study Design and Setting

A cross-sectional research design was employed to investigate the predictive relationship between sleep quality and cognitive performance. The study was conducted at Dayananda Sagar University, Bengaluru, during the academic year 2024-2025. The institutional setting is an established private university with diverse student populations across multiple academic disciplines and year levels, providing an appropriate context for examining sleep-cognition relationships in a university student population.

2.2 Study Population and Sampling

Population Definition: The study population consisted of university students aged 18-25 years, enrolled in undergraduate (Bachelor's degree programs) or postgraduate (Master's degree programs) programs across various academic disciplines including Science, Commerce, and Arts.

Sampling Method: A stratified random sampling method was employed to ensure proportional representation across different academic disciplines and year levels. Stratification variables included academic discipline (Science, Commerce, Arts) and educational level (Undergraduate, Postgraduate).

Sample Size Calculation: The sample size was determined based on statistical power analysis using G*Power 3.1 software with the following parameters: effect size ($f^2 = 0.15$, representing medium effect), alpha level ($\alpha = 0.05$, two-tailed), desired statistical power ($1 - \beta = 0.90$), and anticipated number of predictor variables in regression model ($k = 6$). The calculation yielded a minimum sample size of 127 participants. To accommodate potential attrition and enhance statistical power, the target sample size was set at 150 participants.

Final Sample: A total of 150 university students (68 male, 82 female; mean age = 21.2 ± 1.8 years) were recruited. The sample comprised 94 undergraduate students (62.7%) and 56 postgraduate students (37.3%), distributed across Science (n=52, 34.7%), Commerce (n=48, 32%), and Arts (n=50, 33.3%) disciplines.

Inclusion Criteria: Age 18-25 years; currently enrolled as full-time student; able to provide informed consent; willingness to complete all assessment measures.

Exclusion Criteria: Diagnosed sleep disorder; neurological or psychiatric conditions affecting cognition; current use of medications affecting sleep or cognition; history of head injury with loss of consciousness; excessive alcohol or substance use.

2.3 Data Collection Instruments

2.3.1 Sleep Quality Assessment

Pittsburgh Sleep Quality Index (PSQI)[6]: This 19-item validated instrument assessed sleep quality, duration, consistency, and disturbances over a one-month period. The PSQI yields seven component scores (subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, daytime dysfunction) and a global sleep quality score ranging from 0 to 21. Scores ≤ 5 indicate good sleep quality, 6-10 indicate fair sleep quality, and > 10 indicate poor sleep quality. The PSQI demonstrates strong psychometric properties with Cronbach's $\alpha = 0.83$ and test-retest reliability ICC = 0.85[6]. For this study, Cronbach's $\alpha = 0.81$, indicating acceptable internal consistency.

2.3.2 Cognitive Performance Assessment

Attention Span Assessment (Continuous Performance Test - CPT): A computerized version of the Continuous Performance Test measured sustained attention through a 10-minute task requiring responses to target stimuli while inhibiting responses to non-target stimuli. Outcome measures included accuracy (percentage correct) and reaction time variability. Scores range from 0-100, with higher scores indicating better sustained attention. Test-retest reliability $r = 0.87$[7].

Working Memory Assessment (Digit Span Test - DST): This validated measure required participants to recall sequences of digits in forward and backward directions, assessing working memory capacity. The outcome measure was maximum digit span achieved (range 3-9 digits). The DST demonstrates strong reliability ($r = 0.88$) and correlates significantly with measures of general cognitive ability[7].

Processing Speed Assessment (Symbol Digit Modalities Test - SDMT): This timed test required participants to match digits with symbols according to a key, measuring information processing speed. Outcome was the number of correct matches completed in 90 seconds. SDMT demonstrates strong psychometric properties (ICC = 0.83) and is sensitive to cognitive impairment[8].

Executive Function Assessment (Wisconsin Card Sorting Test - WCST): This computerized version measured executive function through a card-sorting task requiring pattern recognition and cognitive flexibility. Primary outcome measures included categories completed (0-6) and perseverative errors. WCST demonstrates good test-retest reliability ($r = 0.81$)[8].

Academic Performance: Grade Point Average (GPA) was obtained from official university records with student consent. Academic standing was categorized as Excellent (GPA ≥ 3.7), Good (3.3-3.7), Average (2.7-3.3), and Below Average (< 2.7).

2.4 Data Collection Procedures

Data collection occurred over an 8-week period (January-March 2025) in a controlled laboratory setting at the Department of Physical Education and Sports. Each participant completed data collection in a single session lasting approximately 90 minutes. The session consisted of:

1. **Informed Consent and Demographics (10 minutes):** Participants reviewed information about study procedures, risks, and benefits, provided written informed consent, and completed demographic questionnaire.
2. **Sleep Assessment (10 minutes):** Participants completed the PSQI questionnaire in a quiet, distraction-free environment.
3. **Cognitive Testing (60 minutes):** Participants completed four computerized cognitive tests in standardized order (CPT, SDMT, DST, WCST) with 5-minute breaks between tests to minimize fatigue effects.
4. **Debrief and Compensation (10 minutes):** Participants received explanation of study findings and were compensated with a gift voucher valued at ₹500.

All data collection procedures were conducted in accordance with established ethical guidelines, ensuring participant confidentiality through use of coded identification numbers. The research protocol received prior approval from the Dayananda Sagar University Institutional Review Board (Reference: DSU-IRB/2024/456).

2.5 Statistical Analysis Plan

2.5.1 Descriptive Statistics

Descriptive statistics (means, standard deviations, ranges, frequencies) were calculated for all demographic variables, sleep quality measures, and cognitive performance measures. The Kolmogorov-Smirnov test was performed to assess normality of distributions for all continuous variables. Homogeneity of variance was assessed using Levene's test.

2.5.2 Bivariate Correlation Analysis

Spearman's rank-order correlation analysis was conducted to examine associations between PSQI global score and individual cognitive performance measures (attention, working memory, processing speed, executive function). Partial correlation analysis was performed to examine sleep-cognition associations while controlling for demographic variables (age, gender, year of study). Correlation strength was interpreted using standard conventions: $r < 0.3$ (weak), 0.3-0.7 (moderate), > 0.7 (strong).

2.5.3 Group Comparison Analysis

The Mann-Whitney U test (nonparametric alternative to independent samples t-test) was conducted to compare cognitive performance between students with good sleep quality (PSQI ≤ 5) and poor sleep quality (PSQI > 10), controlling for Type I error using Bonferroni correction (adjusted $\alpha = 0.0125$ for four cognitive domains).

One-way ANOVA with post-hoc Tukey HSD tests was employed to compare cognitive performance across three sleep quality categories (Good, Fair, Poor) and examine GPA differences by sleep quality category.

2.5.4 Effect Size Analysis

Cohen's d was calculated to quantify the magnitude of group differences in cognitive performance between good and poor sleep groups. Effect sizes were interpreted as: $d < 0.2$ (negligible), 0.2-0.5 (small), 0.5-0.8 (medium), > 0.8 (large)[9].

2.5.5 Multiple Linear Regression Analysis

Multiple linear regression analysis was performed to examine the predictive role of sleep quality (PSQI global score) in cognitive performance while controlling for potential confounders. The regression model included:

- **Dependent Variable:** Composite cognitive performance score (standardized z-scores of all four cognitive measures averaged)
- **Predictor Variables:** PSQI global score, age, gender (dummy-coded: 0=Male, 1=Female), exercise frequency (hours/week), caffeine consumption (cups/day), academic year (dummy-coded: 0=Undergraduate, 1=Postgraduate)

Regression assumptions were verified: multicollinearity (VIF < 3 for all variables), residual normality (Q-Q plot inspection), and homoscedasticity (plot of standardized residuals vs. fitted values). The model's overall fit was assessed using R^2 and adjusted R^2, and individual predictor significance was evaluated using standardized beta coefficients and t-tests.

2.5.6 Mediation Analysis

Potential mediation pathways were examined using Hayes PROCESS macro (Model 4) to determine whether the sleep-cognition relationship was mediated by: (a) academic stress levels, or (b) daily physical activity engagement. Bootstrap confidence intervals (95%, 5,000 resamples) were used to evaluate indirect effects.

2.5.7 Pre-Post Intervention Analysis

For the intervention group (n=42), paired samples t-tests and Wilcoxon signed-rank tests (depending on normality) compared baseline and post-intervention values for PSQI scores, sleep duration, and cognitive performance measures. Effect sizes (Cohen's d) were calculated to quantify intervention effectiveness. The clinical significance of improvements was assessed using the Reliable Change Index (RCI) to identify individuals demonstrating clinically meaningful change beyond measurement error.

2.5.8 Statistical Software and Significance Level

All statistical analyses were performed using SPSS 27.0 and R 4.3.2 (with ggplot2, corrplot, and mediation packages). The alpha level for statistical significance was set at $p < 0.05$ (two-tailed), except where Bonferroni correction was applied for multiple comparisons. p-values < 0.001 are reported as "p < 0.001"[5][6].

2.6 Ethical Considerations

The study adhered to all ethical guidelines for research involving human participants and international research ethics standards (Declaration of Helsinki). Informed consent was obtained from all participants through a standardized consent form explaining study procedures, risks, benefits, and confidentiality protections. Participants were informed of their right to withdraw at any time without penalty. Confidentiality was maintained through use of coded identification numbers rather than names in all data files. All data were stored on encrypted, password-protected computers accessible only to authorized research personnel. The research protocol received prior review and approval from the Dayananda Sagar University Institutional Review Board (Reference: DSU-IRB/2024/456), ensuring compliance with institutional and regulatory ethics standards.

3. Results

3.1 Sample Characteristics

The study sample comprised 150 university students (68 male, 82 female) with mean age of 21.2 ± 1.8 years (range: 18-25 years). The sample included 94 undergraduate students (62.7%) and 56 postgraduate students (37.3%), distributed across three academic disciplines: Science (n=52, 34.7%), Commerce (n=48, 32%), and Arts (n=50, 33.3%). There were no significant differences in age distribution ($F(2,147) = 0.84$, $p = 0.433$) or gender distribution ($\chi^2(1,150) = 0.92$, $p = 0.339$) across academic disciplines, suggesting balanced stratification.

Demographic Variable	Mean (SD) or n (%)	Range
Age (years)	21.2 (1.8)	18–25
Gender		
Male	68 (45.3%)	–
Female	82 (54.7%)	–
Year of Study		
Undergraduate	94 (62.7%)	–
Postgraduate	56 (37.3%)	–
Academic Discipline		
Science	52 (34.7%)	–
Commerce	48 (32%)	–
Arts	50 (33.3%)	–

Table 1: Table 1: Demographic Characteristics of Study Participants (N = 150)

3.2 Sleep Quality Assessment Results

Descriptive analysis of Pittsburgh Sleep Quality Index (PSQI) components revealed significant variability in sleep characteristics across the sample. Mean sleep duration was 6.2 ± 1.4 hours per night, below the recommended 7-9 hours for optimal cognitive functioning [10]. Sleep efficiency (total time asleep / total time in bed × 100) averaged 78.5 ± 12.3%, indicating that students spent approximately 21.5% of bedtime awake. Sleep latency (time to fall asleep) averaged 18.5 ± 9.2 minutes, with approximately 28% of participants exceeding 30 minutes. Sleep disturbances (frequency of nighttime awakenings, difficulty returning to sleep) averaged 1.8 ± 0.6 on a 0-3 scale, indicating frequent disturbances. Daytime dysfunction (difficulty staying awake during day, lacking enthusiasm) averaged 1.5 ± 0.7 on a 0-3 scale. The global PSQI score averaged 9.3 ± 2.8, indicating fair-to-poor sleep quality in the overall sample.

PSQI Component	Mean (SD)	Classification/Interpretation
Sleep Duration (hours/night)	6.2 (1.4)	Below recommended 7–9 hours
Sleep Efficiency (%)	78.5 (12.3)	Moderate (Target: > 85%)
Sleep Latency (minutes)	18.5 (9.2)	Moderately delayed (Normal: < 15 min)

Sleep Disturbances (0–3 scale)	1.8 (0.6)	Frequent disturbances
Daytime Dysfunction (0–3 scale)	1.5 (0.7)	Moderate dysfunction
Overall PSQI Score (0–21 scale)	9.3 (2.8)	Fair-to-poor sleep quality

Table 2: Table 2: Pittsburgh Sleep Quality Index (PSQI) Component Results (N = 150)

Classification of sleep quality revealed that only 28 students (18.7%) demonstrated good sleep quality (PSQI ≤ 5), 76 students (50.7%) exhibited fair sleep quality (PSQI 6-10), and 46 students (30.7%) experienced poor sleep quality (PSQI > 10). The distribution demonstrates that 81.3% of the sample exhibited suboptimal sleep quality, representing a significant public health concern within the university student population.

Sleep Quality Category	**Number of Students**	**Percentage**
Good Sleep Quality (PSQI ≤ 5)	28	18.7%
Fair Sleep Quality (PSQI 6–10)	76	50.7%
Poor Sleep Quality (PSQI > 10)	46	30.7%

Table 3: Table 3: Sleep Quality Classification Among University Students

3.3 Cognitive Performance Results

3.3.1 Descriptive Statistics for Cognitive Measures

Across the full sample, cognitive performance measures demonstrated considerable variability:

- **Attention Span (CPT Accuracy):** Mean = 76.2 ± 12.1%, Range = 42-98%, indicating considerable individual differences in sustained attention ability
- **Working Memory (Digit Span):** Mean = 7.1 ± 1.4 digits, Range = 4-9 digits, with approximately 35% of participants unable to achieve forward digit span ≥ 7
- **Processing Speed (SDMT Correct Matches):** Mean = 598 ± 138 ms, Range = 312-892 ms, reflecting high variability in information processing efficiency
- **Executive Function (WCST Categories Completed):** Mean = 67.3 ± 13.9, Range = 28-96, indicating deficits in cognitive flexibility and planning in approximately 22% of sample

3.3.2 Group Comparison Analysis: Good Sleep vs. Poor Sleep

Mann-Whitney U tests compared cognitive performance between students with good sleep quality (n=28) and poor sleep quality (n=46). Results demonstrated highly significant differences across all cognitive domains with large effect sizes:

Cognitive Domain	**Good Sleep**	**Poor Sleep**	**U-statistic**	**p-value**	**Cohen's d**
	(Mean ± SD)	**(Mean ± SD)**			**(95% CI)**
Attention Span (%)	87.2 ± 6.4	64.3 ± 11.2	243.0	<0.001**	2.14 (1.68–2.60)
Working Memory (digits)	8.1 ± 1.2	5.8 ± 1.5	187.5	<0.001**	1.61 (1.18–2.04)
Processing Speed (ms)	542 ± 78	687 ± 125	425.0	<0.001**	-1.32 (–1.74 to –0.90)
Executive Function (WCST)	78.5 ± 8.3	52.1 ± 12.6	156.0	<0.001**	2.30 (1.81–2.79)

Table 4: Table 4: Cognitive Performance Comparison Between Good Sleep and Poor Sleep Groups (** $p < 0.001$, Bonferroni-corrected $\alpha = 0.0125$)

The effect sizes (Cohen's d = 1.32 to 2.30) indicate large and clinically meaningful differences, representing substantial cognitive advantages for students with good sleep quality. Notably, executive function demonstrated the largest effect size (d = 2.30), followed by attention (d = 2.14), suggesting particular vulnerability of frontal lobe-dependent functions to sleep deprivation.

3.3.3 ANOVA Across Three Sleep Quality Categories

One-way ANOVA examined cognitive performance differences across three sleep quality groups (Good, Fair, Poor):

Cognitive Domain	Good Sleep	Fair Sleep	Poor Sleep	F-statistic	p-value	\textbf$\eta^2$
	(n=28)	(n=76)	(n=46)			(Effect Size)
Attention Span (%)	87.2 ± 6.4	77.1 ± 10.3	64.3 ± 11.2	78.43	<0.001**	0.51
Working Memory (digits)	8.1 ± 1.2	7.2 ± 1.3	5.8 ± 1.5	52.19	<0.001**	0.42
Processing Speed (ms)	542 ± 78	612 ± 112	687 ± 125	34.67	<0.001**	0.32
Executive Function	78.5 ± 8.3	68.2 ± 11.4	52.1 ± 12.6	92.54	<0.001**	0.56

Table 5: Table 5: Cognitive Performance Across Three Sleep Quality Categories (ANOVA with η^2 effect sizes)

Post-hoc Tukey HSD tests revealed that all three groups differed significantly from each other (all pairwise comparisons p < 0.01), demonstrating a clear dose-response relationship between sleep quality and cognitive performance.

3.4 Correlation Analysis

3.4.1 Spearman's Rank-Order Correlation

Spearman's rank-order correlation analysis examined associations between PSQI score and individual cognitive performance measures. All correlations were statistically significant and in the expected direction (negative, indicating that higher PSQI scores—poorer sleep—were associated with lower cognitive performance):

Variable Pairs	Spearman's r	95% CI	p-value
PSQI Score vs. Attention	-0.623	(-0.706 to -0.520)	<0.001**
PSQI Score vs. Working Memory	-0.598	(-0.685 to -0.491)	<0.001**
PSQI Score vs. Processing Speed	-0.521	(-0.614 to -0.407)	<0.001**
PSQI Score vs. Executive Function	-0.687	(-0.761 to -0.598)	<0.001**
Sleep Duration vs. Attention	0.514	(0.396 to 0.615)	<0.001**
Sleep Efficiency vs. Working Memory	0.487	(0.366 to 0.592)	<0.001**
Sleep Disturbances vs. Processing Speed	-0.456	(-0.563 to -0.331)	<0.001**
Sleep Latency vs. Executive Function	-0.392	(-0.503 to -0.261)	<0.001**

Table 6: Table 6: Spearman's Rank-Order Correlation Between Sleep Quality Dimensions and Cognitive Performance (N = 150, ** p < 0.001)

Correlation strengths were moderate to strong (r = -0.39 to -0.69), with executive function demonstrating the strongest association with overall sleep quality (r = -0.687), followed by attention (r = -0.623).

3.4.2 Partial Correlation Analysis

Partial correlation analysis controlled for demographic variables (age, gender, year of study) to examine associations between sleep quality and cognitive performance independent of demographic confounding:

Variable Pairs (controlling for demographics)	Partial r	p-value	Attenuation from Zero-Order
PSQI Score vs. Attention	-0.612	<0.001**	1.8%
PSQI Score vs. Working Memory	-0.589	<0.001**	1.5%
PSQI Score vs. Processing Speed	-0.508	<0.001**	2.5%
PSQI Score vs. Executive Function	-0.678	<0.001**	1.3%

Table 7: Table 7: Partial Correlations Controlling for Demographic Variables (Age, Gender, Academic Year)

Minimal attenuation of correlations (1-3% reduction) after controlling for demographics indicated that demographic variables did not substantially confound the sleep-cognition associations, confirming the robustness of the relationships.

3.5 Multiple Linear Regression Analysis

3.5.1 Model Specification and Assumptions

A multiple linear regression model was developed to examine the predictive role of sleep quality in cognitive performance while adjusting for demographic and lifestyle covariates. The dependent variable was a standardized composite cognitive performance score (mean of z-scores for attention, working memory, processing speed, and executive function). Predictor variables included:

- PSQI Global Score (continuous)
- Age (continuous, in years)
- Gender (categorical, dummy-coded: 0 = Male, 1 = Female)
- Exercise Frequency (continuous, hours per week)
- Caffeine Consumption (continuous, cups per day)
- Academic Year (categorical, dummy-coded: 0 = Undergraduate, 1 = Postgraduate)

Regression assumptions were verified: (1) Multicollinearity—all VIF values < 2.5 (range: 1.2 to 2.3), indicating acceptable multicollinearity; (2) Normality of residuals—Q-Q plot inspection and Shapiro-Wilk test ($p = 0.087$) confirmed approximate normality; (3) Homoscedasticity—plot of standardized residuals vs. fitted values showed random scatter around zero; (4) Independence of observations—Durbin-Watson statistic = 2.14, indicating no significant autocorrelation.

3.5.2 Regression Results

The regression model demonstrated strong predictive power with $R^2 = 0.587$ and adjusted $R^2 = 0.567$, indicating that the model explains 58.7% of variance in cognitive performance. The overall model was statistically significant ($F(6,143) = 32.45$, $p < 0.001$).

Predictor Variable	Unstandardized *β*	SE	Standardized *β*	t-value	p-value	95% CI
(Intercept)	3.847	1.023	—	3.76	<0.001**	(1.826–5.868)
PSQI Score	-0.182	0.023	-0.512	-7.87	<0.001**	(-0.228 to -0.136)
Age	-0.052	0.041	-0.078	-1.27	0.206	(-0.134 to 0.029)
Gender (Female)	0.083	0.076	0.067	1.10	0.271	(-0.066 to 0.232)
Exercise Frequency	0.216	0.054	0.231	3.97	<0.001**	(0.109–0.323)
Caffeine Consumption	-0.123	0.047	-0.152	-2.64	0.009*	(-0.216 to -0.031)
Academic Year	0.034	0.030	0.068	1.16	0.248	(-0.024 to 0.093)

Table 8: Table 8: Multiple Linear Regression Analysis Predicting Cognitive Performance (N = 150, * p < 0.01, ** p < 0.001)

Key findings:

1. **Sleep Quality (PSQI Score):** PSQI demonstrated the strongest and most significant predictor of cognitive performance ($\beta = -0.512$, $t = -7.87$, $p < 0.001$). Each 1-unit increase in PSQI score was associated with a 0.182 standard deviation decrease in cognitive performance, after adjusting for other variables. This represents a large and clinically meaningful effect.

2. **Exercise Frequency:** Exercise frequency was a significant positive predictor (β = 0.231, t = 3.97, $p < 0.001$), indicating that each additional hour of weekly exercise was associated with improved cognitive performance (β = 0.216), independent of sleep quality.
3. **Caffeine Consumption:** Caffeine consumption demonstrated a significant negative association (β = -0.152, t = -2.64, p = 0.009), suggesting that higher caffeine consumption was associated with reduced cognitive performance, potentially reflecting reverse causality (students with poor concentration may consume more caffeine for stimulation).
4. **Non-Significant Predictors:** Age (p = 0.206), gender (p = 0.271), and academic year (p = 0.248) were not statistically significant predictors, after adjusting for sleep quality and lifestyle factors.

Interpretation: Sleep quality remained a robust independent predictor of cognitive performance (supporting H_2), explaining 51.2% of standardized variance in cognitive outcomes after adjusting for demographic and lifestyle covariates.

3.6 Sleep Quality and Academic Performance

One-way ANOVA examined the relationship between sleep quality categories and academic performance as measured by GPA:

Sleep Quality Category	Mean GPA (SD)	Academic Standing	n
Good Sleep Quality	3.56 ± 0.32	Excellent/Good	28
Fair Sleep Quality	3.12 ± 0.48	Good/Average	76
Poor Sleep Quality	2.34 ± 0.67	Average/Below Average	46

Table 9: Table 9: Relationship Between Sleep Quality Categories and Academic Performance (GPA) (ANOVA: $F(2,147) = 78.34$, $p < 0.001$, $\eta^2 = 0.517$)

Results demonstrated significant GPA differences across sleep quality groups ($F(2,147) = 78.34$, $p < 0.001$, $\eta^2 = 0.517$), representing a large effect size. Post-hoc Tukey HSD tests revealed all three groups differed significantly (all $p < 0.001$). Students with good sleep quality had significantly higher GPAs (M = 3.56) compared to fair (M = 3.12, difference = 0.44) and poor sleep groups (M = 2.34, difference = 1.22). This represents substantial academic achievement differences associated with sleep quality.

3.7 Intervention Group Results

An intervention group of 42 students (28% of sample) participated in a 6-week sleep hygiene and stress management intervention program. The intervention included: (1) Sleep hygiene education addressing sleep environment optimization, consistent sleep-wake schedules, caffeine/alcohol avoidance, and pre-sleep relaxation; (2) Stress management training including progressive muscle relaxation, mindfulness meditation, and cognitive-behavioral techniques; (3) Behavioral goal-setting for sleep-related behaviors; and (4) Weekly group sessions (90 minutes) plus daily practice recommendations.

Paired samples t-tests and Wilcoxon signed-rank tests (depending on normality) compared pre- and post-intervention values:

Outcome Measure	Baseline	Post-Intervention	Mean Difference	t/Z-statistic	Cohen's d / Effect Size
	(Mean ± SD)	(Mean ± SD)		(p-value)	
PSQI Score (n=42)	10.2 ± 2.1	6.8 ± 1.9	-3.4 ± 1.8	t(41) = 12.24	d = 1.89**
				<0.001**	(Very Large)
Sleep Duration (hours)	5.8 ± 1.2	7.1 ± 0.8	+1.3 ± 0.9	t(41) = 9.34	d = 1.44**
				<0.001**	(Large)
Sleep Efficiency (%)	74.2 ± 11.3	86.7 ± 8.4	+12.5 ± 9.8	t(41) = 8.25	d = 1.27**
				<0.001**	(Large)
Sleep Latency (minutes)	23.4 ± 8.7	14.8 ± 6.2	-8.6 ± 6.1	t(41) = 9.15	d = 1.41**

				<0.001**	(Large)
Attention Span (%)	62.1 ± 12.4	74.3 ± 8.2	+12.2 ± 9.1	t(41) = 8.73	d = 1.35**
				<0.001**	(Large)
Working Memory (digits)	5.6 ± 1.4	7.2 ± 1.1	+1.6 ± 1.2	t(41) = 8.56	d = 1.32**
				<0.001**	(Large)
Processing Speed (ms)	681 ± 118	573 ± 92	-108 ± 87	t(41) = 8.04	d = 1.24**
				<0.001**	(Large)
Executive Function (WCST)	50.2 ± 11.8	69.5 ± 9.3	+19.3 ± 11.7	t(41) = 10.73	d = 1.65**
				<0.001**	(Large)

Table 10: Table 10: Pre- and Post-Intervention Outcomes for Intervention Group (n=42, ** $p < 0.001$, Very Large to Large Effect Sizes)

Key Findings:
The intervention demonstrated dramatic improvements across all outcome measures with large effect sizes (Cohen's d = 1.24 to 1.89). PSQI scores decreased significantly from 10.2 ± 2.1 to 6.8 ± 1.9 (d = 1.89), representing a transition from poor to fair sleep quality. Sleep duration increased by 1.3 hours (5.8 to 7.1 hours), approaching recommended levels. All cognitive performance measures improved significantly:

- Attention improved by 12.2 percentage points (d = 1.35)
- Working memory improved by 1.6 digits (d = 1.32)
- Processing speed improved by 108 ms (d = 1.24)
- Executive function improved by 19.3 points (d = 1.65)

Clinical significance assessment using Reliable Change Index identified that 73.8% (31/42) of intervention participants demonstrated clinically meaningful improvement in sleep quality (beyond measurement error), and 78.6% (33/42) demonstrated clinically meaningful cognitive improvement.

3.8 Additional Statistical Analyses

3.8.1 Mediation Analysis

Hayes PROCESS macro analysis (Model 4) examined whether academic stress mediated the relationship between sleep quality and cognitive performance. Results indicated a significant indirect effect:

- Direct effect of sleep on cognition (c' path): $\beta = -0.182$, $p < 0.001$
- Indirect effect through stress (c'direct effect - total effect): $\beta = -0.043$ (95% CI: -0.072 to -0.018)
- Mediation proportion: 19.1% of total sleep-cognition effect mediated through stress
- Point estimate of indirect effect: 0.043 (SE = 0.013), 95% bootstrap CI excludes zero

This indicates that approximately 19% of the sleep-cognition relationship operates through academic stress as a mediating mechanism, while 81% reflects direct pathways.

3.8.2 Moderation Analysis

Moderation analysis tested whether gender moderated the sleep-cognition relationship. Results indicated no significant gender moderation (interaction term $p = 0.423$), suggesting that sleep quality effects on cognition were similar for male and female students.

3.8.3 Sensitivity Analysis

Sensitivity analyses using alternative cognitive composite scores (unweighted average vs. principal components analysis) and alternative sleep quality cutoffs yielded consistent results, confirming robustness of primary findings.

4. Discussion

4.1 Summary of Key Findings

This comprehensive investigation examined sleep quality as a predictor of cognitive performance in university students, incorporating advanced statistical methodology including correlation analysis, multivariate regression, effect size calculations, and intervention evaluation. The study yields several significant findings:

Finding 1 - High Prevalence of Sleep Problems: Approximately 81.3% of the university student sample (122/150 students) demonstrated suboptimal sleep quality, with 30.7% experiencing poor sleep quality (PSQI > 10) and 50.7% exhibiting fair sleep quality (PSQI 6-10). Only 18.7% achieved good sleep quality (PSQI ≤ 5). This prevalence is consistent with epidemiological estimates in university populations and represents a substantial public health concern[1][3][10].

Finding 2 - Significant Sleep-Cognition Association: Spearman correlation analysis demonstrated significant negative associations between PSQI scores and all cognitive domains ($r = -0.521$ to -0.687, all $p < 0.001$), with moderate-to-strong effect sizes. Executive function demonstrated the strongest association ($r = -0.687$), followed by attention ($r = -0.623$), suggesting particular vulnerability of frontal lobe-dependent processes to sleep deprivation.

Finding 3 - Large Group Differences: Mann-Whitney U tests revealed large and clinically meaningful differences in cognitive performance between students with good vs. poor sleep quality (Cohen's $d = 1.32$ to 2.30 across domains). Students with good sleep demonstrated 22.9 percentage point advantage in attention (87.2% vs. 64.3%), 2.3-digit advantage in working memory (8.1 vs. 5.8 digits), 145 ms faster processing speed (542 vs. 687 ms), and 26.4-point advantage in executive function (78.5 vs. 52.1).

Finding 4 - Independent Prediction After Controlling for Covariates: Multiple linear regression analysis confirmed sleep quality as a robust independent predictor of cognitive performance ($\beta = -0.512$, $t = -7.87$, $p < 0.001$), explaining 58.7% of variance in cognitive outcomes ($R^2 = 0.587$) even after adjusting for demographic variables (age, gender, year) and lifestyle factors (exercise, caffeine). This supports the hypothesis that sleep quality effects on cognition are not merely artifacts of demographic or lifestyle confounding.

Finding 5 - Academic Achievement Impact: ANOVA revealed significant differences in GPA across sleep quality categories ($F(2,147) = 78.34$, $p < 0.001$), with students demonstrating good sleep quality achieving significantly higher GPAs ($M = 3.56$) compared to fair sleep ($M = 3.12$, $\Delta = 0.44$ points) and poor sleep groups ($M = 2.34$, $\Delta = 1.22$ points).

Finding 6 - Effective Intervention: The 6-week sleep hygiene and stress management intervention demonstrated large effect sizes ($d = 1.24$-1.89) across outcome measures, with PSQI scores decreasing from 10.2 to 6.8 ($d = 1.89$), sleep duration increasing from 5.8 to 7.1 hours ($d = 1.44$), and cognitive performance improving significantly across all domains. Clinically meaningful improvement occurred in 73.8% of intervention participants.

4.2 Theoretical and Mechanistic Interpretation

The findings align with established neuroscientific understanding of sleep's role in cognition. Sleep deprivation impairs prefrontal cortex functioning, reducing executive control, attention regulation, and working memory capacity[2][3]. The stronger associations observed for executive function and attention reflect the disproportionate dependence of these frontal-lobe dependent functions on sleep-dependent synaptic plasticity and neurotransmitter regulation[4].

The mediation analysis findings suggest that academic stress represents one (though not the sole) mechanism through which poor sleep impairs cognition, with 19.1% of the total effect operating through stress-related pathways. This suggests that interventions addressing both sleep quality and stress management (as implemented in this study) may demonstrate enhanced effectiveness through multiple mechanistic pathways.

4.3 Alignment with Existing Literature

The findings are consistent with an extensive literature establishing associations between sleep quality and cognitive performance. Okano et al.[5] reported correlations of $r = -0.58$ to -0.71 between sleep quality and attention/executive function in university students, nearly identical to the r = -0.52 to -0.69 found here. Hershner and Chervin[3] documented GPA differences of 0.3-0.5 points between good and poor sleep groups; this study found a 1.22-point GPA difference, suggesting even stronger associations in this Indian university context.

The intervention effect sizes (d = 1.24-1.89) exceed those reported in previous sleep intervention trials (typically d = 0.60-1.20)[6], suggesting that the integrated sleep hygiene plus stress management approach may be particularly effective. The finding that 73.8% of participants demonstrated clinically meaningful improvement (using Reliable Change Index) represents a high intervention response rate.

4.4 Implications for University Policy and Practice

The findings have substantial implications for university administration and student affairs:

1. Sleep Health Curriculum Integration: Results support integration of sleep health education into first-year orientation programs and academic curricula. Given the high prevalence of sleep problems (81.3%) and documented cognitive consequences, universities should consider sleep health a priority comparable to physical fitness and nutrition.

2. Flexible Academic Scheduling: The study's findings suggest that inflexible early morning class schedules may impose unnecessary cognitive burden on students with naturally delayed sleep-wake cycles (chronotypes). Consider implementing flexible start times (e.g., 9:00-10:00 AM minimum) to accommodate natural sleep cycles.

3. Campus-Based Sleep Interventions: Given the demonstrated effectiveness of evidence-based sleep hygiene and stress management interventions (effect sizes d = 1.24-1.89, 73.8% clinically meaningful response rate), universities should develop and implement targeted sleep health programs. Programs could be delivered by student health services, counseling centers, or student peer educators.

4. Stress Management and Wellness Programs: The mediation analysis findings suggest that addressing academic stress as a component of sleep interventions may enhance effectiveness. Universities should expand access to evidence-based stress reduction programs (mindfulness, progressive muscle relaxation, cognitive-behavioral techniques).

5. Research and Advocacy: Universities should conduct institutional sleep quality assessments and advocate for policy changes that prioritize student sleep health. High-stakes testing, excessive academic pressures, and unrealistic workload expectations may systematically undermine student sleep quality.

6. Institutional Culture Change: Results suggest need for culture change regarding sleep's importance for academic success. Currently, "sleep deprivation badges" and "grinding" are sometimes celebrated in academic culture. Universities should explicitly communicate that adequate sleep is essential for academic performance, not a luxury.

4.5 Limitations

While this study contributes substantially to understanding sleep-cognition relationships in university students, several limitations warrant acknowledgment:

Limitation 1 - Cross-Sectional Design: The observational phase employed a cross-sectional design, capturing a single snapshot of sleep quality and cognitive functioning. This precludes establishing causal directionality. While the strong theoretical rationale and intervention findings support sleep quality impacting cognition (rather than reverse causality), only longitudinal designs can definitively establish causality.

Limitation 2 - Self-Reported Sleep Measures: Reliance on the PSQI (self-report questionnaire) introduces potential recall bias and social desirability bias. Objective measures such as actigraphy (movement-based sleep detection) or polysomnography (gold-standard electrophysiological measurement) would strengthen findings. However, practical constraints often necessitate self-report in large-scale university research.

Limitation 3 - Selective Exclusions: The study excluded students with diagnosed sleep disorders, which may have truncated the range of sleep quality values and reduced generalizability to the full university student population. Future research should include students with sleep disorders to examine clinical populations.

Limitation 4 - Limited Geographic Scope: Data collection occurred at a single university (Dayananda Sagar University, Bengaluru) with primarily urban, middle-to-upper-class students. Generalizability to other universities, geographic regions, or socioeconomic contexts remains uncertain.

Limitation 5 - Intervention Group Self-Selection: The 42 students in the intervention group self-selected to participate, introducing potential selection bias. These participants may have been more motivated or health-conscious than non-participants, potentially inflating intervention effect estimates. Future research should employ randomized controlled trial designs.

Limitation 6 - Unmeasured Confounders: While the study adjusted for several important variables, additional unmeasured confounders may influence results. Examples include family history of sleep disorders, presence of mental health conditions (depression, anxiety), medication use, and socioeconomic stress.

Limitation 7 - Academic Performance Data: Academic performance was measured using institutional GPA, which may reflect factors beyond cognitive performance (motivation, attendance, study skills, teacher relationships). A more direct academic achievement measure (standardized academic assessments, course exams) might strengthen conclusions.

4.6 Recommendations for Future Research

Based on limitations and findings, the following recommendations guide future investigation:

1. Longitudinal Design: Conduct prospective cohort studies following students across academic years to establish temporal relationships and examine whether baseline sleep quality predicts subsequent cognitive decline or academic performance changes.

2. Objective Sleep Measurement: Incorporate objective sleep measurement methods (wrist-worn actigraphy, home polysomnography) alongside self-report measures to reduce measurement error and examine whether objective vs. subjective sleep quality differentially predict cognition.

3. Randomized Controlled Trial: Employ a randomized controlled trial design with adequate blinding and control conditions (attention-control, waitlist control) to rigorously establish intervention effectiveness and reduce selection bias.

4. Multi-Site Studies: Conduct research across multiple universities in different geographic regions, with diverse student populations (rural, urban, different socioeconomic backgrounds, different academic disciplines) to enhance generalizability.

5. Mechanistic Studies: Employ neuroimaging (fMRI, EEG) and biomarker assessment (cortisol, inflammatory markers) to elucidate neurobiological mechanisms through which sleep deprivation impairs cognition.

6. Clinical Populations: Explicitly include students with diagnosed sleep disorders (insomnia, sleep apnea, narcolepsy) to examine whether sleep-cognition relationships differ between clinical and non-clinical populations.

7. Moderator Analysis: Examine potential moderators of the sleep-cognition relationship including chronotype (morningness-eveningness preference), age, gender, psychiatric comorbidity, and academic discipline.

8. Implementation Science: Conduct implementation research examining which intervention delivery models (group-based, individual, peer-delivered, technology-based) are most effective, feasible, and acceptable for university student populations.

4.7 Conclusion

This comprehensive cross-sectional study with embedded intervention component provides robust empirical evidence that sleep quality serves as a significant, independent predictor of cognitive performance in university students. The findings demonstrate that a substantial proportion of university students (81.3%) experience suboptimal sleep quality, which is associated with clinically meaningful cognitive impairments and reduced academic achievement. Multiple regression analysis confirmed sleep quality as the strongest predictor of cognitive performance ($\beta = -0.512$, $p < 0.001$), explaining 58.7% of variance even after adjusting for demographic and lifestyle variables.

The intervention study demonstrates that targeted sleep hygiene and stress management programs can produce large, clinically meaningful improvements in sleep quality and cognitive performance (effect sizes d = 1.24-1.89; 73.8% clinically meaningful response rate). These findings underscore the urgent necessity for evidence-based institutional interventions to address sleep-related issues as essential components of student well-being and academic success initiatives.

University administrators, student affairs professionals, educators, and policymakers should prioritize sleep health as a critical factor in student success and well-being. Implementation of evidence-based sleep health programs, flexible academic scheduling, stress management resources, and campus-based awareness campaigns represents a cost-effective, empirically-supported strategy to enhance cognitive functioning and academic achievement in university populations.

5. Recommendations for Implementation

1. **Implement evidence-based sleep hygiene programs** including education on sleep environment optimization, consistent sleep-wake schedules, caffeine and alcohol management, and pre-sleep relaxation techniques.
2. **Develop flexible academic scheduling policies** to accommodate individual chronotypes and natural sleep patterns, with consideration for later class start times to align with adolescent/young adult sleep biology.
3. **Establish campus sleep clinics and counseling services** staffed by trained sleep health professionals to provide screening, education, and treatment for students experiencing sleep-related difficulties or sleep disorders.
4. **Integrate sleep health education into academic curricula** across multiple disciplines (health sciences, education, social sciences) to elevate awareness of sleep's importance for academic and professional success.
5. **Implement stress management and mindfulness programs** through student health and counseling centers, as mediation analysis indicates stress represents one significant pathway through which poor sleep impairs cognition.
6. **Conduct regular institutional sleep quality assessments** to monitor trends and evaluate the effectiveness of implemented interventions.
7. **Develop campus awareness campaigns** highlighting the relationship between sleep quality and academic performance, utilizing social media, student organizations, and academic events.
8. **Create peer educator networks** training advanced students as sleep health advocates to deliver interventions and normalize conversations about sleep importance within student communities.
9. **Establish institutional policies** addressing sleep-related issues such as exam scheduling, assignment deadlines, and extracurricular expectations that may undermine student sleep quality.
10. **Advocate for cultural change** within academic communities, explicitly communicating that adequate sleep is essential for academic success rather than a luxury or indulgence.

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