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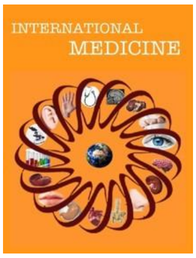

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Original Research

Neurophysiological Correlates of Academic Stress Among Undergraduate Medical Students: A Cross-Sectional Study

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Abstract

Background: Academic stress is a prevalent phenomenon among medical students and has been associated with alterations in autonomic nervous system activity, cognitive performance, and sleep quality. Neurophysiological parameters such as heart rate variability (HRV), reaction time, and sleep quality may serve as objective indicators of stress-induced changes in neural function. ***Objectives:*** To evaluate the neurophysiological correlates of academic stress among undergraduate medical students and determine the relationship between perceived stress levels and autonomic nervous system activity. ***Materials and Methods:*** A cross-sectional study was conducted among 120 undergraduate medical students aged 18–25 years. Academic stress was assessed using the Perceived Stress Scale (PSS-10). Neurophysiological assessment included resting heart rate, blood pressure, HRV parameters, auditory reaction time (ART), visual reaction time (VRT), and sleep quality using the Pittsburgh Sleep Quality Index (PSQI). Participants were categorized into low-, moderate-, and high-stress groups based on PSS scores. Data were analyzed using one-way ANOVA and Pearson's correlation test. ***Results:*** Students with high academic stress demonstrated significantly higher resting heart rate and systolic blood pressure and significantly lower HRV indices compared with low-stress students ($p < 0.001$). Visual and auditory reaction times were prolonged in the high-stress group. PSS scores showed a significant negative correlation with RMSSD ($r = -0.61$, $p < 0.001$) and a positive correlation with reaction time and PSQI scores. ***Conclusion:*** Academic stress is associated with measurable neurophysiological alterations characterized by autonomic imbalance, impaired cognitive processing speed, and poor sleep quality. These findings emphasize the need for stress-management interventions in medical education.

Keywords: *Academic stress, heart rate variability, reaction time, neurophysiology, medical students, autonomic nervous system.*

Introduction

Academic stress refers to the physiological and psychological response that occurs when educational demands exceed an individual's adaptive capacity. Among university students, particularly those enrolled in medical programs, academic stress has become a major public health concern because of intense coursework, frequent examinations, and high expectations regarding academic performance. Studies have demonstrated that medical students experience significantly higher levels of stress compared with age-matched peers in other academic disciplines (1,2).

Stress activates the hypothalamic-pituitary-adrenal (HPA) axis and the sympathetic-adrenal-medullary system, resulting in the release of cortisol, adrenaline, and noradrenaline (3). These neuroendocrine responses are essential for adaptation to acute stress but may become maladaptive when stress is chronic. Prolonged activation of stress pathways can alter autonomic nervous system regulation, cognitive function, emotional processing, and sleep architecture (4).

Heart rate variability (HRV) has emerged as a reliable non-invasive marker of autonomic nervous system function. Reduced HRV reflects diminished parasympathetic activity and increased sympathetic dominance and has been associated with chronic stress, anxiety, and burnout (5). Research suggests that students experiencing examination-related stress exhibit significant reductions in HRV parameters, indicating autonomic dysregulation (6).

Cognitive performance is another important domain affected by academic stress. Reaction time, a measure of information processing speed and sensorimotor integration, is frequently used in neurophysiological studies. Elevated stress levels have been associated with slower reaction times due to impaired attention, working memory, and executive functioning (7). These changes may negatively influence academic performance and learning outcomes.

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Sleep quality is also closely linked with stress. Chronic academic stress often disrupts sleep patterns through increased physiological arousal and altered circadian regulation (8). Poor sleep quality further exacerbates cognitive impairment, emotional instability, and autonomic dysfunction, creating a vicious cycle of stress and reduced performance (9).

Several investigators have examined psychological stress among students; however, fewer studies have simultaneously assessed multiple neurophysiological parameters such as autonomic function, reaction time, and sleep quality. Understanding these objective correlates may provide valuable insights into the physiological burden of academic stress and help identify students at risk of adverse health outcomes.

Therefore, the present study aimed to evaluate the neurophysiological correlates of academic stress among undergraduate medical students by assessing HRV, cardiovascular parameters, reaction time, and sleep quality. Additionally, the study sought to determine the relationship between perceived stress levels and these neurophysiological measures.

Materials and Methods

A cross-sectional observational study was conducted in the Department of Physiology at a tertiary care teaching institution between January and June 2025.

Study Population

The study included undergraduate medical students aged 18–25 years. Participants were recruited through voluntary enrollment after obtaining informed consent.

Inclusion Criteria

- Undergraduate medical students aged 18–25 years.
- Apparently healthy individuals.
- Willingness to participate.

Exclusion Criteria

- History of neurological or psychiatric disorders.
- Cardiovascular diseases.
- Use of medications affecting autonomic function.
- Smoking or substance abuse.
- Acute illness during data collection.

Sample Size

Based on previous studies evaluating stress and HRV among students, a sample size of 120 participants was considered adequate to detect significant differences among stress categories with 80% power and 5% significance level.

Ethical Considerations

The study protocol was approved by the Institutional Ethics Committee. Written informed consent was obtained from all participants.

Assessment of Academic Stress

Perceived stress was assessed using the Perceived Stress Scale (PSS-10). The questionnaire consists of ten items rated on a five-point Likert scale. Total scores range from 0 to 40.
Participants were classified as:

- Low stress: 0–13
- Moderate stress: 14–26
- High stress: 27–40

Cardiovascular Assessment

Resting heart rate and blood pressure were measured after 10 minutes of seated rest. Blood pressure was recorded using a calibrated digital sphygmomanometer. Three readings were obtained and averaged.

Heart Rate Variability Analysis

HRV was recorded using a computerized ECG system in a quiet laboratory environment. Participants were instructed to avoid caffeine and strenuous exercise for 12 hours before testing.
The following parameters were analyzed:

Time-domain measures

- SDNN (ms)
- RMSSD (ms)

Frequency-domain measures

- LF power
- HF power
- LF/HF ratio

Reaction Time Assessment

Visual reaction time (VRT) and auditory reaction time (ART) were measured using a computerized reaction time apparatus.
Participants completed:

- Three practice trials.
- Five recorded trials.

Mean values were used for analysis.

Sleep Quality Assessment

Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI). A global score >5 indicated poor sleep quality.

Statistical Analysis

Data were analyzed using SPSS version 25. Continuous variables were expressed as mean ± standard deviation.
Statistical tests included:

- One-way ANOVA
- Post hoc Tukey test
- Pearson correlation coefficient

A p-value <0.05 was considered statistically significant.

Results

Table 1. Baseline Characteristics of Study Participants

Variable	Low Stress (n=35)	Moderate Stress (n=55)	High Stress (n=30)	p-value
Age (years)	20.3 ±1.4	20.8 ±1.5	21.0 ±1.3	0.321
BMI (kg/m²)	22.1 ±2.4	22.8 ±2.6	23.0 ±2.7	0.415
PSS Score	10.8 ±1.9	20.5 ±3.1	31.4 ±2.8	<0.001

No significant differences were observed in age or BMI among groups. Stress scores differed significantly according to group classification.

Table 2. Cardiovascular and HRV Parameters

Parameter	Low Stress	Moderate Stress	High Stress	p-value
Heart Rate (bpm)	72.4 ±5.6	78.3 ±6.2	85.6 ±7.1	<0.001
SBP (mmHg)	114.2 ±8.5	118.7 ±9.4	126.3 ±10.1	<0.001
RMSSD (ms)	48.5 ±10.2	36.4 ±8.9	24.8 ±6.7	<0.001
SDNN (ms)	58.7 ±11.1	46.9 ±9.5	31.2 ±8.2	<0.001
LF/HF Ratio	1.5 ±0.4	2.2 ±0.5	3.6 ±0.7	<0.001

Students with high stress demonstrated elevated heart rate, blood pressure, and LF/HF ratio, indicating sympathetic dominance. HRV parameters showed significant reduction, suggesting impaired parasympathetic modulation.

Table 3. Reaction Time and Sleep Quality

Parameter	Low Stress	Moderate Stress	High Stress	p-value
VRT (ms)	248 ±21	271 ±24	308 ±29	<0.001
ART (ms)	212 ±19	234 ±22	268 ±25	<0.001
PSQI Score	4.1 ±1.5	6.3 ±2.0	8.9 ±2.4	<0.001

High-stress students showed significantly prolonged reaction times and poorer sleep quality compared with low-stress participants.

Table 4. Correlation Between PSS Score and Neurophysiological Variables

Variable	Correlation Coefficient (r)	p-value
RMSSD	-0.61	<0.001
SDNN	-0.58	<0.001
LF/HF Ratio	+0.64	<0.001
VRT	+0.55	<0.001
ART	+0.49	<0.001
PSQI	+0.67	<0.001

Perceived stress demonstrated significant negative correlations with HRV parameters and positive correlations with reaction time and sleep disturbance.

Discussion

The present study investigated the neurophysiological correlates of academic stress among undergraduate medical students. The findings indicate that increasing stress levels are associated with significant alterations in autonomic nervous system function, cognitive processing speed, and sleep quality.

A major finding was the reduction in HRV indices among students with higher stress levels. RMSSD and SDNN, which primarily reflect parasympathetic activity, were significantly lower in the high-stress group. Similar findings have been reported by Kim et al., who observed reduced vagal modulation among students during periods of academic stress (10). Chronic stress activates sympathetic pathways and suppresses parasympathetic regulation, resulting in autonomic imbalance (11).

The increase in resting heart rate and systolic blood pressure observed in highly stressed students further supports sympathetic nervous system activation. Thayer and Lane proposed that reduced autonomic flexibility contributes to cardiovascular dysregulation during psychological stress (12). Persistent sympathetic dominance may predispose individuals to future cardiovascular morbidity.

The present study also demonstrated prolonged auditory and visual reaction times among students experiencing high stress. Stress-related increases in cortisol can affect attention, working memory, and executive functioning through their effects on the prefrontal cortex and hippocampus (13). Previous investigations have similarly reported slower cognitive processing during examination periods and high-stress conditions (14).

Sleep quality emerged as another important correlate of academic stress. Students with elevated PSS scores reported significantly poorer sleep quality. Lund et al. reported that academic demands and psychological stress contribute substantially to sleep disturbances among university students (15). Poor sleep can further impair cognitive performance and autonomic regulation, thereby amplifying stress-related dysfunction (16).

The observed correlations between perceived stress and neurophysiological variables indicate a dose-response relationship. Higher stress scores were associated with greater autonomic dysfunction, slower reaction times, and poorer sleep quality. These findings are consistent with the biopsychosocial model of stress, which proposes that psychological stress manifests through measurable physiological alterations (17).

The strengths of the present study include simultaneous assessment of multiple neurophysiological domains and the use of validated tools. However, several limitations should be acknowledged. The cross-sectional design prevents causal inference. Stress levels were assessed using self-reported measures, which may be influenced by reporting bias. Additionally, cortisol levels and electroencephalographic measures were not evaluated.

Future longitudinal studies incorporating neuroendocrine biomarkers and neuroimaging techniques may provide a more comprehensive understanding of stress-related neural adaptations in students.

Overall, the findings highlight the importance of implementing stress-management programs such as mindfulness training, physical exercise, yoga, and counseling services within educational institutions. Such interventions may improve autonomic balance, cognitive functioning, and overall well-being.

Conclusion

Academic stress is associated with significant neurophysiological changes among medical students, including reduced heart rate variability, increased cardiovascular activation, prolonged reaction times, and poor sleep quality. These findings suggest that academic stress affects both autonomic and cognitive functions. Early identification and intervention strategies aimed at stress reduction may improve student health, academic performance, and long-term well-being.

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