



Original Article

Changes in EEG Frequency and Dominant Wave Patterns Before and After University Examinations Among First-Year Medical Students: A Repeated-Measures Observational Study

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ABSTRACT

Background: University examinations are time-limited academic stressors capable of altering cortical arousal. Electroencephalography (EEG) provides a non-invasive measure of these neurophysiological changes. This study evaluated changes in EEG frequency and dominant wave-band distribution among first-year medical students before and after an examination period.

Methods: This repeated-measures observational study included 200 first-year medical students. Resting EEG recordings were obtained 15 days before and 15 days after university examinations using a computerized 32-channel system with international 10–20 electrode placement. Dominant frequency was summarized continuously and classified as theta (4–7.9 Hz), alpha (8–12.9 Hz), beta (13–30 Hz), delta (<4 Hz), or gamma (>30 Hz). Paired continuous measurements were compared using the paired t-test.

Results: Participants had a mean age of 19.48 ± 1.31 years; 100 (50.0%) were male and 100 (50.0%) female. Mean EEG frequency decreased from 15.96 ± 6.28 Hz before examinations to 14.70 ± 5.10 Hz after examinations. The paired mean change (after minus before) was -1.26 ± 8.55 Hz (95% confidence interval -2.45 to -0.07 ; $t=2.083$; $df=199$; $p=0.039$). The mean absolute within-participant change was 6.81 ± 5.31 Hz. Descriptively, beta-band predominance declined from 138 (69.0%) to 106 (53.0%), alpha-band predominance increased from 44 (22.0%) to 94 (47.0%), and theta-band predominance declined from 18 (9.0%) to zero.

Conclusion: EEG profiles changed significantly across the university examination period, with a small reduction in mean dominant frequency and a descriptive redistribution from beta/theta toward alpha-band predominance. These findings support the sensitivity of resting EEG to examination-period neurophysiological change, but do not by themselves establish causality or quantify stress severity.

Keywords: Electroencephalography; examination period; medical students; alpha rhythm; beta rhythm; academic stress; repeated measures.

INTRODUCTION

Medical education exposes students to a dense curriculum, repeated high-stakes assessment, time pressure, and concerns about academic performance. These demands can produce substantial psychological distress and may affect attention, sleep, memory, and well-being. Studies across medical schools have consistently identified academic workload and examinations as prominent stressors, particularly in the early years of training.^{1,2} Although questionnaire-based instruments

are valuable for estimating perceived stress, objective physiological measures can add information about cortical responses that are not fully captured by self-report.

Stress responses involve coordinated activation of the sympathetic-adreno-medullary system and the hypothalamic-pituitary-adrenal axis. The resulting catecholamine and glucocorticoid activity can modify attention, memory retrieval, and cortical network dynamics.^{3,4} The direction and magnitude of these effects depend on the timing, intensity, and duration of the stressor; consequently, examination-related neurophysiological responses may vary across individuals and across the examination cycle.⁴

EEG records the summed electrical activity of cortical neuronal populations with high temporal resolution and is therefore suitable for assessing dynamic changes in brain state.⁵ Standard scalp recordings use the international 10–20 system to provide reproducible electrode placement.⁶ Conventionally, resting EEG is interpreted using frequency bands: theta activity is associated with drowsiness and several cognitive processes, alpha activity with relaxed wakefulness and internally directed processing, and beta activity with alertness and active cognitive engagement. Alpha and theta oscillations also participate in attention and memory, so simple one-to-one interpretations of a frequency band as “stress” should be avoided.⁷

Previous studies have nevertheless shown that examination periods can be accompanied by measurable EEG alterations. Jena reported examination-related EEG changes in students,⁸ while Siripongpan and colleagues compared baseline and pre-examination recordings in medical students and found beta activity at both time points with frequency differences in a stress subgroup.⁹ Roy and colleagues demonstrated examination-proximity-related changes in EEG current-source density and relationships among EEG activity, cortisol, and memory performance.¹⁰ Such findings indicate that EEG may be responsive to the changing cognitive and emotional demands surrounding examinations, although protocols, recording intervals, outcomes, and analytic methods differ considerably.

Objective: To evaluate changes in EEG wave activity among first-year medical students before and after the university examination period.

METHODS

Study design and setting: This repeated-measures observational study was conducted from July 2024 to January 2026 in the Department of Physiology, in collaboration with the Department of Neurology, Jawahar Lal Nehru Medical College and its attached hospital, Ajmer, Rajasthan, India.

Participants: Two hundred first-year medical students were included. Eligible participants were students of either sex, aged 18–25 years, in good general physical and mental health, who provided written informed consent. Exclusion criteria were known anxiety or depressive illness; hypertension, diabetes, cardiac disease, neurological disease, or another chronic illness; alcohol or tobacco use; excessive caffeine intake; refusal of consent; or dissimilar examination preparation as defined in the thesis protocol.

Sample size: The thesis calculated a standardized mean difference of 0.21 using preliminary means of 9.80 and 9.54 with pooled SD 1.24. With a two-sided alpha of 0.05 and 80% power, the estimated sample was 178. After allowing 10% attrition, the target was rounded to 200.

EEG assessment: Participants underwent EEG at two prespecified time points: 15 days before and 15 days after university examinations. Recordings were obtained using a computerized 32-channel digital EEG system. Scalp electrodes were positioned according to the international 10–20 system.⁶ Conductive gel or paste was used to improve electrode contact. The protocol included resting baseline recording with eyes-closed and eyes-open responses; recording duration was approximately 15–30 minutes. Signals were amplified, digitized, filtered, and reviewed to minimize eye-movement, muscle, movement, and electrical artifacts. The recorded dominant frequency was expressed in hertz and categorized as delta (<4 Hz), theta (4–7.9 Hz), alpha (8–12.9 Hz), beta (13–30 Hz), or gamma (>30 Hz). These conventional bands permit clinically understandable description but do not replace quantitative spectral-power analysis.^{5,7,11}

Outcome: The primary outcome was the paired change in dominant EEG frequency (after examination minus before examination). Secondary descriptions within this article were the absolute magnitude of change and the distribution of dominant frequency bands at the two time points. No analysis by stress category, sex, age, or psychological score was included.

Statistical analysis: Data were analysed using SPSS version 19.0 (IBM Corp., Armonk, NY, USA), as documented in the thesis. Continuous data are presented as mean $\pm$ standard deviation (SD), median, range, and 95% confidence interval (CI), where available; categorical data are presented as number and percentage. The paired t-test compared mean dominant EEG frequency before and after examinations. A two-sided p value <0.05 was considered statistically significant.

Ethical considerations: Institutional Ethics Committee approval was obtained from Jawahar Lal Nehru Medical College before study commencement. All participants gave written informed consent.

RESULTS

Participant characteristics: All 200 records included in the thesis analysis were used. The mean age was 19.48 ± 1.31 years (median 19 years; range 18–25 years). The sample comprised equal numbers of male and female students (Table 1).

Change in dominant EEG frequency: Before examinations, mean EEG frequency was 15.96 ± 6.28 Hz; after examinations it was 14.70 ± 5.10 Hz. The paired mean change was -1.26 ± 8.55 Hz (95% CI -2.45 to -0.07). The paired t-test demonstrated a statistically significant difference ($t=2.083$; $df=199$; $p=0.039$). The absolute magnitude of individual change was 6.81 ± 5.31 Hz, showing substantial inter-individual variability despite the modest net mean reduction (Table 2).

Dominant frequency-band distribution: Beta was the most frequent dominant band before examination (69.0%) and remained the most frequent after examination (53.0%). Alpha predominance increased from 22.0% to 47.0%, whereas theta predominance decreased from 9.0% to zero. No dominant delta or gamma recordings were reported at either assessment (Table 3). These aggregate distributions do not identify which individual participants changed bands.

Table 1: Baseline characteristics of participants (n=200)

Characteristic	Value
Age, years, mean $\pm$ SD	19.48 ± 1.31
Age, years, median (range)	19.00 (17–25)
Male	100 (50.0%)
Female	100 (50.0%)

SD=standard deviation.

Table 2: Paired comparison of dominant EEG frequency before and after examinations (n=200)

Measure	Before examination	After examination	Paired (after–before) change
Mean $\pm$ SD, Hz	15.96 ± 6.28	14.70 ± 5.10	-1.26 ± 8.55
Median, Hz	15.00	13.00	–2.00
Range, Hz	4–28	8–28	–18 to 23
95% CI for mean, Hz	15.08 to 16.83	13.98 to 15.41	–2.45 to -0.07

Paired t-test for before-versus-after frequency: $t=2.083$; $df=199$; $p=0.039$. Mean absolute change= 6.81 ± 5.31 Hz (95% CI 6.07 – 7.55). CI=confidence interval; SD=standard deviation.

Table 3: Distribution of dominant EEG frequency bands before and after examinations (n=200 at each assessment)

Dominant frequency band	Before examination, n (%)	After examination, n (%)
Delta (<4 Hz)	0 (0.0)	0 (0.0)
Theta (4–7.9 Hz)	18 (9.0)	0 (0.0)
Alpha (8–12.9 Hz)	44 (22.0)	94 (47.0)
Beta (13–30 Hz)	138 (69.0)	106 (53.0)
Gamma (>30 Hz)	0 (0.0)	0 (0.0)
Total	200 (100.0)	200 (100.0)

DISCUSSION

This repeated-measures analysis found a statistically significant change in dominant EEG frequency across the university examination period. Mean frequency decreased by 1.26 Hz from the pre-examination to the post-examination assessment, while the mean absolute within-participant change was much larger (6.81 Hz). The distinction between net change and

absolute change is important: individual responses varied in direction, so opposing increases and decreases partly cancelled in the overall mean.

The categorical summary supported a redistribution of dominant rhythms. Beta remained the most common band, but its representation fell from 69% to 53%; alpha increased from 22% to 47%; and theta declined from 9% to zero. Because recordings were obtained 15 days before and 15 days after examinations, the post-examination assessment may reflect recovery, altered vigilance, sleep restoration, reduced anticipatory demand, or other examination-cycle effects rather than peak acute examination stress. The observed increase in alpha predominance after examinations is compatible with a comparatively more relaxed cortical state, but this interpretation is inferential and cannot be confirmed without concurrent stress scores or quantitative spectral measures.

The findings are broadly consistent with evidence that examination periods can alter EEG characteristics, although the direction and location of reported changes are not uniform. Jena described examination-related EEG alteration in students.⁸ In 60 Thai medical students, Siripongpan et al. compared baseline with a recording one week before examination; beta activity remained dominant, and the magnitude of frequency change differed by stress grouping.⁹ That study's pre-examination assessment captured anticipatory stress, whereas the present study compared assessments on either side of the examination period. These distinct timings may explain differences in direction and magnitude.

Roy et al. used repeated EEG measurements, salivary cortisol, memory testing, and source localization around examinations. They identified changes in medial frontal 19–20 Hz activity, examination-proximity-related parahippocampal activation, and relationships among lower-frequency parahippocampal activity, cortisol, and memory.¹⁰ Their work illustrates that stress-related EEG effects may be frequency-specific, region-specific, and time-sensitive. The present study used a simpler dominant-frequency summary, which is easier to interpret clinically but cannot localize cortical sources or quantify band power.

Alpha and theta activity should not be treated as exclusive labels for relaxation or stress. Alpha rhythms are influenced by eye closure, attention, inhibitory control, and task demands, while theta rhythms contribute to memory encoding and retrieval.⁷ Similarly, beta activity can reflect alertness and cognitive engagement but is also vulnerable to electromyographic artifact. Accordingly, the present data demonstrate a change in EEG profile across time; they do not establish that any single rhythm is a specific biomarker of psychological stress.

The paired design is a strength because each participant served as his or her own control, reducing between-person variability. The sample of 200 is also larger than several earlier examination-EEG studies.^{9,10} Standardized electrode placement and use of a consistent assessment framework further support internal comparability. However, the observed *p* value was close to the conventional threshold and the mean effect was modest relative to the wide SD of paired change. Clinical or educational significance should therefore not be inferred from statistical significance alone.

Several limitations require emphasis. First, no non-examination control group was included, so maturation, sleep, circadian variation, caffeine exposure, routine academic workload, and repeated-testing effects cannot be separated from examination-period effects. Second, the timing of 15 days after examinations does not measure the acute examination state. Third, detailed quantitative EEG spectral power, amplitude, coherence, topographic distribution, and artifact-rejection metrics were not available.

The findings support further longitudinal work with recordings at a low-stress baseline, immediately before examination, during the examination period where feasible, and after recovery. Future protocols should standardize time of day, sleep, caffeine, eye condition, impedance, filters, artifact rejection, and recording duration, and should report participant-level band transitions and quantitative spectral power. Such refinements would permit stronger conclusions about the temporal physiology of academic stress.

CONCLUSION

Among 200 first-year medical students, dominant EEG frequency changed significantly across the university examination period, decreasing from 15.96 ± 6.28 Hz before examinations to 14.70 ± 5.10 Hz after examinations. Beta predominance declined and alpha predominance increased descriptively. The results show examination-period EEG variability but should not be interpreted as proof of a causal stress effect or as validation of a single EEG band as a stress biomarker. Confirmation with standardized quantitative EEG, participant-level transition analysis, and contemporaneous stress measures is required.

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