Alleviating Chronic Stress in University Students: An EEG Analysis of Binaural Beat Therapy

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***Abstract*— The COVID-19 pandemic has significantly elevated chronic stress levels, especially among university students. This study examined the effectiveness of binaural beat auditory stimulation in reducing chronic stress, using both the DASS-21 questionnaire and electroencephalography (EEG) as measurement tools. Six students identified with high stress were randomly assigned to one of three four-week interventions: alpha binaural beat music, beta binaural beat music, or non-binaural beat control music. EEG analysis revealed a general increase in power spectrum across all groups, indicating changes in brainwave activity. Notably, a significant increase in sample entropy—a measure of neural complexity—was observed exclusively in the alpha binaural beat group by week four. Correspondingly, this group showed the greatest reduction in self-reported DASS-21 stress scores. These findings suggest that alpha binaural beat stimulation promotes effective neural entrainment and is more successful than beta or non-binaural beat stimuli in alleviating chronic stress among university students. This study highlights the potential of binaural beat auditory stimulation as a non-invasive tool for improving mental health.**

***Index Terms*— Binaural Beats, Brainwaves, Chronic Stress, Electroencephalography (EEG), Neural Entrainment, Mental Health**

I. Introduction

The mental health of university students is a critical public health concern, particularly in the post-COVID-19 era. Alarming statistics from a 2022 survey of student health behaviors in Thailand revealed that 40% reported frequent stress, 30% experienced sadness, and significant proportions exhibited self-harm, suicidal ideation, and diagnosed mental illness. Compounding this, student suicides have increased, with a disproportionate number occurring in 2021 [1]. These findings emphasize the profound impact of mental health challenges on student well-being, which are inherently linked to brain function and neurophysiological states.

Neuroscience research has established a clear correlation between electroencephalography (EEG)-measured brainwave activity and emotional/behavioral states. Delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz), and gamma (>30 Hz) frequencies correspond to sleep, drowsiness, relaxation, alertness, and heightened focus, respectively [2]. Chronic stress elevates EEG frequencies, potentially leading to adverse effects like sleep disturbances. Conversely, auditory stimulation, notably music, modulates brain function and promotes positive neurochemical release [3].

Binaural beat auditory stimulation, involving the presentation of slightly offset frequencies to each ear, has emerged as a promising technique for brainwave entrainment. The resulting perceived frequency difference is hypothesized to drive neural oscillations towards target frequencies. For instance, a 10 Hz difference (alpha range) is theorized to enhance alpha activity, promoting relaxation [4]. This study investigates the efficacy of alpha and beta binaural beat stimulation in mitigating chronic stress among university students, utilizing EEG and self-reported measures to assess neurophysiological and psychological outcomes.

To comprehensively assess the neurophysiological impact of binaural beat auditory stimulation, this study employed a multi-faceted electroencephalographic (EEG) analysis. Specifically, we utilized: (1) Time-Frequency Analysis, which visualizes changes in spectral power over time, allowing for the identification of event-related spectral perturbations (ERSP) through color-coded spectrograms reflecting deviations from baseline activity [5]; (2) Sample Entropy, a measure of signal complexity and irregularity, particularly sensitive to non-linear dynamics often present in biological signals like EEG, thereby providing insights into the level of disorder or randomness in brain activity [6]; and (3) Mean Power Analysis, which quantifies the power distribution across different frequency bands, revealing changes in the amplitude of specific brainwave components [7].

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Building upon prior research demonstrating the influence of binaural beat auditory stimulation on brainwave activity, this study investigated the effects of alpha and beta binaural beats, embedded within piano music, on chronic stress in university students. We hypothesized that binaural beat stimulation would elicit measurable changes in EEG parameters, reflecting stress reduction, compared to a non-binaural beat control condition. This research seeks to explore the potential of binaural beat music as an accessible and effective intervention for stress management by examining the neurophysiological and psychological outcomes in a population highly vulnerable to stress.

II. METHOD

A. Participants

Six university students (n=6), aged 18 to 25 years (M=21.5), participated in this study. The participants were purposively recruited through faculty announcements and provided informed consent prior to enrolment. Inclusion criteria required participants to: (1) be currently enrolled university students, (2) score within the "severe" to "extremely severe" range on the stress subscale of the Thai version of the Depression, Anxiety, and Stress Scale-21 (DASS-21), indicating clinically significant stress levels, and (3) report no history of neurological or auditory disorders. The participants were excluded if they reported current use of psychoactive medications or a history of substance abuse.

Following baseline DASS-21 assessment, the participants were randomly assigned to one of three experimental groups using a simple randomization procedure:

Group 1 (Alpha Binaural Beat Group): the participants listened to binaural beat music with frequencies designed to induce alpha brainwave activity (8-12 Hz) [8].

Group 2 (Beta Binaural Beat Group): the participants listened to binaural beat music with frequencies designed to induce beta brainwave activity (12-30 Hz) [8].

Group 3 (Non-Binaural Beat Control Group): the participants listened to piano music without embedded binaural beats.

All participants confirmed the absence of any self-reported hearing impairments or difficulties prior to their participation.

B. Binaural Auditory Stimuli

To examine the impacts of binaural beat therapy on chronic stress, three 10-minute auditory stimuli were developed by the RSU Music Academy Conservatory of Music. Three different types of piano music included: (1) an alpha binaural beat stimulus with frequencies of 8 Hz; (2) a beta binaural beat stimulus with frequencies of 15 Hz; and (3) a non-binaural beat control stimulus consisting solely of piano music, designed to isolate the independent effects of the music.

To ensure participants received the binaural beat stimuli accurately, high-fidelity JBL T110 in-ear headphones (9mm drivers) were used. The target binaural beat frequencies were verified using spectral analysis with MATLAB (R2019a) in order to confirm their presence in the alpha and beta stimuli and absence in the control.

C. Data Collection

Electroencephalography (EEG) Data Acquisition

EEG data were collected using the OpenBCI Cyton Biosensing Board (OpenBCI, Inc.), an 8-channel wireless EEG system. Electrode placement followed the 10-20 international system, with electrodes positioned at Fp1, Fp2, F3, F4, T3, and T4. Conductive gel was used to ensure low impedance between the electrodes and the scalp. To eliminate minor noise signals, the Filter function in EEGLab was employed. A bandpass filter with cut-off frequencies of 0.5 Hz and 30 Hz was applied to isolate the desired frequency range. Subsequently, a notch filter with cut-off frequencies of 49.5 Hz and 50.5 Hz was used to remove unwanted electrical noise. The raw EEG data were acquired and visualized using the OpenBCI GUI software (version 5.0.5) in real-time. The acquired data were subsequently exported in Excel (.xlsx) file format for offline analysis using MATLAB (R2019a) software.

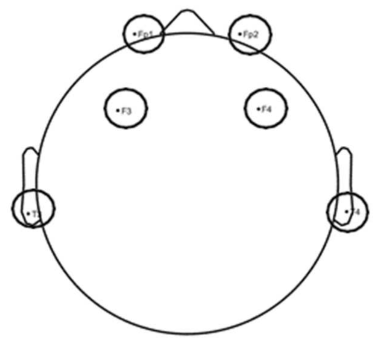

Fig. 1. The positions of the six-channel electrodes.

DASS-21 Data Acquisition

The participants completed the Thai version of the Depression, Anxiety, and Stress Scale-21 (DASS-21), a self-report questionnaire comprising 21 items. The DASS-21 assesses three distinct subscales: depression (D), anxiety (A), and stress (S), each consisting of 7 items. Participants rated each item on a 4- point Likert scale, ranging from 0 (did not apply to me at all) to 3 (applied to me very much). This study focused primarily on the stress subscale (S), which measures the severity of tension, irritability, and difficulty relaxing. The DASS-21 was administered at baseline, week 4 to assess changes in stress levels over the course of the intervention. A reduction in scores indicates a positive change.

D. Experimental Protocol

This four-week study was designed to investigate the impact of binaural auditory stimulation on chronic stress, employing three sessions of electroencephalography (EEG) and auditory stimulation at three different times (i.e., baseline, week 2, and week 4), alongside two administrations of the Depression, Anxiety, and Stress Scale-21 (DASS-21) at baseline and week 4. During each EEG and auditory stimulation session, the participants underwent EEG recording using the OpenBCI system, as detailed in Section C. To minimize external interference, recordings were conducted in a quiet, dimly lit room. The participants listened to their assigned auditory stimulus—alpha binaural beat, beta binaural beat, or non-binaural beat control—through high-fidelity stereo headphones for 10 minutes. Five-minute baseline EEG recordings were acquired both before and after each auditory stimulation period.

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The participants completed the Thai DASS-21 at baseline and week 4, providing self-reported measures of stress, anxiety, and depression. To ensure adherence to the daily protocol—listening to their assigned stimulus for 30 minutes daily before bedtime throughout four weeks—daily reminders were delivered via the Line application. Participants were blinded to their group assignment, determined by a simple randomization method. The non-binaural music control group served as the control. Following data collection, EEG data (Excel) were analyzed using MATLAB (R2019a) software and DASS-21 scores were tabulated in spreadsheets for statistical analysis.

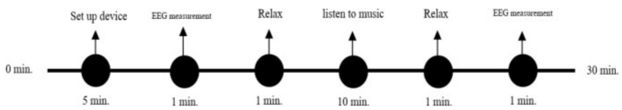

Fig. 2. Detailed protocol for EEG data collection and processing.

The details for the EEG data collection and processing protocol outlines the experimental procedure as depicted in the Time diagram of Figure 2. Initially, the participants underwent preparation and electrode placement, where an EEG electrode cap or individual electrodes were attached to their scalp according to the 10-20 international system, ensuring impedance levels remain below 5 kΩ using conductive gel. In-ear headphones were then fitted for audio delivery, and the participants were instructed to minimize movement and relax throughout the session. Subsequently, a 1-minute resting-state EEG recording was obtained, serving as the baseline, with participants fixating on a designated reference point. Following this, a 1-minute resting period allowed brain activity to stabilize before the music stimulus. The experiment proceeds with a 10-minute presentation of the pre-selected music stimulus through the headphones, maintaining a consistent and comfortable volume. After the music ended, the participants rested for another minute, continuing to focus on the reference point. Finally, a 1-minute post-stimulus EEG recording was conducted immediately after this resting period.

E. EEG Analysis

The analysis of acquired EEG signals involved a multi-stage process. The initial stage of EEG data analysis involved pre-processing the raw data for subsequent analysis. Using EEGLab software, specific data channels, namely channels 1 through 6, were selected to isolate the relevant EEG signals for this study. Subsequently, the positions of the EEG electrodes for each channel were adjusted within EEGLab to ensure accurate spatial representation, aligning them with the standard 10-20 system locations: Fp1, Fp2, F3, F4, T3, and T4, as depicted in Figure 1. These locations, covering the frontal and temporal brain regions, are particularly relevant for studies investigating auditory stimuli and relaxation. The 10-20 system, an internationally recognized electrode placement method, ensures standardized and comparable EEG data. Following this pre-processing, custom MATLAB scripts were developed to extract and average key features: Time-frequency, Sample Entropy, and Mean Power, for further statistical analysis, as detailed in Figure 3.

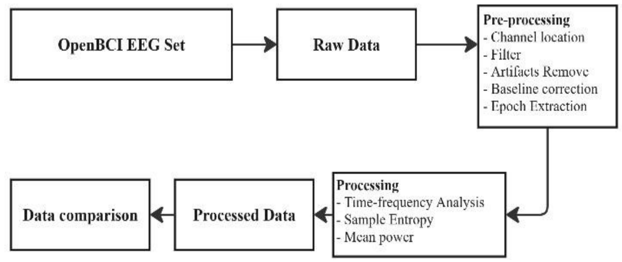

Fig. 3. EEG data processing diagram.

III. RESULTS

A. DASS-21 Mental Health Assessment

The study evaluated stress levels before and after exposure to three different types of music stimuli—alpha binaural beats, beta binaural beats, and non-binaural beat music—using the DASS-21 (Depression Anxiety Stress Scales – 21 items). Each group consisted of two participants, and results showed a noticeable reduction in mean stress scores across all groups after four weeks of nightly music listening. The average stress scores decreased as follows:

Alpha binaural beats: from 15.0 to 4.0

Beta binaural beats: from 17.5 to 10.0

Non-binaural beats: from 15.0 to 10.5

These reductions suggest that all three music types may contribute to stress relief, with alpha binaural beats having the most pronounced effect. This aligns with the theory that alpha-frequency stimulation promotes a relaxed mental state, which in turn helps reduce perceived stress more effectively than other stimuli.

B. Time-frequency Analysis

To investigate neural responses to the music interventions, Event-Related Spectral Perturbation (ERSP) analysis was performed using EEG recordings. This method measures changes in brainwave energy across various frequency bands in response to auditory stimuli. EEG signals were recorded at the T3 electrode site, located over the left temporal lobe—an area key to auditory processing and emotional regulation. Measurements were taken at three time points: Week 0 (baseline), Week 2, and Week 4.

As shown in Figure 4, the results revealed that the binaural beat music groups (alpha and beta) exhibited a progressive increase in energy within the target frequency bands over the four-week period. This trend suggests enhanced neural entrainment and deeper engagement with the auditory stimuli. In contrast, the non-binaural beat music group showed minimal changes in spectral energy, indicating a weaker influence on brainwave synchronization and stimulation.

Furthermore, at Week 4, the distribution of the frequency spectra displayed an expanded red area, representing a broader spread of spectral energy compared to Week 0, prior to the intervention. This finding implies increased neural activity and wider frequency engagement following repeated exposure to the music stimulus.

Overall, these observations support the idea that binaural beats can more effectively enhance frequency-specific brain activity, thereby promoting cognitive and emotional modulation beyond what conventional music alone can achieve.

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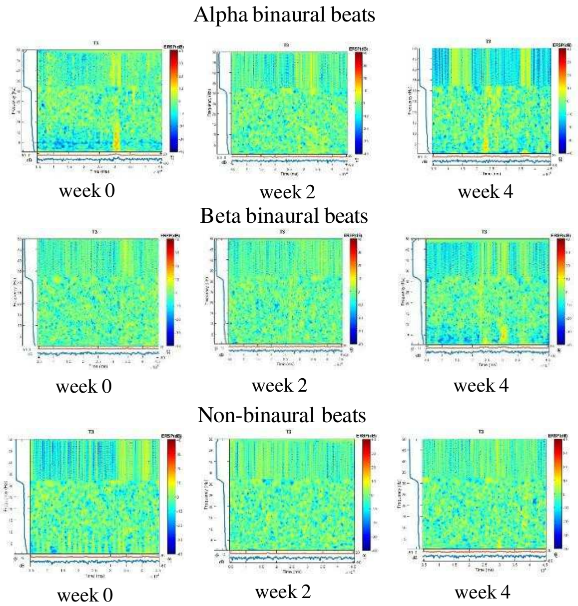

Fig. 4. ERSP of EEG energy at T3 electrode in weeks 0, 2, and 4.

C. Sample Entropy Analysis

Sample Entropy (SampEn) was analyzed to assess the complexity and irregularity of the EEG signals, providing insight into the dynamical behavior of brain activity during the music interventions. Using a MATLAB program, the raw EEG data were processed through established entropy calculation algorithms to quantify the unpredictability within the brainwave patterns.

The average Sample Entropy values were then computed for each participant and summarized graphically in Figure 5. Higher Sample Entropy values indicate greater signal complexity and more variable neural activity, which can reflect a flexible and adaptive brain state. Conversely, lower values suggest more regular and predictable brain patterns, often associated with reduced cognitive flexibility.

This analysis allows us to compare how different types of music—such as alpha binaural beats, beta binaural beats, and non-binaural music—affect the complexity of brain activity over the course of the intervention.

D. Mean Power

The frequency component analysis of the EEG signals involves decomposing the overall power spectrum to quantify the contributions of specific brainwave frequency bands, particularly the alpha and beta bands. This process allows us to assess the relative strength or dominance of these frequency components within the brain's electrical activity.

Specifically, the mean alpha power and mean beta power values were computed to evaluate how the different music stimuli influenced brainwave intensity and neural synchronization.

The results are summarized and visualized in Figure 6, illustrating the changes in mean power over the course of the experiment. An increase in mean power within a particular band suggests enhanced neural synchrony and engagement in that frequency range, which is often linked to specific cognitive and emotional states—such as relaxation for alpha waves or alertness and focus for beta waves.

This analysis provides valuable insight into how binaural beats and other musical stimuli modulate brain activity, highlighting potential mechanisms underlying their effects on stress and cognitive function.

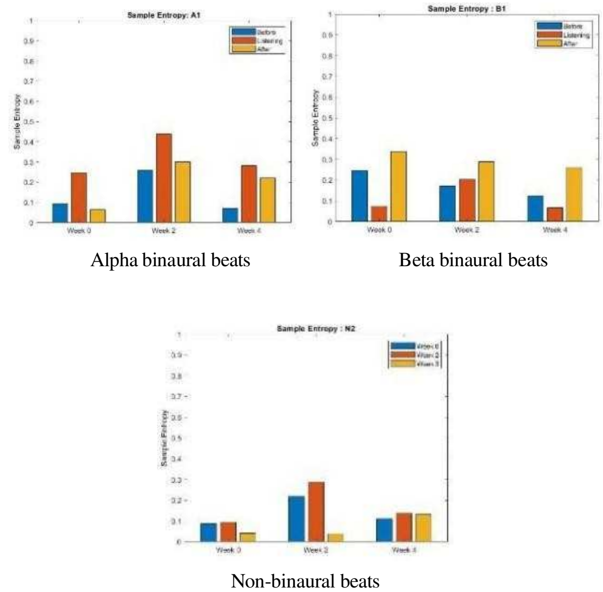

Fig. 5. Sample entropy in three groups.

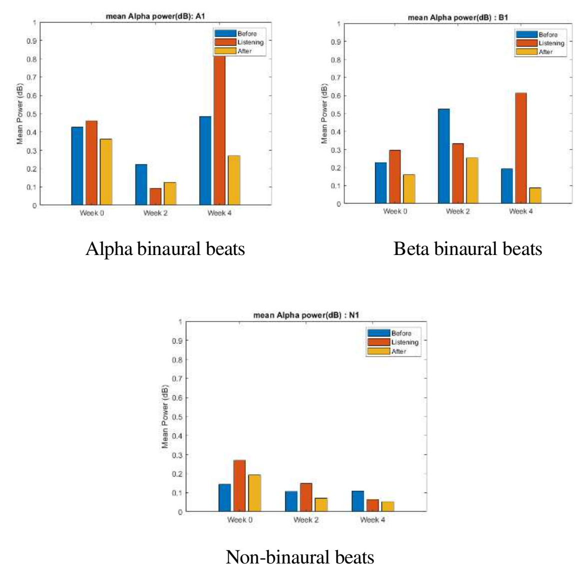

Fig. 6. Samples of mean power in three groups.

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IV. Discussion

A. DASS-21 Mental Health Assessment

The study demonstrated a notable reduction in DASS-21 stress scores across all volunteer groups after a four-week intervention involving bedtime music listening. These findings suggest that music, particularly when paired with binaural beat therapy, may alleviate stress-related symptoms.

The most remarkable improvement was observed in the group that listened to alpha-frequency binaural beats. This group experienced the greatest reduction in stress scores, lending strong support to the hypothesis that alpha waves (8–12 Hz), which are associated with a relaxed and calm mental state, can be effectively stimulated through binaural beats. This enhanced alpha activity likely contributed to the observed improvements in psychological well-being.

B. Time-frequency Analysis

Time-frequency analysis of the music stimuli revealed that the frequency spectrum of music with binaural beats increased in intensity after the intervention, indicating a measurable auditory stimulation effect. In contrast, the frequency spectrum of music without binaural beats remained unchanged before and after the experiment, suggesting that binaural beats may actively modulate brainwave activity through auditory entrainment, whereas regular music alone does not elicit this effect.

C. Sample Entropy

The results showed that exposure to alpha-frequency binaural beats and non-binaural beat music both led to an increase in sample entropy, indicating greater complexity and variability in brain signal patterns, often associated with a healthier or more adaptive brain state. Conversely, listening to beta-frequency binaural beats resulted in a decrease in sample entropy, which could indicate reduced variability or adaptability in neural responses—possibly reflecting a more alert or focused but less relaxed state.

D. Mean Power

After four weeks, the mean power of brainwave activity increased significantly in participants who listened to alpha-frequency binaural beats, suggesting heightened neural engagement in the alpha band, associated with relaxation and reduced stress. The beta-frequency binaural beats, however, did not produce any measurable change in mean power. In contrast, participants exposed to music without binaural beats exhibited a decrease in mean power, possibly indicating a lower level of neural activation or engagement by the end of the study period.

E. Effect Size and Limitations

Although inferential statistical tests were not performed due to the small sample size ($n = 6$), effect sizes were calculated to estimate the magnitude of observed changes. In the alpha binaural beat group, the mean stress score dropped from 15 to 4, resulting in a Cohen's d of 4.4—a value that indicates an extremely large effect size.

These preliminary but promising results suggest that alpha-frequency binaural beats may significantly reduce perceived stress. However, due to the limited sample, further studies with larger participant groups are necessary to confirm these findings and establish statistical significance.

V. Conclusion

This study explored the impact of three types of music—alpha binaural beats, beta binaural beats, and non-binaural beat music—composed and co-designed by the RSU Music Academy Conservatory of Music. All three types of music were found to contribute to stress reduction among participants. However, the alpha binaural beats demonstrated the most substantial effect, confirming previous research on the benefits of binaural beat stimulation in stress management using functional near-infrared spectroscopy (fNIRS) [9].

The superior effectiveness of alpha binaural beats can be attributed to their alignment with alpha brainwave frequencies (typically 8–12 Hz), which are known to promote relaxation, calmness, and a meditative mental state. This makes them particularly suitable for alleviating stress that accumulates throughout the day. On the other hand, beta binaural beats (typically 13–30 Hz) are more associated with increased alertness, focus, and cognitive engagement. While beneficial for learning and attention enhancement, beta waves may not be as effective in stress relief. This distinction is consistent with existing studies on how EEG activity changes in response to alpha and beta binaural beats [9].

Additionally, the findings suggest that individual preferences and emotional responses to music may influence brainwave changes. This was observed in the variation of sample entropy and mean power values across participants. For some individuals, these values increased notably upon first exposure to the music, indicating a strong initial cognitive or emotional response. These personal differences highlight the subjective nature of music perception and its interaction with neurophysiological responses.

Given these observations, it is recommended that future studies expand the range of musical genres and styles examined. Investigating other types of music—including classical, ambient, nature-inspired, or culturally specific genres—may provide deeper insights into how music interacts with brainwave activity and emotional regulation, especially in stress-related contexts.

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