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Investigation of the effect of alpha wave-containing music on the cognitive performance and brain activity of university students

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Abstract:

Cognition is one of the most vital brain functions, which ranges from assisting students in recalling what they have been taught to assisting us in concentrating while accomplishing chores. Nowadays, many jobs require advanced cognitive abilities, particularly among high school and university students. As a result, preserving or improving our cognitive abilities has become necessary in modern society. Alpha-wave music, which targets the brain frequency range from 8 to 12 Hz, is a promising approach to boosting cognitive performance. The purpose of this study is to evaluate the immediate, short term, or long term effects of alpha wave music on the cognitive performance and brain activity of students. In an online experiment, two groups of students were recruited and randomized into control and experimental groups. The experimental group was required to listen to alpha music for two weeks (here called the intervention). Participants from both groups will have their cognitive performance assessed before, immediately after, and two weeks following the intervention. In the immediate effect experiment, another group of participants have their alpha relative power evaluated while performing different tasks. The results of the online experiment revealed that feedback from participants listening to alpha music are mostly positive, while the response time of cognitive tasks indicated an improvement trend ($p<0.05$). The positive potential of alpha music was also confirmed with the immediate effect study where the alpha power was higher during alpha music exposure than during the remaining sessions. In conclusion, this study provided preliminary evidence to support the implementation of alpha music intervention to improve the cognitive function of students.

Keywords: **alpha music, cognitive performance, electroencephalography, university students.**

Classification number: **3.6**

Introduction

Cognitive function is a set of human capacities such as concentration, memory, mathematical calculations, and verbal or non-verbal language decisions, which all imperatively contribute to the learning and working process. Undoubtedly students face complex examinations and competition pressure from peers and frequently utilize cognitive functions throughout their academic performance and daily life. Consequently, their productivity and academic score may gradually decrease without proper techniques to enhance their cognitive performance in these environments [1, 2]. To ameliorate those adverse effects, continuous training to strengthen and enhance cognitive abilities has been implemented to accelerate students' working productivity [3, 4]. Therefore, finding a feasible and effective intervention is demanded by students to improve their cognitive functions.

Alpha wave-containing music is considered a promising solution, which applies the principle of alpha brainpower within the frequency range of 8 Hz to 12 Hz. Fundamentally, the alpha wave represents states of relaxation and consciousness that manifests itself as decreased anxiety and increased creativity [5]. The alpha wave-containing music operates based on binaural beats, which comprise two distinct sound frequencies transmitting into each ear, for instance, 200 Hz in the right ear and 210 Hz in the left ear. Eventually, an alpha wave of 10 Hz is generated by the brain when the listeners are listening to the music in an enclosed environment by using earphones or headphones [1, 6]. In the relationship between cognitive performance and brain activity, alpha waves in the frontoparietal area have a strong connection with short-term memory [7], working memory [8, 9], and analytical capabilities [10]. Furthermore, some studies suggest that individuals in the

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experimental group could considerably raise their upper alpha power (9.5-12 Hz) when listening to alpha music whereas the control group did not [11, 12], which indicates an increase in the relaxation state of the experimental group. However, there has not been a meticulous investigation of how alpha music improves the cognitive performance of the Vietnamese population, especially university students. Moreover, previous studies have not investigated the changes in brain wave activity when listening to alpha music versus other music genres.

Therefore, this study aims to assess the effect of alpha music therapy on improving the cognitive function of Vietnamese university students in the short-term and the long-term aspects. By using cognitive tasks, we will examine the performance outcomes of the applied tasks after listening to alpha music for at least 30 minutes/day for 14 days. Moreover, subjective responses to alpha music would also be collected from the experimental group. Regarding the immediate effect experiment, the comparison of alpha relative power in alpha music listening sessions with control music can examine the instantaneous effect of alpha music on the subject. From the obtained results, a conclusion of whether alpha music could be applied broadly in academic settings can be formed.

Methodology

Experimental design

The experiment included two types of data collection: an online experiment that evaluates short term and long term effects using remote data collection and an immediate effect experiment using on-site data collection, which assesses the Electroencephalography (EEG) signal. The protocol used for the immediate effect subjects would not be applied in the online experiment and vice versa.

Online experiment: the experimental group and control group data collection were conducted on an online platform under the supervision of technicians due to the impact of the Covid-19 (Fig. 1A). Subjects were required to attend three evaluating sessions, and the protocol was similar in each session: They were asked to perform two cognitive tasks: operation span task (12 trials) and matrix span task (16 trials) (see section 3). After the first session (week 1) finished, the experimental group was asked to listen to the alpha wave containing music for two weeks (14 days) for at least 30 minutes each day before the start of the second session (week 3). After the week 3 data collection, the experimental group was required to stop listening to alpha music. The third session (week 5) was conducted to examine the sustained effect of alpha music.

Immediate effect experiment: subjects participated in only one session, in which EEG acquisition was recorded using Philips Respironics Alice 6 and Sleepware G3 application. Before conducting the experiment, subjects were required to listen to alpha music for one week (seven days) for at least 30 minutes per day at home. Subsequently, they attended the eight stages of EEG data collection: bio-calibration, resting phase (3 minutes), listening to control music, 1st operation span task, 1st 30-second rest, listening to alpha music, 2nd operation span task, 2nd 30-second rest (Fig. 1B). Regarding the "control music", subjects were allowed to choose music based on preference, for which the song duration was limited to 5 minutes. After finishing listening to the chosen music, they would do the operation span task (12 trials) and rest for 30 seconds afterward. Sequentially, subjects listened to alpha wave-containing music for the same period (5 minutes) and repeated the same task, then ended with a 30-second resting phase.

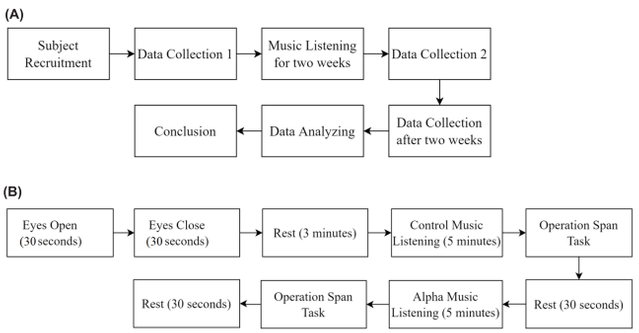

Fig. 1. (A) Data collection protocol for the short term and long term experiments and (B) data collection protocol for the immediate effect experiment.

Subject recruitment

Forty students with age range from 18 to 22 years old studying at International University were recruited (male n=15, mean age=20.5 years old; female n=32, mean age=19 years old). All participants met the following criteria: right-handed, with no visual impairment, non-smoking, and not using substances like depressants, inhalants, or stimulants, which have detrimental effects on the nervous system. After signing the consent form, the 40 subjects who participated in the online experiment were randomly assigned to two groups: the experimental group, which listens to alpha music (n=20) and the control group that will not listen to alpha music (n=20). In the final data collection session (week 5), the total number of remaining subjects was 20 (n=10 for the experimental group and n=10 for the control group).

On the other hand, the immediate effect experiment included seven subjects (immediate group) who listened to alpha music while recording EEG data (n=7) and met the same requirements as the online experiment.

This study was approved by the Institutional Review Board - IRB of the School of Biomedical Engineering, International University, Vietnam National University, Ho Chi Minh city.

Cognitive tasks

The content of the operation span and matrix span tasks primarily focuses on testing comprehensive cognitive functions, including memorizing capacities and calculation skills, which students frequently use in their academic performance and daily life.

Since the main scope of the study is to estimate the improvement of cognitive functions of students after listening to alpha music, these chosen tasks are suitable for our experiment [13].

The operation span task aims to evaluate the memory and attention capacity of the subjects, and it consists of two tasks (remembering and arithmetic tasks) (Fig. 2A and 3A) [13-15]. In the remembering task, the screen displays a random number to memorize. Subsequently, the arithmetic task shows a mathematical calculation and requires subjects to confirm accuracy by pressing the left and right arrows on the laptop keyboard. The process is repeated for the following rounds. After reaching the final round, the subjects are asked to type the numbers that appeared in chronological order. The first trial begins with three rounds, then the numbers and calculations gradually increase after two trials, ending after 12 trials.

The matrix span task examines spatial, memory, and attention ability (non-verbal memory) [13-15]. In this task, participants must memorize the location of a coloured box that randomly appears on the screen and use their mouse to click the exact location of the box on a blank 4x4 grid, in chronological order. After every three trials, the number of coloured boxes increased by one unit and the experiment ended after 16 trials (Figs. 2B and 3B). In both tasks, subjects were informed of which trial they were attempting and the accuracy of their answers at the top of the screen (Figs. 3C and 3D).

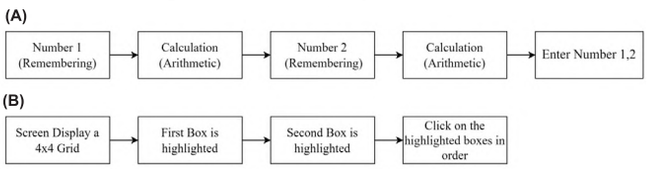

Fig. 2. (A) Operation span task and diagram of the first three trials; (B) Matrix span task and diagram of the first three trials.

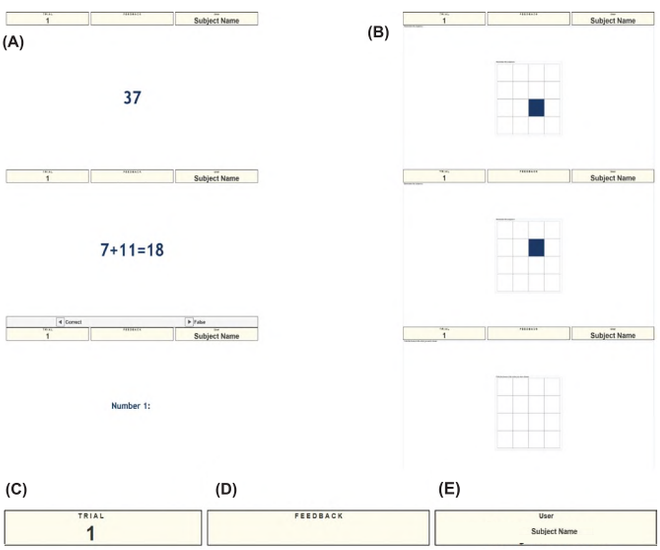

Fig. 3. Illustration of (A) operation span task and (B) matrix span task; header bar for the two cognitive tasks with (C) trial numerical order, (D) feedback from subject's answer, and I subject's name or identification number.

EEG signal acquisition

For the immediate effect study, a Philips Respironics Alice 6 (Fig. 4A) device was utilized for EEG recording. Ten main channels (Fig. 4B), namely, Fp1, Fp2, F7, F8, F3, F4, T5, T6, O1, O2, EOG1, and EOG2, were selected. Each channel represents a brain area: Fp stands for Pre-frontal; F stands for Frontal; T stands for Temporal; O stands for Occipital; and EOG for Electrooculogram.

During EEG acquisition, subjects were asked to restrain body movements to limit electromyography (EMG) noises. Moreover, continuous supervision during data recording was necessary to detect any possible abnormalities in the recorded channels and guarantee their stability for subsequent noise removal.

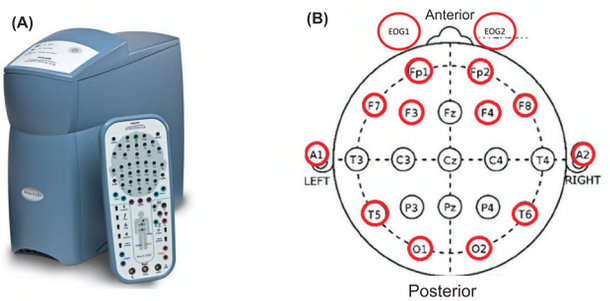

Fig. 4. (A) The ALICE 6 Device and (B) the selected EEG channels for measurement [16].

Signal processing and EEG power calculation

During the EEG acquisition, several instances of noise were caused by eye blinking (EOG noise) as well as head orientation and neck muscle electromyography (EMG noises), which can lead to incorrect data and an inaccurate calculation of EEG power. Consequently, the designed protocol utilized the EEGLAB toolbox (shown in Fig. 5), which enhances signal quality and aids the EEG power computing accuracy by implementing noise removal techniques. A bandpass filter was the first filter technique applied and it confines the collected data within a desired frequency range, which is between 0.5 and 45 Hz in this study. The reason for choosing these limits is that they cancel out noise contributions beyond the neurological range (EMG noise). The sequential noise filter technique uses independent component analysis (ICA), which involves separating a variety of signals (independent signal sources) into statistically-independent and non-Gaussian signal components [17]. After applying both techniques, the data was segmented to calculate the relative alpha band power. Based on the protocol, the segmented sessions are 30-s rest; 3-min rest; music listening - either control or alpha music; operation span task; and eyes open/eyes closed.

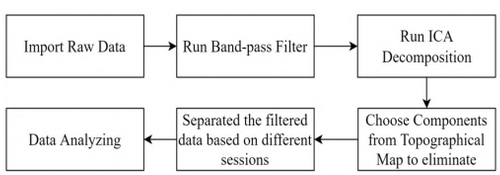

Fig. 5. Electroencephalogram noise filtering protocol.

An EEG's relative power is a fundamental EEG feature, which is defined as the ratio between the total power of all bands and the overall energy intensity of an electrode on a specific region at different frequency bands [18-20]. In addition, the relative power is frequency band power expressed as a percentage of the total signal power. Specifically, the calculation of alpha relative power in this study will enable an understanding of the percentage of total signal power in the alpha frequency range in different sessions [21]. The "EEGLAB" toolbox in MATLAB was utilized for calculating the relative power of each brain wave in each session. The frequencies are defined as follows: Delta from 1 to 4 Hz, Theta from 4 to 8 Hz, alpha from 8 to 12 Hz, and beta from 12 to 30 Hz.

$$\text{Alpha band relative power} = \frac{\text{Alpha band absolute power}}{\text{Total absolute power}}$$

Statistical analysis

The statistical analysis was performed in GraphPad Prism 8.0 software. Two-way ANOVA and multiple comparisons were applied to compare performance scores and response time in the cognitive tasks between the experimental group and control group. The statistics used to evaluate the (sustained) impact of the intervention confirmed a difference between the two groups and the results in each session within a group. For the EEG data, the analysis of the relative power is illustrated based on observations of the trendlines and a comparison of each session of EEG alpha relative power. This is because statistical analysis cannot be used due to the inadequate number of subjects. The analyses described below demonstrated significant results with p-value <0.05, which is represented by the star (*) in column graphs (see Fig. 7D).

Results

Students' feedback after listening to alpha music

The purpose of collecting a student's subjective estimation about the alpha music was to understand the personal reaction of the student to the intervention. Most of the experimental subjects gave positive feedback after two weeks, such as increased relaxing state, eased mind, and improved sleep quality (Fig. 6). On the other hand, a few subjects (15%) reported being uncomfortable with the intervention while others gave neutral feedback (15%) while listening to the alpha music. Detailed feedback is included in Supplementary Table 1.

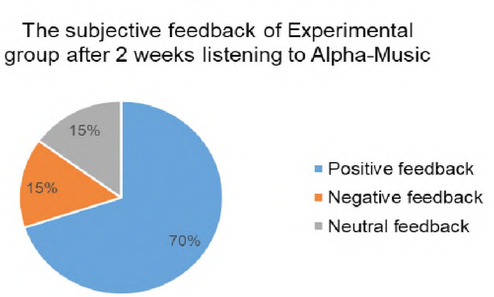

Fig. 6. Pie chart of feedback from the experimental group after listening to alpha music for two weeks.

The effect of alpha music intervention on improving cognitive function

Because the main goal of the study was to observe the cognitive improvement of students, we hypothesized that the short-term and long-term effects of alpha music in enhancing cognitive functions could be demonstrated after 14 days of listening to alpha music [10]. To validate this hypothesis, a designed a set of cognitive tasks including operation span task and matrix span task and applied Two-way ANOVA to confirm the effects of our proposed intervention are done.

Short term effect

Arithmetic task-operation span task: There were no differences detected in the accuracy of the task for the experimental group during the two-week alpha music listening period. Average accuracy for the experimental group in weeks 1 and 3 were 40.15±1.46; 40.15±1.63, respectively; p>0.99. On the other hand, the accuracy marginally decreased for the control group. The average accuracy for the control group was 40.6±1.79; 40.35±1.39. respectively, p=0.78 (Fig. 7A).

Unlike the remembering task's results, both groups displayed a reduction in completed time; however, only the experimental group showed a significant reduction. The average completion time for the experimental group before and after listening to alpha music was 2.34±0.73; 2.10±0.69 with p=0.05 (Fig. 7D). Based on the significant decrease in response time with the experimental group, we can conclude that the mathematic calculation skills of the subjects mildly improved.

Remembering task-operation span task: Within the experimental group, there was an increasing trend in performance accuracy after listening to alpha music for two weeks. Nevertheless, the increase was not significant according to ANOVA analysis. The average scores in weeks 1 and 3 were 35.40±6.082 and 36.25±3.837, respectively, with p=0.724. On the other hand, a mild reduction in the control group's average score was shown, which is insignificant. The average scores for weeks 1 and 3 were 33.65±5.613 and 33.05±7.323, respectively, while p=0.85 (Fig. 7B).

In contrast to the accuracy, both the control and experimental groups exhibited a decreasing trendline in the average task completion time, however both were statistically insignificant. Specifically, the average response time in the control group for weeks 1 and 3 were 2.14 ± 0.56 and 1.99 ± 0.44, respectively; p = 0.145. Also, the average response time in the experimental group was 2.08 ± 0.86 and 2.00 ± 0.72, respectively; p=0.62 (Fig. 7E). In conclusion, no effect of alpha music was observed in the experimental group from the remembering task.

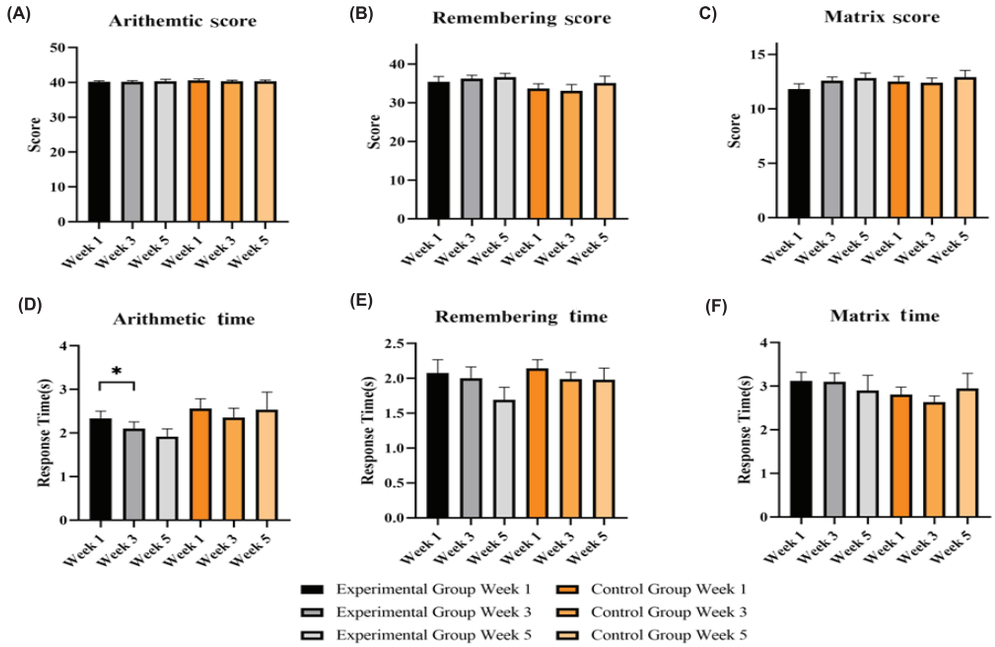

Fig. 7. Results from the accuracy of (A) arithmetic task, (B) remembering task, and (C) matrix span task. Response time of (D) arithmetic task, (E) remembering task, and (F) matrix span task.

Matrix span task: The mean scores of the experimental and control groups exhibited different trends. While the control group's average score moderately dropped, the experimental group has risen to a notable degree. Average scores for the experimental and control groups within a 2-week duration were 11.8±2.2 and 12.6±1.47; 12.5±2.11 and 12.4±1.96; with p=0.21 and p=0.97; respectively (Fig. 7C). The same trend in the response time after a two-week intervention, which was observed in the remembering task, was also recorded in the matrix span task. Both groups demonstrated a reduction in task completion time. The average response time for experimental group and control group within the 2-week duration were 3.12±0.90 and 3.10±0.88; 2.81±0.77 and 2.64±0.61; with p=0.99 and p=0.61; respectively (Fig. 7F). Overall, the results from the matrix span task did not indicate any effect from alpha music listening in the experimental group.

Long term effect

The long term effects of alpha music intervention on improving cognitive functions were validated throughout the utilized cognitive tasks (operation span task and matrix span task). According to Fig. 7, no difference in trendlines were observed between week 1 and week 5 and week 3 and week 5.

Electroencephalogram signal and power-immediate effect experiment

Noise filtering efficacy: After applying noise removal techniques like band-pass filter and ICA, the peaks caused by eye movements, which are found at the end of the EEG raw signal (Fig. 8A), were completely removed or dampened (Fig. 8B). The pre-processing step, therefore, enhanced the quality of the EEG signal.

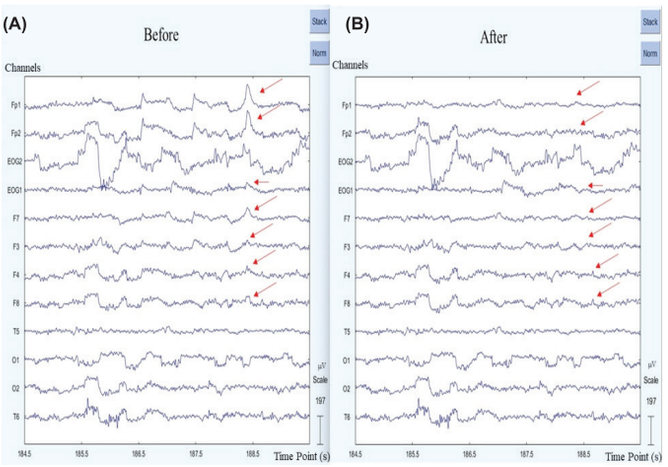

Fig. 8. Signal quality and noise cancellation: (A) before and (B) after signal processing.

Alpha-band relative power: This evaluation was conducted on seven subjects. Five of them show higher alpha band relative during alpha music listening compared to other sessions (rest sessions, tasks sessions, and control-music listening sessions) in all ten channels (Fig. 9). Specifically, the average relative power for the alpha music session is higher than the control music session (Supplementary Table 2). In addition, a comparison of the average power in each channel (i.e., which takes the average power from all subjects in that one specific channel) also yielded similar results. Analysing the relative power in alpha music and control music with 3-minute rest confirms that the power is much higher for alpha music. To summarize, the instantaneous effect of alpha music on alpha

band relative power was observed based on the comparison between the alpha music listening session with other sessions.

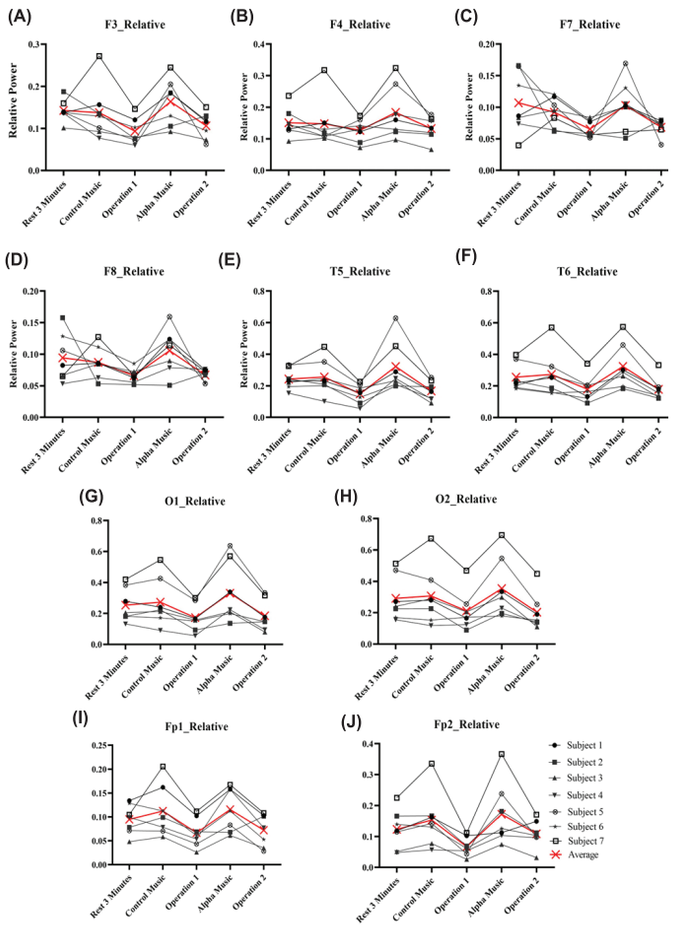

Fig. 9. EEG relative power of alpha band over the ten channels: (A) F3; (B) F4; (C) F7; (D) F8; (E) T5; (F) T6; (G) O1; (H) O2; (I) Fp1; (J) Fp2 of seven subjects in different stages (rest 3 min, control music listening, operation task 1, alpha music listening, operation task 2).

Discussion

The effect of alpha music on the enhancement of cognitive function

After examining the effect of alpha music therapy on the subject's cognitive performance, the results have achieved the following positive effects: Considering the accuracy, although no significant changes were noticed between the first and third week, an increasing pattern was noticed in the experimental group, with the average task scores increased after alpha music listening. On the other hand, looking at the response time, only the arithmetic task result showed a significant decrease in the task completion time, suggesting that mathematical skills and working memory performance have been significantly ameliorated. Regarding the two remaining tasks, the trend remains indifferent. Another positive outcome of the experiment is the student feedback, in which approximately 70% of the responses are positive. To be more specific, they reported that their concentration had been improved, resulting in increased performance in their daily lives (Fig. 6). Contradictory to the short-term effect, the results of the long-term effect do not show any specific pattern, which can be due to the limited number of listening days and minutes [10].

The immediate effect of alpha music on the brain response

Regarding the immediate effect experiment, even though the number of participants in this study is relatively small (only seven subjects involved), the majority have shown an increase in their relative alpha power during the alpha music listening session in approximately all channels. Moreover, their relative alpha power is higher than other sessions, including task sessions, the 30-second rest sessions, and notably, the 3-minute rest session and the control music (preferred music) session. The result indicates that listening to alpha music can immediately affect the EEG power in subjects, which is consistent with previous studies involving the effect of alpha music on EEG [22]. In addition, the increase in the average relative power of all ten channels suggests that alpha music can positively enhance the alpha power on frontal, occipital, and temporal lobes. Moreover, the increase in alpha band power during the listening of alpha music can lead to the enhancement of cognitive performance. Additionally, this study confirms the better effect of listening to alpha music on subjects brain wave, rather than listening to the music type chosen by the participants or resting silently for three minutes.

Limitations

During the experiment, the study encountered the following challenges that can contribute to a minimal effect of the intervention on cognitive function. First of all, the number of subjects is relatively low in both experiments. Particularly, there were only 20 subjects in each group for the online experiment. Moreover, only ten subjects from each group participated in the long-term experiment. Meanwhile, there were only seven participants in the immediate effect experiment. The reason for the lack of subject numbers was due to the Covid-19 outbreak in Ho Chi Minh city (2021) and restricted commuting post-social distance, which prevented the broadcast of our project to potential candidates (for the online experiment), and the mobility of subjects joining the Offline experiment (immediate effect experiment). Secondly, with the online experiment conducted close to a Vietnamese national holiday and final exams, 60% of the participants reported that their daily workloads were arduous. Therefore, they tended to complete their assigned tasks at a competitively faster rate without focusing on their performance accuracy, which led to increasing inaccuracy.

Conclusions

From all yielded results of the two experiments (online and immediate effect), it can be concluded that alpha music positively affects the cognitive skills and mood of subjects. In

addition, listening to alpha music can have an instantaneous effect on alpha band relative power. However, an improvement in experiment protocol and new approaches are needed for more apparent results. The preliminary findings have pointed to a potent application of alpha wave-containing music therapy for a variety of working contexts.

Supplementary

Supplementary Table 1. Students' feedback after listening to alpha music for two weeks.

Positive feedback	Negative feedback	Neutral feedback
Ease the mind, and feel more alert (4 subjects)	Music sounds frightening, leading to an emptiness feeling (1 subject)	Music is normal (3 subjects)
Feel quite relaxed, reduce stress (7 subjects)	Making sleepier more than wanted (2 subjects)	
Easier to fall into sleep (3 subjects)		

Supplementary Table 2. Average relative power of alpha wave on ten channels in the different states.

	Rest-3 min	Control music	Task 1	Rest 2	Alpha music	Task 2	Rest 3
F3	0.14	0.14	0.09	0.13	0.16	0.11	0.14
F4	0.15	0.15	0.13	0.16	0.18	0.13	0.17
F7	0.11	0.09	0.07	0.08	0.1	0.07	0.09
F8	0.09	0.09	0.07	0.09	0.11	0.07	0.1
Fp1	0.09	0.11	0.07	0.09	0.12	0.07	0.1
Fp2	0.12	0.15	0.1	0.16	0.17	0.11	0.14
O1	0.25	0.27	0.17	0.26	0.33	0.18	0.27
O2	0.29	0.31	0.21	0.27	0.35	0.2	0.25
T5	0.24	0.26	0.15	0.22	0.32	0.17	0.25
T6	0.26	0.27	0.18	0.23	0.32	0.18	0.25
Average power	0.18± 0.02	0.18± 0.03	0.12± 0.02	0.17± 0.02	**0.22± 0.03**	0.13± 0.02	0.18± 0.02

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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