ORIGINAL ARTICLE

Features of Brain Rhythms During the Visual Memorizing Task and Auditory Stimuli Using Electroencephalography

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ABSTRACT

Introduction: Brain rhythms are usually measured using electroencephalography (EEG) to detect changes in neuronal activity associated with specific human activity and behavior. This research determines the effectiveness of auditory stimulation for visual memory based on the features of brain rhythm. **Methods:** The research design involved three main stages: data acquisition, data processing, and data analysis. Sixty university students were selected as participants. They are inquired to memorize and recalled the visual memory assessment under exposure to Mozart's Sonata music and white noise stimulation with EEG recording. The data acquisition was obtained using 10-20 electrode placement of EEG imaging technique. The wavelet transform approach was used to process the EEG dataset, and the features were statistically analyzed using a t-test. **Results:** Participants were found to memorize better under the white noise stimulation with a mean score of 64.0%. Based on statistical analysis, it was shown that the stimuli had a significant impact on the EEG voltage trend and relative rhythm power. The relative alpha, gamma, and beta power were higher when exposed to white noise, indicating that alertness and sensory information processing were improved. **Conclusion:** Therefore, it showed that memorizing visual memory tasks under white noise auditory stimulation had improved participants memory due to activation of certain brain rhythms at specific locations.

Keywords: Brain signal, Electroencephalography, Memorizing, Mozart's music, White noise

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INTRODUCTION

Visual memory is one of the crucial skills to determine a person's ability to remember or recall information such as pictures, words, or activities observed by visual sensations and perceptions in the past. Many researchers have stated that 80% of learning activities involve visual memory (1). In university, the student is always engaged with the learning process. They require an excellent visual memory to store the new and old information related to the study. Visual memory can be trained to improve its performance.

One of the methods is by listening to specific auditory stimuli. Some researchers believe that pure or instrumental music/sound can improve human memory (2–4). Mozart is a famous classical music in a European country that used pianos as the major instrument. It is found that Mozart's music had a positive influence on human memory and mental development (5–8). The first research from 1993 states that listening to Mozart music for 15 minutes had improved college students' ability to solve the spatial reasoning task (2). Several studies found that Mozart music influences the people's performance in solving the visual oddball tasks, Spatio-temporal rotation tasks, attentional blink tasks, trigonometry tasks, and other mental tasks (9–11). However, some researchers state that Mozart does not directly affect spatial reasoning tasks and general intelligence (12,13).

Another potential auditory stimuli for improving visual memory is white noise. The white noise is a random signal with equal intensity at different frequencies, providing a constant power spectral density (14). Past studies state that noise can improve cognitive tasks that involve memory, vigilance, reasoning, and decision making (3). The main factors that influence the effectiveness of noise on mental or cognitive tasks are intensity, time exposure, and type of noise. Vanessa et al., (4) found that the midbrain activity was changing when the participant listens to white noise. The midbrain part was associated with the learning and reward pathways. Besides that, the other studies also found that the white noise increased sleep time and improved verbal learning tasks, visuospatial tasks, oddball tasks, and others (15,16). Based on previous research, it showed that auditory stimuli had a significant influence on the brain function. The brain consists of several parts: the frontal lobe, parietal lobe, temporal lobe, occipital lobe, cerebellum, spinal cord, and brain stem. Each of them plays a critical role in processing the information. Measuring the brain signals using imaging modalities is the best way to determine the changes in brain performance through capturing the brainwaves or neural oscillations.

Neural oscillations are rhythmic or distinct patterns of massed neuronal activity linked with specific actions, behaviors, arousal levels, and sleep states effectively measured in the thalamus, hippocampus, and neocortex (17,18). EEG is one of the imaging techniques that can record brain signals or rhythms. The EEG rhythms are categorized into several types based on their specific frequencies, which are delta (0.5 – 4 Hz), theta (4 – 8 Hz), alpha (8 – 13 Hz), beta (13 – 30 Hz), and gamma (> 30 Hz) (19). The EEG was preferred to measure and record the brain signal because of the short duration (milliseconds) in signal recording, affordable cost, non-invasive approach, and non-painful to subject (19).

Obtaining vital brain rhythms features helps researchers deeply understand the brain's function while performing specific physical or mental tasks. Generally, feature extraction categorizes into two types which are time-domain and frequency-domain features. Commonly, the raw EEG dataset is in the time-domain characteristic that requires converting and processing it into the frequency domain. Besides, the raw EEG dataset also disturbs by noise or artifact due to small amplitude. This artifact may come from external or internal sources. The existence of this artifact led to misinterpretation of data information. Thus, a practical approach to process the data is required to remove the artifact. Wavelet transform is one of the promising approaches to process the EEG dataset by filtering the unwanted signal and extract important features. Furthermore, the wavelet transform approach is more suitable for processing electrophysiology signals because it can preserve important information due to time-frequency characteristics (20–22). In general, the wavelet family is a set of elementary functions obtained from dilations and translations of a unique admissible mother wavelet and implemented via a pair of finite impulse response (FIR) filters named quadrature mirror filters pair. Therefore, the wavelet transform based on the stationary type was used in this research to process and extract the important features of the EEG dataset for investigating the influence of auditory stimuli on visual memory.

In general, this research article describes the influence of listening to Mozart's Sonata music and white noise stimulation while performing the visual memory task. Motivated from past studies, Mozart's Sonata music and white noise may positively influence memory; therefore, this research selects these two auditory stimuli as manipulated/investigated variables. In this research, the visual memory assessment is chosen because limited studies focus on this type of memory. Most literature investigated the influence of auditory stimuli on verbal memory, spatial memory, and declarative memory. As mentioned earlier, improvement of visual memory is also essential to retrieve more visual information. Therefore, throughout this experimental work, the influence of Mozart's Sonata music and white noise can be investigated and provide the guidelines for future work based on visual memory. Besides, the research findings could benefit college students in choosing suitable auditory stimuli to listen while studying, exercising, or doing any daily activities.

MATERIALS AND METHODS

Participant

Sixty healthy students (mean age: 23 years old) from Universiti Teknologi Malaysia, Skudai Malaysia, were selected as the participants for this research where 40 of them are females, and 20 are males. All of them had normal hearing/vision conditions and passed the mini-mental state examination (MMSE) (23). The MMSE aimed to evaluate the participant's mental condition to confirm their mental status. The person need to score of 26 and above before participating in any memory or cognitive assessment. In this experiment, the participants were equally categorized into two groups (30 participants for each group). The first group needs to memorize/recall in silence, listen to Mozart's Sonata music, and listen to white noise. Meanwhile, the second group was required to memorize/recall in silence, listen to white noise, and listen to Mozart's Sonata music. The auditory stimuli during memorization/recall are changed reversely to equilibrate their influence toward participants.

Visual memory task and auditory stimuli

The 2 pianos in D Major, K 448 of Mozart's Sonata music, and pure white noise were used as the auditory stimuli. The volume was measured using decibel meter software and set between 40 to 55 dB to reduce the bad influence of volume on participants. The speaker was used to expose the auditory stimuli. Meanwhile, the visual memory task based on images and numbers is preferred in this research (Fig. 1). The visual memory task was modified from Zhang et al., 2009 (13) study. The task in language was avoided to eliminate the effect of language on participant's performance. The visual memory task was categorized into easy and difficult levels. The easy level consists of an image with a two-digit number, while the difficult level contains an image with a four-digit number. The task was design in black, white, and grey interface to minimize the effect of color and display on the laptop screen. The task was created using movie maker software in MPEG-4 or MP4 to control the duration of memorizing, recalling, and resting state. The distance between the participants and the laptop screen was fixed at a distance of 0.9 m.

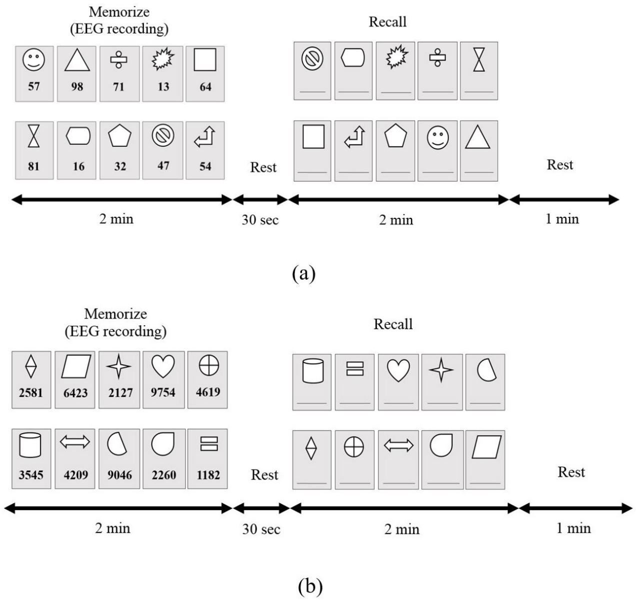

Figure 1: Duration of visual memory task for the experiment: (a) easy level and (b) difficult level

Experimental procedure and EEG acquisition

The participants were required to memorize the easy and difficult level visual memory task in three different environments: silent (control), listening to Mozart's Sonata music, and exposure to white noise. First, the participants need to relax for 5 minutes before starting the memorize/recall task. Then, the consent form and survey questionnaire were given to obtain their basic background information and permission to be involved in the experiment. After that, the EEG scalp was worn on their head, and the EEG was set up accordingly. The Neurofax9200 EEG machine with 10-20 electrode placement was used in this research to obtain the EEG dataset. The EEG was set to 10 mV of sensitivity, 0.3 s of the time constant, 70 Hz of a high-pass filter, average (AV) of EEG pattern, average (Aav) of reference, and sampling at 500 Hz for the acquisition process. Among the channels, this research selected five electrodes which were Fp1, Fz, T3, T4, and Pz channels associated with visual memory and auditory stimuli (25). The EEG datasets were saved in ASCII format and further processed using wavelet in MATLAB software.

The experiment was started by instructing the participants to read and understand the instruction. The participants were required to memorize the visual task in 2 minutes and recalling back after 0.5 minutes lapse. Then, the answer sheet was provided to fill the missing number of each image within 2 minutes. They needed to solve the easy level first before the difficult level. For every environmental change, 3 minutes of resting are given by seeing the scenery picture displayed on the laptop screen to refresh the participant's mind. During the auditory stimuli experiment, the participants were exposed to sound for 5 minutes with eyes closing to influence brain activity significantly.

EEG processing and feature extraction

The raw EEG dataset was processed into two parts which were time-domain and frequency-domain. At the first stage, the EEG dataset was filtering using stationary wavelet transform of db3 and 5 decomposition levels to remove the artifact. The db3 mother wavelet was chosen because of its spiky properties that could eliminate the muscle movement and eye blinking artifact (26,27). Then, the time-domain features were extracted, such as mean, standard deviation, peak-to-peak amplitude/range, and coefficient of variation for all five selected channels (Equation 1-3).

$$\bar{y} = \frac{\sum y}{n} \qquad (1)$$

where $\bar{y}$ refer to the mean, y refer to the observed value, and n refer to the total number of observations for the EEG dataset.

$$D = \sqrt{\frac{\Sigma(Yi-\bar{Y})^2}{n}} \qquad (2)$$

where D refers to the standard deviation, n refer to the total observed value, Yi refers to the observe EEG dataset, and Y refer to the mean value of the EEG dataset.

R = Max value – Min value (3)

After that, the EEG dataset was further processed using discrete wavelet transform of db4 and 7 decomposition levels to extract alpha, beta, and gamma rhythms. The relative power of rhythms was obtained to determine the brain activities, as shown in Equation 4. Finally, all of the extracted features were normalized using a z-score to standardize the values.

$$P = \sum_{j=1}^{n} \frac{|E_{ij}|^2}{n}, \quad i = 4, 5, 6, 7 \qquad (4)$$

where, $\sum_{j=1}^{n}|E_{ij}|$ refer the energy value to the detail coefficient value (n) for each decomposition level of the discrete wavelet transform.

Ethical clearance

This research was approved by Malaysian National Medical Research Register No. 21-02365-GVD.

RESULTS

Score of visual memory task

The percentage corrected answer of the visual memory task was obtained to determine participants' ability to memorize and recall the task and its relation with the brain activity. Table I showed the score result of the tasks. The answer was considered correct if the filled missing number on the figure is similar to the displayed. In addition, the t-test was performed to determine the difference between the mean score of the visual memory task in a silent environment with the auditory stimuli environment. The alpha value of p = 0.05 was used

Table I: Percentage correctness of recalling visual memory task at different auditory stimuli and task difficulties

	Mean (%)		
	Easy level	Difficult level	Total = (easy + difficult)/2
Silent	72.8	29.1	51.0
Mozart's Sonata music	80.7	36.3	58.5
White noise	85.6	42.3	64.0

as a benchmark to evaluate the difference. According to Table I, the participants memorized better when listening to White noise than Mozart's Sonata music and silent environment for the easy and difficult level task.

Time-domain features of EEG rhythm

Based on Table II, the highest normalized mean ($\overline{yn}$) of EEG voltage was found at the Fp1 channel for all of the tested environments. Meanwhile, the lowest ($\overline{yn}$) was shown at Fz channel for silent, T3 channel for Mozart's Sonata music, and T4 channel for white noise environment. The highest variation was found at the Fp1 channel compared to others for all of the tested environments. Besides, listening to Mozart's Sonata music caused the highest ($\overline{yn}$) at T4 channel and the lowest ($\overline{yn}$) at the Fz channel, while under a white noise environment, the Fp1 channel had the highest ($\overline{yn}$) voltage and the lowest ($\overline{yn}$) was T4 channel. In the silent environment, the Fz channel obtained the highest ($\overline{yn}$) voltage, while the lowest ($\overline{yn}$) voltage was at the T4 channel.

In addition, Table II also showed that the normalized peak-to-peak amplitude (Rn) value of the silent environment was the highest at the Fz channel and the lowest at the T3 channel. Meanwhile, Mozart's Sonata music showed the highest Rn for Fz and Pz channel of the lowest and white noise found at Fp1 of the highest and T4 of the lowest.

The highest normalized standard deviation (Dn) was obtained from the Fp1 channel among the tested environment. Meanwhile, the lowest Dn was observed at T4 for silent and white noise environment and Fz channel for Mozart's Sonata music. On the other hand, the highest Rn of EEG voltage was observed at the Pz channel for Mozart's Sonata music and white noise environment, while for silent was at the Fp1 channel. Besides, the lowest Rn was observed at the Pz channel for silent and white noise, whereas for Mozart's Sonata music was shown at the Fz channel.

Frequency-domain features of EEG rhythm

Table III showed the relative power of alpha, beta, and gamma for the EEG dataset during memorizing visual memory tasks at the different environmental conditions. Listening to white noise had increased the relative gamma power for all selected channels' easy level task compared to others. Focusing on auditory stimuli, listening to Mozart's Sonata music had increased the relative power of alpha rhythm at the Fp1 channel, a beta rhythm at the Pz channel, and gamma rhythm at the T4 channel. Meanwhile, exposure to white noise caused high relative alpha power at the Fp1 channel, a beta rhythm at the Pz channel, and a gamma rhythm at the T4 channel.

The relative beta power showed that the Fp1, Fz, T3, and Pz channels were increased when listened to auditory stimuli. In contrast, the T4 channel decreased when participants memorized Mozart's Sonata music and white noise. Among the auditory stimuli, no significant difference was found for relative beta power. The alpha rhythm obtained the highest relative power compared to other selected rhythms for Fp1, Fz, T3, T4, and Pz channels. Similar trends were also found in the relative power of difficult task level where the alpha rhythm obtained the highest value (Table III).

DISCUSSION

Listening to auditory stimuli had improved the ability of participants to memorize the visual memory task where

Table II: Time-domain features of selected EEG channels for the easy and difficult level of visual memory task under different environment

	Silent			Mozart's Sonata music			White noise		
	Easy level								
Channel		*Dn*	*Rn*		*Dn*	*Rn*		*Dn*	*Rn*
Fp1	39.6	38.2	25.8	42.9	23.2	32.7	38.3	37.7	41.0
Fz	28.0	17.9	31.6	37.0	21.1	35.6	28.6	19.3	26.3
T3	36.3	25.2	22.1	35.9	20.5	28.9	37.9	30.0	40.0
T4	33.0	21.8	26.4	36.2	21.9	30.3	10.8	15.5	25.9
Pz	34.7	24.5	26.7	40.1	19.5	27.3	37.8	28.8	38.5
	Difficult level								
Fp1	32.8	43.5	35.9	20.0	25.0	25.3	32.7	37.8	35.3
Fz	35.7	21.6	28.9	18.6	19.1	24.3	28.0	19.8	31.6
T3	29.3	30.7	28.5	19.3	21.8	25.0	28.9	29.2	23.1
T4	23.8	15.5	30.0	26.2	22.7	27.3	13.2	15.3	26.1
Pz	35.7	29.1	29.4	19.2	22.9	27.8	30.8	25.3	39.4

Table III: Relative rhythms power of selected EEG channels for the easy and difficult level of visual memory task under different environment

	Silent			Mozart's Sonata music			White noise		
	Easy level								
Channel	**Alpha**	**Beta**	**Gamma**	**Alpha**	**Beta**	**Gamma**	**Alpha**	**Beta**	**Gamma**
Fp1	17.5	8.7	3.8	17.7	9.0	3.8	17.7	8.8	4.2
Fz	17.2	10.5	5.4	17.4	11.2	5.7	17.3	11.0	5.8
T3	16.2	11.0	7.0	16.5	11.7	6.9	16.8	11.5	7.3
T4	16.2	11.6	6.6	16.4	11.4	7.1	16.4	11.5	7.6
Pz	16.5	11.9	6.2	16.8	12.1	6.6	16.7	12.2	7.0
	Difficult level								
Fp1	18.0	8.8	3.8	18.0	8.6	3.6	17.6	9.0	3.6
Fz	17.5	10.3	5.0	17.6	10.8	5.6	17.3	11.4	6.0
T3	16.8	11.3	6.5	16.8	11.3	7.2	16.1	12.2	7.4
T4	16.8	11.1	7.0	16.8	11.3	6.9	16.0	11.9	8.1
Pz	17.2	12.1	5.9	17.1	11.9	6.7	16.6	12.8	7.0

more high percentage mean correctness of score was found than in a silent environment. The t-test indicated that under a white noise environment, the p-value = < 0.050 was 0.009 for the easy level and 0.001 for the difficulty level, which was significantly improved than the silent environment. Meanwhile, the Mozart's Sonata music obtained p-value = 0.203 for easy level and p-value 0.061 for difficult level which indicated no significance difference (p-value = < 0.050) in relative to silent environment. Therefore, it showed that Mozart's Sonata music had little influence on visual memory performance. In white noise, a positive influence was found on visual memory performance where significant differences existed on the easy and difficult task levels. The score result showed that memorizing and recalling under a silent environment was not efficient for the participant. Listening to auditory stimuli had improved visual memory compared to silent because the white noise and Mozart's Sonata music provide beneficial influence on participant's attention level, alertness level, mood, arousal, and sensory input processing. A comparison of task difficulty showed that the participants could memorize better for easy level than difficult level due to the different number of items that need to be remembered. Increasing of items/objects to be memorized reduced the ability of memory to store the information. This research also shows where the percentage correctness of the difficult level was lowered than the easy level. The presence of auditory stimuli along with mental tasks had improved the ability of participants to memorize the difficult level task. Based on the finding, this research found that the auditory stimuli had improved visual memory.

The aim of the analyzed EEG dataset in the time-domain was to determine the increasing and a decreasing trend in time unit of selected channels based on ($\overline{yn}$), Dn, and Rn values of the EEG voltage (Table II). The voltage is a potential difference of charge in two points of the electrical field divided into direct and alternating voltage. The EEG detects voltage fluctuations obtained from ionic current within the neurons of the brain. Greater EEG voltage indicates the higher ionic current flow inactive neurons. Listening to Mozart's Sonata music produced greater ($\overline{yn}$) the voltage at Fp1, Fz, T4, and Pz channels compared to other environments. For white noise, the T4 channel showed the lowest ($\overline{yn}$) value (10.8) than others which indicated the lowered electrical activity of neurons during memorizing easy level task associated with emotional memory function. Standard deviation refers to the variation of data around the mean value. Higher Dn indicated more significant dataset variation. The Rn of EEG voltage determined the difference between the maximum and minimum values of selected channels.

In this research, the alpha, beta, and gamma rhythms were selected to associate with visual memory scores and related brain activities. Generally, the alpha rhythm is linked with a relaxing awareness state without concentration, while the gamma activity refers to sensory processing, muscle movement, and high cognitive thinking, whereas the beta rhythm is related to active thinking, concentration, and attention. The result indicated that listening to white noise while memorizing visual memory tasks had improved the sensory processing associated with visual information captured by eyes. High relative gamma power for Fp1, Fz, T3, T4, and Pz means more visual information was obtained by eyes and processed (register/encoded) in the brain. The alpha activity most influences during memorizing task compared to other rhythms. It indicated that the participants were calm and relaxed during the experiment, even listening to auditory stimuli. Some studies claimed that listening to auditory stimuli may negatively influence a person's mood and arousal. However, in this research, the participants remained calm during listening to auditory stimuli for the easy level task (8,9). It does not significantly influence beta activity for the easy level task because participants require only less attention to memorize the visual information since fewer items are needed to be remembered. The relative alpha power of auditory stimuli was comparable with a silent environment, indicating that Mozart's Sonata music and white noise do not lead the participant to stress condition while memorizing. Listening to white noise had increased the beta activity where great attention was achieved in this environment compared to others. Thus, it showed that the exposure to white noise had increased the concentration and attention level during memorizing difficult levels of the visual memory task. Meanwhile, the gamma activity was improved at Fz, T3, and Pz channels during listening to auditory stimuli compared to the silent environment. These brain locations are essential for storing, encoding, and processing visual memory items (25). Therefore, it indicates that exposure to auditory stimuli had stimulated the brain cell to process the input information successfully.

CONCLUSION

This research had successfully investigated the influence of auditory stimuli, which were Mozart's Sonata music and white noise on the visual memory of university students. The visual memory task was selected because it is one of the important parts of obtaining information during the learning process. Through experimental work, it found that the participants could memorize better the easy and difficult level task when listening to white noise. Based on frequency-domain features, the possible reason for successful visual information stored and recalled was that the attention, concentration, mood, and input processing are improved. Furthermore, the different trend of mean, standard deviation, and peak-to-peak amplitude was found from EEG voltage, which indicates that the auditory stimuli and visual memory task had other influences on the brain activity. Therefore, this research suggests that the white noise could be used as auditory background stimuli during learning activities to improve study performance.

ACKNOWLEDGEMENTS

This work was financially supported by the Universiti Teknologi Malaysia under the Research University Grant with reference number UTM ER: Q.J130000.2651.17J69 and Post-Doctoral Fellowship Scheme: Q.J130000.21A2.05E52.

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