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Original Research

EEG Analysis for Images Encode and Retrieval under White Noise Stimulation

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ABSTRACT

Utilization of an EEG machine aids researchers in detecting the brain responses and states during provided stimulation. The EEG comes with multiple electrode channels for recording the electrical activity of the brain. This work aims to discover the brain responses under stimulation of white noise during images encoding and retrieving using the EEG machine. The motivation of this research is because limited previous works determine the association between memory encoding and retrieving process based on EEG analysis. Twenty college students participated in this experimental work. They were required to remember the images in two different conditions: control/silent and exposure to white noise with two task difficulties: easy and difficult phases. The EEG was recorded during the remembering and recalling period for data acquisition. The obtained raw EEG dataset was imported to .txt format for further processing. The Butterworth bandpass filter with a frequency range of 4 to 45 Hz was applied to filter the low and high noise components in the EEG signal. Next, the mean of de-noise EEG voltage was obtained to select the most affected channels. It was found that the Fp1, Fp2, F7, and F3 channels achieved the highest mean voltage that higher than 5 µV. Therefore, these channels were selected for extraction of relative rhythm power to investigate the effect of white noise on memory performance. The findings showed that the alpha, gamma, beta, and theta activities were highly found during the encoding and retrieving process when participants were exposed to white noise. These brain rhythms were related to participants' attentional level, information processing and calm state during the assessment. The behavioral data showed that the participants successfully remembered the images more when exposed to white noise compared to the control condition with percentage differences of 21% and 33% for easy and difficult phases due to the stochastic resonance effect and activation of brain rhythms.

INTRODUCTION

Electroencephalography (EEG) is a standard brain imaging tool used in research that relates to human cognitive and memory performance. The EEG is used for recording the electrical activity of the brain. The EEG signal is non-stationary, dynamic, and small in the amplitude of microvolts value (Biasiucci et al., 2019; Katyal et al., 2020). Notably, the EEG signal contains essential information that can be interpreted in time-domain, frequency-domain, and time-frequency domain features. These features will indicate brain patterns and states. The signal was acquired using 10 to 256 metal electrodes attached to the head scalp. Each electrode is positioned at a specific location for ease of interpretation. The benefits of using EEG are non-invasive and non-painful technique, has short acquisition duration, excellent temporal resolution, and affordable cost, but the signal easily to be corrupted by noises and poor spatial resolution (Al-qazzaz et al., 2015; Daud and Sudirman, 2022). Although the EEG signal disrupts by noises, but there are various computational filtration techniques, and precautions can be taken before data acquisition to minimize the occurrence of noises. Therefore, there is no doubt about employing EEG analysis for brain research.

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Learning condition are among the factors that influence brain function and performance. The condition may provide beneficial or adverse impacts on the brain. There is various type of learning conditions that can improve brain function and performance, which depend on condition characteristic, learner characteristic, and their association (Magiera and Solecka, 2021; Silva et al., 2020; Söderlund and Jobs, 2016; Ullah et a., 2020). Typically, two types of conditions were used, which are pleasant and unpleasant. These conditions may gain naturally or artificially created. A pleasant condition is a condition that makes people feel happy, comfortable, relaxed, and calm. The common pleasant conditions are in a silent place such as in the library, exclusive restaurants, and hotels, as well as the existence of sound stimulation such as jungle, musical concert, and beach. In contrast, unpleasant conditions usually make people uncomfortable, stress, and unhappy, such as in heavy traffic jams, busy markets, and industrial places. However, it cannot easily remark that pleasant conditions can positively affect human cognitive function, whereas unpleasant conditions will produce adverse or null effects. This is because some studies found that pleasant and unpleasant conditions may benefit human cognitive function. For instance, Hsu et al., discovered the effect of silent and noisy conditions at the library and cafeteria on multitasking assessment and found that older people perform better in noisy conditions (Hsu and Bai, 2022). Stenfors et al., investigated the effect of nature and urban conditions through real-world and artificially created on backwards digit span tasks (Stenfors et al., 2019). They found that the performance was better in nature than in urban conditions. Motohiro et al., determined the effect of neighbourhood conditions on the cognitive performance of rural older adults (Motohiro et al., 2021). They indicated that cognitive performance declined in neighbourhood conditions.

Cognition refers to acquiring and understanding knowledge through experience, learning, and being taught (Besseret al., 2017; Cowan et al., 2008; Wingfield and Peelle, 2012). The common approaches to gathering facts and new information are remembering, thinking, speaking, and solving problems involving encoding, storage, and retrieval phases (Ballesteros, 1999; Daud et al, 2022). Cognition plays a vital role in controlling human thoughts and behaviors. It is regulated by discrete brain circuits, which underpin some neurotransmitter systems. Brain chemicals are included in regulating cognitive processes: noradrenaline, serotonin, dopamine, acetylcholine, glutamate, and gamma-aminobutyric acid (Kahana, 2006; Parkin et al., 2015). Therefore, it is crucial to consider cognition and underlying brain function to investigate better the factors that drive specific behaviors. Cognitive performance indicates how well the brain function. Obtaining high-performance cognitive function benefit people in life. Until now, many studies have been conducted to measure cognitive performance through various cognitive assessments such as the Wonderlic test (Pesta et al., 2008), Cognitive Assessment Battery (Golan et al., 2019), Raven's tests (Friedman et al., 2019), and Montreal Cognitive Assessment (Chiti and Pantoni, 2014). However, the research usually used behavioral data as the main indicator for evaluating cognitive function without considering the brain responses. It is vital to include brain responses during cognitive assessment to discover what occurs in the process and how it triggers brain activities. Through this way the association between behavioral data and brain responses can be determined.

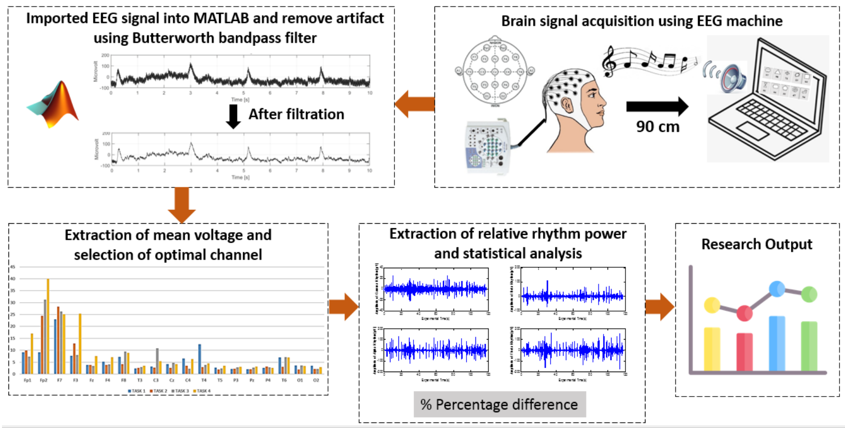

Fig 1 The proposed architecture of study the effect of learning conditions on image encoding and retrieval based EEG analysis.

The recent work goal is to discover the effect of silent and noisy conditions on adult cognitive performance using EEG analysis and behavioral data. This work measured the EEG signal during images' encoding and retrieving duration to determine their association with memory performance. Besides, this work also initially determines the higher voltage for selecting the optimal EEG channels for feature extraction. The outcome of this research will recommend the best condition for encoding and retrieving the images and guiding the reader in EEG analysis.

METHODOLOGY

This section describes the flow process of acquiring and processing the EEG dataset and obtaining behavioral data. Several steps were involved: experimental set-up, data acquisition, data pre-processing (artifacts elimination, bad data removal, EEG channel selection), data processing (features extraction), data analysis, and data interpretation. This research work had been registered under Malaysian National Medical Research Register with No. 21-02365-GVD. Figure 1 illustrates the proposed architecture for this work, and a brief explanation for each step can be found in the following subsections.

Research Participants

The research participants were recruited from a local university in Malaysia and were paid for involvement in the experiment. The data were collected from twenty university students (fourteen females and six males) at the age between 19 to 26 years old. All of them were right-handed and had engineering education backgrounds. They were all enrolled in a graduate-level engineering program at the time of the research. They were required to undergo Mini-mental State Examination (MMSE) test before participation to determine their mental status (Folstein et al., 1975). The participants were in good health, had no insomnia problem, did not have bad vision and hearing problems, and were not hypersensitive to sound stimulation. They needed to fill up the written informed consent, and their anonymity was preserved throughout the duration of the study and beyond its completion.

Stimuli and Software

This work used two types of learning conditions, which are silent and noisy. The noisy condition was artificially created by playing the white noise using an external speaker in the laboratory. The volume was measured using decibel meter software and set at a range of 40 to 55 decibels to avoid bad effects on hearing. The cognitive function in this work was based on visual memory assessment (Jain and Wagani, 2019). The task consists of images that need to be remembered and recalled by the participants. Two levels of difficulty were used: easy phases and difficult phases. The easy phase contains an object with 2-digit numbers, and the difficult phase contains an object with 4-digit numbers. The assessment was created using Microsoft power point and imported to a video editor for controlling the duration of the task. The images were in grey, black, and white interface to avoid the attraction of color on memory performance. The MP4 video consisting of the assessment was played using a laptop that was placed 0.9 meters from the participants. Each assessment phase was presented for 2 minutes. The brain signal was acquired using an EEG machine (Neurofax 9200, Nihon Kohden) using the ECI Electro-cap inserted with Silver/SilverChloride gel. The electrode cap was placed by the 10-20 electrode placement system. The acquired EEG signal had 500 hertz of sampling frequency.

Experimental Protocol

The laboratory was set up for data recording and measurement purposes. After the participant entered the laboratory, they were asked to sit comfortably and relax. During this time, they were prepared for EEG recording. Then, the instructor explained the experimental flow and related instruction. The participant was also asked to limit muscle and eye movement to minimize the noise in the EEG signal. The non-related electrical appliances and mobile phones were off to reduce power line interference (50-60 hertz). Then, the stimulation program was played, and the participant started memorizing the easy phase images. They were given 2 minutes to remember at the desired condition. The experiment started with a silent condition, followed by a noisy condition. After the memorization period ended, the participant rested for 30 seconds and recalled the images of the easy phase for 2 minutes. Then, they rested for 1 minute. The brain signal was recorded using EEG for both memorization and recalled periods. Next, a similar procedure was carried out for the difficult phase before changing to the noisy condition. Figure 2 shows the timeline for this experiment.

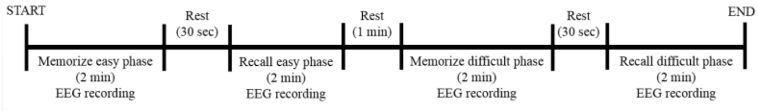

Fig 2 Timeline for memorization and recall of memory assessment at different conditions

EEG Signal Acquisition and Pre-processing

The EEG machine was set to 0.01 volts for sensitivity, 0.3 seconds for the time constant, 70 hertz for internal high-pass filter, average pattern, and sampled at 500 hertz. All of 19 channels (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, T4, T5, T6, C3, C4, P3, P4, O1, and O2) was used with two mastoid reference electrodes (A1 and A2). The acquired was imported into ASCII format and saved in an external hard drive for further processing. Initially, the EEG dataset was pre-processed by removing the undesired information and bad value. Then, the EEG dataset was imported into MATLAB R2020a to remove the artifact via the Butterworth bandpass filter at a frequency range of 4 to 45 hertz. Next, the mean voltage was determined from a clean EEG dataset to select the optimal EEG channel.

Extraction of EEG Features and Analysis

After selecting the optimal EEG channel, the Butterworth bandpass filter at different frequency ranges was applied to generate brain rhythms, as indicated in Table 1. The delta rhythm was excluded from the analysis because it does not relate to the study. Four types of brain rhythms are obtained that are alpha (8-13 hertz), beta (13-30 hertz), theta (4-8 hertz), and gamma rhythm (30-45 hertz). Each of them represents a different state of the brain. The relative power was extracted from each absolute rhythm power. The percentage difference was calculated to determine the increasing and decreasing trend of the extracted features.

RESULT AND DISCUSSION

The research findings are discussed based on behavioral data and EEG analysis to determine the effect of silent and noisy conditions on participant memory performance.

Behavioral Data

According to Table 1, the participants memorized the images better under noisy condition than under silent for both assessment phases. The average score for the total mark was 10. The participants obtained 8.8 for noisy and 7.3 for silent conditions of the easy phase. There was no significant difference ($0.101 > p = 0.05$) found for the easy phase between both conditions. Meanwhile, the score of the difficult phase was lower than the easy phase due to the increased number of images that reduced the memory performance needed to be remembered. The silent condition score was 3.35, and the noisy score was 4.45, which is less than ½ of the total mark. However, the score for noisy condition was significantly higher than for silent based on t-test analysis $0.024 < p = 0.05$). Therefore, it revealed that exposure to noise during memorization had improved the images' encoding and retrieval process. Then, the

EEG analysis will further describe to relate the score assessment with the brain state.

Table 1 Description of brain rhythms properties

Brain rhythms	Amplitude (μV)	Frequency (Hz)	Brain states
Delta 	100 – 200	0.5 – 4	Deep sleep or waking state
Theta 	5 – 10	4 –8	Drowsiness, the first step of sleep, access to unconscious material, creative inspiration, and deep meditation
Alpha 	20 – 80	8 – 13	Relaxed awareness without attention and concentration
Beta 	1 – 5	13 – 30	Active thinking, high state of wakefulness, alert and focused
Gamma 	0.5 – 2	> 30	Higher mental activity, including perception and consciousness, related to the movement, sensory processing

Table 2 Behavioral data of easy and difficult phases of memory assessment under different conditions.

Learning conditions	**Average (Standard deviation) score**	***t*-value**	***p*-value**
Easy Phase			
Silent	7.3 (2.4)	-2.463	0.101
Noisy	8.8 (2.18)		Non-significant
Difficult Phase			
Silent	3.35 (2.03)	-1.726	0.024
Noisy	4.45 (1.56)		Significant

EEG Analysis

This section initially described the optimal channel selection for memorization and recalled period based on mean voltage before further discussing the EEG features pattern. Referring to Figure 3 and Figure 4 showed that the Fp1, Fp2, F7, and F3 channels obtained the highest mean value than other channels for the memorization period. These channels are related to the frontal lobe of the brain that represents: Fp1 – attention, Fp2 – judgment and restrain of impulses, F7 – verbal expression, and F3 – motor planning. It indicated that the brain's activities were related to that functions. The Fp2 channel showed the highest mean voltage, which revealed the judgment action was highly involved in this assessment. This could be due to participants judging the position of the object and image during the memorization and recall period. Besides, the Fp1 and F3 channels are also involved in this assessment because the participants need to give high attention and motor planning to memorize and recall the images. Based on mean voltage, the Fp1, Fp2, F7, and F3 channels were selected for extraction of alpha, beta, theta, and gamma rhythms to determine their relative power.

Tables 3 and 4 represent the relative rhythms power for easy and difficult phases of memory assessment under silent and noisy conditions. It can be seen that the relative gamma power was the highest compared to others for both memorization and recalled periods, as well as under silent and noisy conditions. Therefore, it indicated that higher sensory processing has occurred in the brain during this assessment. The relative gamma power was higher in the retrieval/recalling than encode/memorizing period. This could be due to the increased brain working to retrieve the encoded information for the recalled process. Based on Table 3, the noisy conditions (easy phase: 10142.63; difficult phase: 10569.57) obtained the highest relative gamma power for both task phases compared to the silent (easy phase: 8812.92; difficult phase: 7760.57). The percentage difference of relative gamma power for noisy in relative to silent was 15% for the easy phase and 36% for the difficult phase. The relative gamma power was increased when

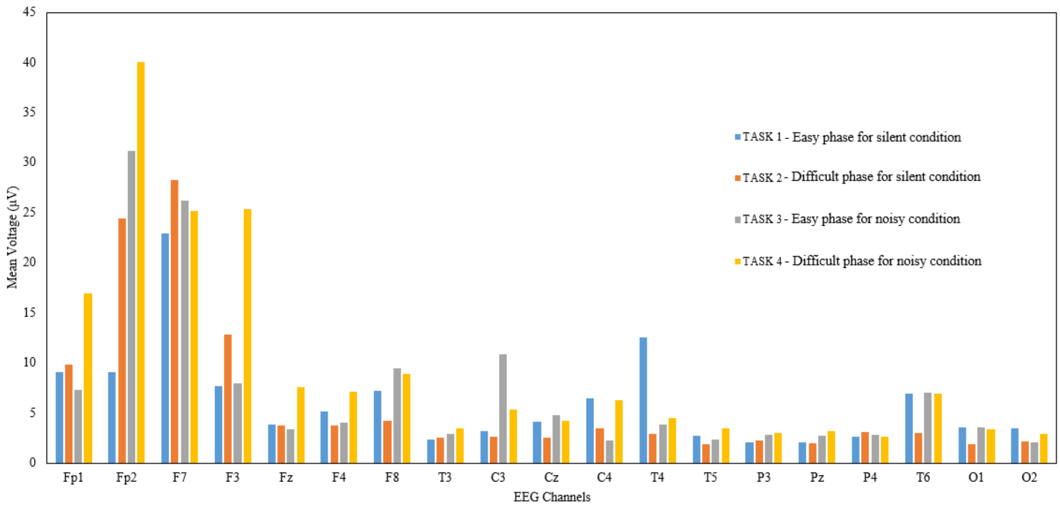

Fig 3 Mean voltage of EEG channels at different assessment phases and conditions for memorization period.

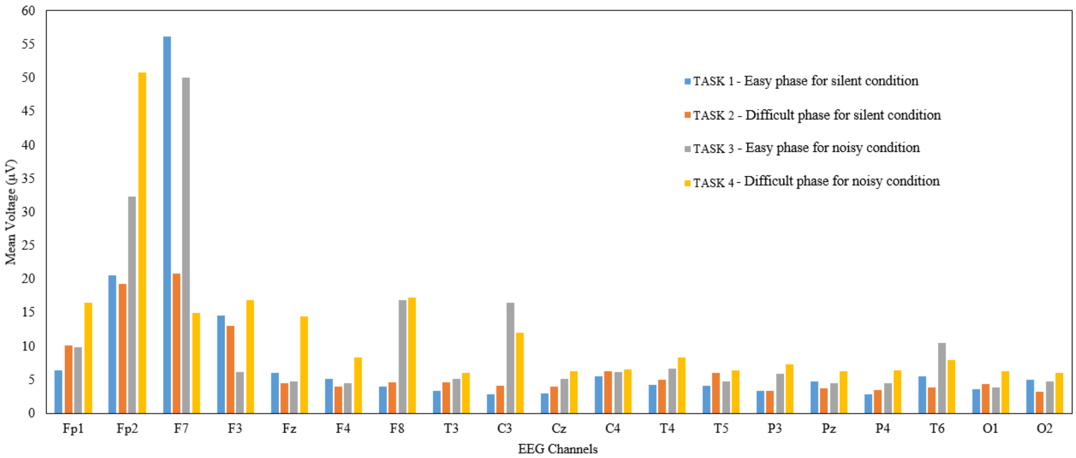

Fig 4 Mean voltage of EEG channels at different assessment phases and conditions for recalling period.

participants were exposed to white noise during memorization. This revealed that more images were processed in the brain when listening to noise than in silent conditions. In contrast, a different trend pattern was observed for the recalled period, where the relative gamma power was decreased when noise was exposed for both task phases (easy phase: 42%; difficult phase: 33%). Higher relative gamma was found in silent compared to noisy condition. It indicated that higher sensory processing was required to retrieve the encoded images for recalling under the silent condition

The relative alpha power showed the second highest for tested conditions and memory assessment phases. The alpha rhythm was related to the participant's calm state during the assessment. According to Table 3, the relative alpha power of noisy was 26% and 43% higher than silent for easy and difficult phases, respectively. Therefore, it indicated that the participants were a little bit disrupted when in silence condition during memorizing, which caused lower relative alpha power. This could be due to the silent state that makes participants think about other matters in their brains, which causes them to be less focused on memory assessment. Meanwhile, the relative alpha power was higher for noisy condition because the participant felt comfortable with the constant intensity of white noise, which made them more focused on assessment than thinking about other things. Increased of assessment difficulty caused a little bit increased of relative alpha power. It led from the participants that force themselves to still calm during memorizing, which caused an increase in alpha activity. Referring to Table 4, the relative alpha power was decreased for both assessment phases for the noisy condition (easy phase: 36%; difficult phase: 31%) in relative to the silent condition during the recalling period. Less alpha activity was observed when listening to the noise, which indicated the participant was calmer than in silent condition.

Beta rhythm represents active thinking, high wakefulness, alert, and focused state. Table 3 showed that the relative beta power was higher when exposed to noisy (easy phase: 37%; difficult phase: 48%) for both assessment phases than in silent condition. The participants had higher attentional levels and focused when they heard white noise than silent condition. This can be related to the stochastic resonance concept that the person needs to filter the external disturbance, in this case, sound stimulation, to focus on the required task, which causes high beta activities. Less attention and focus were observed for a silent condition when assessment difficulty increased (easy phase: 3579.56; difficult phase: 3400.30). Meanwhile, the noise improved the attention and focus of participants when assessment difficulty increased. According to Table 4, the relative beta power decreased by about 20% for the easy phase and 23% for the difficult phase when participants listened to noise compared to silent condition. It stated that the participants required less attention and focused when retrieving back images when exposed to noise compared to silence. Besides, it also can seem that the relative beta of recalling is also lower when task difficulty increases. This could be due to the increased number of images needed for retrieval, which caused less attention and focus on assessment.

The lowest relative power was obtained from theta rhythm. The theta rhythm refers to drowsiness, the first step of sleep, access to unconscious material, creative inspiration, and deep meditation. This rhythm was less observed in the brain for this assessment due to not being affected much. This is because the participants need to be alert to the provided task. A similar trend was found for relative theta power, where the relative power was higher for the memorization period and lower for the recalling period when exposed to noise compared to the silent condition.

Throughout the EEG analysis, exposure to noise condition led to an increasing trend of relative rhythm power for the memorization/encode period. In contrast, there was a decreasing trend of relative rhythm power for the recalling/retrieval period relative to silence. Listening to noise led to the activation of alpha, beta, gamma, and theta activities during memorization. This could be the main factor leading to a better memory assessment score for both phases. The participants obtained high attention and focused when listening to the noise, which caused more images to be encoded in the brain. In addition, the brain does not need to work hard to retrieve the encoded images, as represented by the low relative power of alpha, beta, theta, and gamma during the recalling period when exposed to noise. Therefore, it can be indicated that the successfulness of images encoded and retrieved was associated with brain activities, where activation of alpha, beta, theta, and gamma led to improved memory performance.

Table 3 Relative power of EEG rhythms at different assessment phases and conditions for the memorization period.

Learning conditions	Alpha	PD_{NvsS}	Beta	PD_{NvsS}	Theta	PD_{NvsS}	Gamma	PD_{NvsS}
Easy Phase								
Silent	4817.95	↑ 26%	3579.56	↑ 37%	532.27	↑ 45%	8812.92	↑ 15%
Noisy	6076.47		4915.74		772.19		10142.63	
Difficult Phase								
Silent	4305.65	↑ 43%	3400.30	↑ 48%	552.19	↑ 49%	7760.57	↑ 36%
Noisy	6163.91		5048.66		824.46		10569.57	

Table 4 Relative power of EEG rhythms at different assessment phases and conditions for recalling period.

Learning conditions	Alpha	PD_{NvsS}	Beta	PD_{NvsS}	Theta	PD_{NvsS}	Gamma	PD_{NvsS}
Easy Phase								
Silent	10797.29	↓ 36%	8447.41	↓ 20%	1264.73	↓ 13%	19210.98	↓ 42%
Noisy	7965.59		6764.92		1122.19		13566.17	
Difficult Phase								
Silent	11145.12	↓ 31%	8424.87	↓ 23%	1260.04	↓ 16%	19833.37	↓ 33%
Noisy	7684.18		6495.70		1056.17		13362.63	

Conclusion

The recent work discovers the effect of silent and noisy conditions on memory performance. Two indicators were used for evaluation which are the behavioral result and EEG analysis. This work mitigates the previous work that mostly depends on behavioural results to evaluate the memory performance, which limits the understanding of their effect on brain state. Besides, this work also proposed selecting the EEG channel as the first step before extracting the desired features. In this way, the most influential EEG channel can be determined instead of processing all the channels, which reduces the execution MATLAB time. The Butterworth bandpass filter was used to remove the noises in EEG signal and extract the rhythms. The relative power was determined from each of the rhythms. The behavioral result showed that the participants had better scores when listening to white noise related to the activation of alpha, beta, theta, and gamma activities. It had been found that attentional, alertness and image processing were improved when listening to white noise, which contributed to the successfulness of image encoding and retrieval. The participant had better scores for easy and difficult phases of noisy condition. Therefore, this work suggested that the white noise at 40 to 55 decibels of volume could be played while memorizing the images. However, the recent work may need a few improvements for further investigation, such as increasing the number of participants, considering other types of EEG features, varying the types of noises, and employing an advanced processing method.

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