Journal of Medical Devices Technology 1 (2022) 38-44

Journal of Medical Devices Technology

jmeditec.utm.my

Original Research

Electroencephalogram Pattern under Exposure of Audio Stimulation and Verbal Memory Assessment

Syarifah Noor Syakiylla Sayed Daud[1], Rubita Sudirman[1,2*], Norhafizah Ramli[1]

[1] School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[2] Medical Device and Technology Center (MEDITEC), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

ARTICLE INFO

Article History:
Received 18 August 2022
Accepted 5 September 2022
Available online 15 September 2022

Keywords:
Electroencephalography pattern,
Verbal memory,
Brain rhythms,
Relative power,
Features,
Ambient noise,
Favorite song.

ABSTRACT

Discovering brain activities during mental and cognitive assessments is interesting research work. It aids people in understanding how the information is stimulated and processed in the brain. This recent work aims to investigate brain activities using electroencephalography (EEG) under audio and verbal memory assessment stimulation. Besides, the effect of audio on verbal memory performance was investigated based on behavioral data and its association with EEG patterns. The subject was required to memorize a list of words at three difficulties level under control conditions, listening to their favorite song, and exposure to ambient noise. The brain signal was acquired during the memorizing period using an EEG machine based 10-20 electrode placement system. The raw EEG signal was filtered using a Butterworth bandpass filter at 4 to 40 Hz. After that, the brain rhythms of alpha, beta, gamma, and theta were extracted from the EEG signal. The mean voltage and relative rhythm power were obtained to determine their pattern under provided stimulation. The findings indicated that the mean EEG voltage and relative rhythms power were the highest and the most influenced under audio stimulation for all assessment phases compared to the control condition. The relative rhythm power showed the increment and decrement trend relative to the control condition. Theta rhythms exhibit the highest relative power with the maximum value found in ambient noise stimulation. The behavioral data revealed that the subject memorized better the word lists in ambient noise conditions.

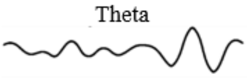
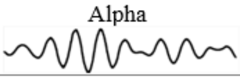
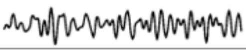
INTRODUCTION

The advancement of brain imaging tools contributes increment of research related to brain function and process. The need for brain research to better understand its structure, roles, and factors that influence its performance is vital. Electroencephalography (EEG) is often utilized to measure and record the brain's electrical signal (Dadebayev et al., 2021; Jackson and Bolger, 2014). EEG is widely preferred because it is portable, accessible, affordable, short signal acquisition duration, non-invasive, non-painful, and non-harmful to the subject (Rashid et al., 2020). The raw EEG signal requires to be processed to obtain the time-frequency features. The EEG signal is commonly decomposed into specific frequencies associated with particular behaviors, awareness levels, arousal levels, and sleep states. This specific frequency is defined as the brain rhythms, which can be divided into five types: alpha rhythm, beta rhythm, theta rhythm, gamma rhythm, and delta rhythm (Suresh et al., 2014; Zhuang et al., 2009). Table 1 describes the specific state of these rhythms and their related properties.

The investigation of the influence of audio stimulation on memory performance is usually based on behavioral data, which limits the understanding of its association with brain activities. Hence, this research aims to determine the connection between behavioral data and brain activities to gain better information about memory. Many types of audio stimulation have been tested to determine their effectiveness on cognitive and memory performance. For instance, classical music (Lange-Küttner and Rohloff, 2020; Limyati et al., 2019; Silva et al., 2020), rock song (Bugter and Carden, 2012; Wang et al., 2020; Yeoh and North,

* Rubita Sudirman
Medical Device and Technology Center (MEDITEC), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Table 1 Brain rhythms and it related properties (Rashid et al., 2020; Suresh Manic et al., 2014).

Brain Rhythms	Amplitude (µV)	Frequency (Hz)	Brain States
Delta 	100 – 200	0.5 – 4	Deep sleep or waking state
Theta 	5 – 10	4 – 8	Memory formation, information processing, working memory, sensorimotor integration, relaxed, and meditative state of mind
Alpha 	20 – 80	8 – 13	Relaxed awareness without concentration and attention
Beta 	1 – 5	13 – 30	Active and conscious thinking, intellectual activity, a high level of alertness, attention, and arousal
Gamma 	0.5 – 2	> 30	Responsible for sensory processing, higher mental activity, and activities related to movement

2010), sentimental song (Aubé et al., 2013; Nineuil et al., 2020), pure music (Su and Wang, 2010), white noise (Daud and Sudirman, 2017; Söderlund et al., 2010), pink noise (Hatayama et al., 2021), and many more. Meanwhile, the cognitive assessment such as spatial tasks (Pecci et al., 2016; Raouf and Raiesdana, 2020), mathematical questions (Cranmore and Tunks, 2015; Incognito et al., 2022), and visual memory (Abrahan et al., 2021; Moltrasio et al., 2020) had been used. Some audio provides a positive effect, while some have a negative effect or null effect. Due to this, it has attracted researchers worldwide to discover the effect of audio stimulation on cognitive and memory performance.

The brain has three main types of memory processes: sensory, short-term, and long-term (Ballesteros, 1999; Tyng et al., 2017). Figure 1 shows the types of human memory. Human memory is an essential mental process that gains many implications in life. The person needs a good memory to remember the meaningful event and enable to perform various tasks and achieve desired goals. The information acquired from stimuli will be detected by human senses: sight, hearing, touch, smell, and taste. The sensory memory is created and immediately processed in the brain at this stage. The information is stored in sensory memory for less than one second. Then, the information is encoded into short-term memory, and some are transferred to long-term memory. The storing process of information in the brain can be disturbed by a few factors such as cognitive, environmental, emotional, meta-memory, and physical state (Martín Gómez, 2016; Zhuang et al., 2009). As a result, it leads to the disremembering or forgotten condition. Therefore, investigating memory and its influential factors is required to reduce disremembering and improve memory performance. This recent research work determines environmental factors' effect on memory performance using verbal assessment. Verbal memory is often considered a short-term memory class that reflects the ability of the person to hold the verbal information in the brain for a brief amount of time (Echaide et al., 2019). Verbal memory is vital in individual life because every day, the person engages with verbal information in working, learning, shopping, and other daily activities. Hence, it is necessary to discover which environmental condition is the best for verbal memory that can be applied by the person when deal with verbal information

MATERIALS AND METHOD

This section describes the criteria of subjects, type of stimuli, materials, and equipment used, experimental process, data processing, and features extraction procedures. Figure 2 represents the research framework for this study.

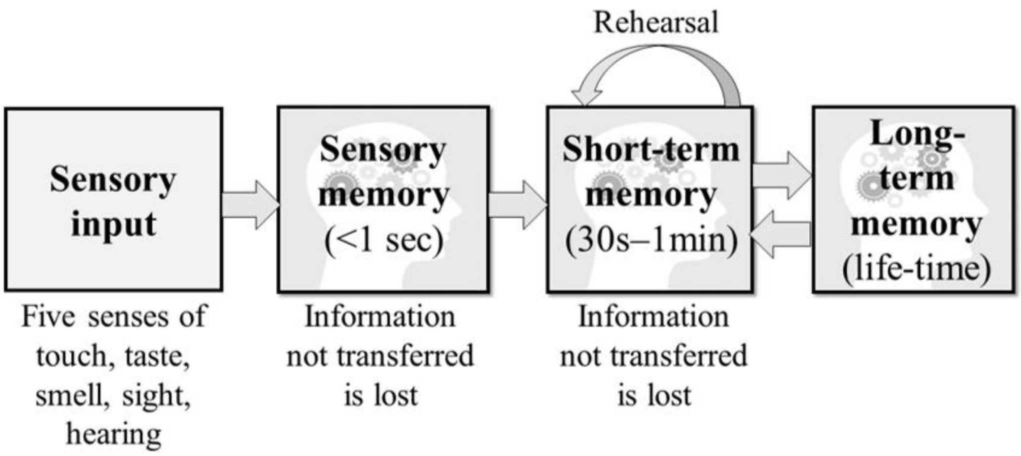


Fig.1 Stages of information process in memory (Daud & Sudirman, 2022).

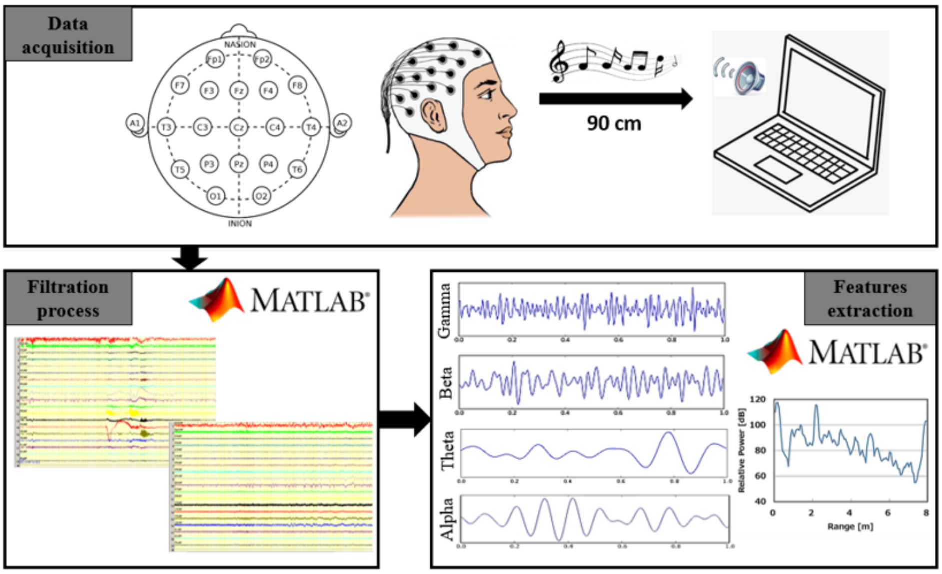


Fig. 2 Illustration of a research framework for discovering the effect of environments on verbal memory.

Criteria of Subjects

Fourteen college students with ages ranging from 22 to 24 (mean: 22; standard deviation: 0.48) years old were selected for the experiment. Seven of them are males, and seven are females. All of them are well-conditioned, have no hearing problem, are not hypersensitive to audio stimulation, have normal sight, and have no memory-related disease. They were required to complete the ethical consent form, demographic information, and survey questions about learning activities. The procedure of the experiment was explained to the subject before it began. The experiment was conducted in control and acoustically insulated room. This research work was approved by Malaysia National Medical Research Register, No. 21-02365-GVD.

Verbal Assessment and Testing Environments

The verbal assessment based on the list of words was selected in this research. Three phases of task difficulties were chosen to determine the subject's capability to memorize the words. The assessment was divided into phase 1: easy level, phase 2: medium level, and phase 3: high level. The easy level assessment contains five words that are routinely applied, whereas the medium level consists of ten words that combine the word routinely and are seldom used. Meanwhile, the high level contains sixteen words that combine the word routinely and are seldom used. The testing environments were divided into three conditions: silent/control, listening to a favorite song, and listening to ambient noise. The audio was played using the external speaker, and volume was controlled at 200% of VLC media players. The subjects were exposed to the audio during the memorizing process.

Experimental Process and EEG Signals Recording

The subjects were required to fill up the required forms and instructed to limit their movement during the data acquisition process to reduce the noise. After all the equipment and material

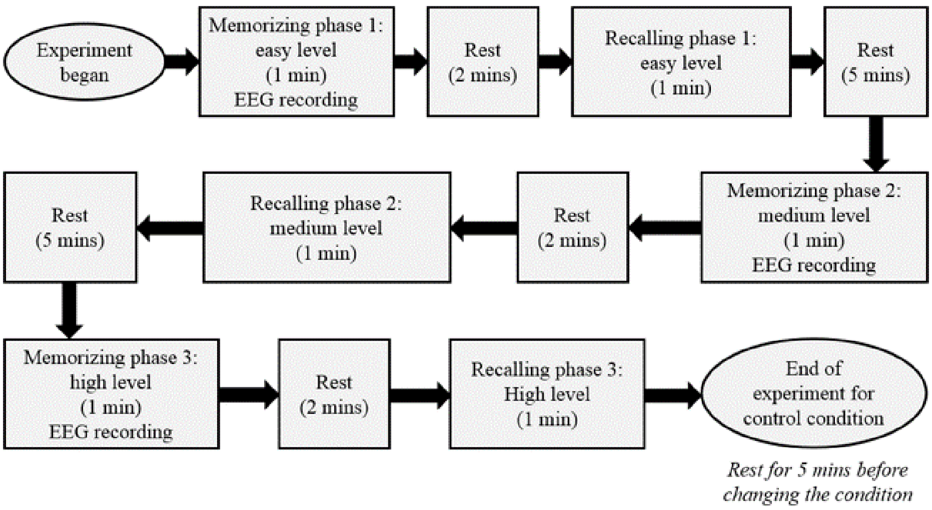


Fig. 3 Flow of experiment.

had been set up, the subject was asked to follow the instruction given in the provided stimulation program. The memorization began with the control condition, followed by listening to ambient noise and a favorite song. They were given 1 minute to memorize and rest for 2 minutes before recalled back the words. The recalling duration was 1 minute. The task given started with an easy level, followed by medium and high levels. The flow of the experiment was summarized in Figure 3.

The EEG machine (Neurofax 9200, USA) used 10-20 electrode placement (Figure 2) with two electrodes referencing A1-left and A2-right mastoid, recording the brain signal during the memorization period. The EEG signal acquired from 19 (Fp1, Fp2, F3, F4, F7, F8, Fz, T3, T4, T5, T6, C3, C4, Cz, P3, P4, Pz, O1, and O2) selected electrodes that placing on the head scalp of subjects. The EEG system was set to 70 hertz of amplifier high-pass filter, 500 hertz of sampling rate, 10 microvolts of sensitivity, 0.3 seconds of time constant, Aav of reference, an average of EEG pattern, and impedance ≤ 10 kiloohms. The raw EEG signals were saved in ASCII format and exported in Matlab R2021b for further processing.

EEG Signals Pre-processing and Features Extraction

Even though extra precautions had been taken during acquisition, the raw EEG signals were still contaminated with noises. Therefore, the noises need to be removed to avoid the confusion of EEG real information. This work used a Butterworth bandpass filter with 4 to 40 hertz to remove low-frequency and high-frequency components of noises. The low-frequency noise comes from eye movements and blinking, whereas high-frequency noise is associated with muscle movements. After filtration, the EEG signals were decomposed into alpha, beta, theta, and gamma rhythms using a bandpass filter. Then, the mean of EEG voltage and relative power was extracted from each rhythm. Finally, the behavioral data were obtained from recalled words.

RESULT AND DISCUSSION

This section describes the effect of control, a favorite song, and ambient noise on verbal memory based on brain rhythms activities and behavioral data.

Effect of Stimulation on Brain Rhythms

The mean EEG voltage and relative power were calculated from alpha, beta, theta, and gamma rhythms. The delta rhythm was excluded from analysis because it is more related to sleep behavior, which is not involved in this study. Table 2 and Figure 4 show the relative power in different environments and assessment phases.

The highest mean EEG voltage was found at ambient noise stimulation for phase 1 and favorite song for phase 2. Meanwhile, a similar highest mean value was found for phase 3 at the control and favorite song. The difference in mean EEG voltage was not obvious between each environmental condition and phase. The EEG voltage is an alternating voltage that measures ionic current flow through the brain's neurons. Higher EEG voltage indicates a more significant flow of ionic current from activated neurons. In Table 2, a slight high in ionic current flow was observed under audio stimulation for all assessment phases, except for high level difficulty, including control condition. Therefore, it can be stated that the audio stimulation had more influence on the ionic current flow of the neuron compared to the control condition.

Brain rhythms represent the repetitive and distinct patterns of aggregated neuronal activity associated with particular actions of sleep states, awareness, and arousal levels. It can be divided into several types depending on its characteristics, as in Table 2. According to Table 2, the theta rhythm exhibited the highest relative power at 3500-5000, followed by the alpha rhythm with the range 1000-2000. On the other hand, the lowest relative power was observed for gamma rhythm. The theta rhythm was the most influential because the study involved memory-related activities. As mentioned earlier, the theta represents memory formation and processing; therefore, high theta activities were found. Meanwhile, the gamma activities were the lowest because this work does not involve high cognitive function. This work only requires the subject to memorize the list of words, which does not need high critical thinking and spatial ability.

The alpha rhythm in Table 2 and Figure 4 associated with a relaxed state showed that the relative power was the highest when subjects listened to their favorite song for all assessment phases. High relative alpha power represents subjects more relaxed memorizing the words while exposed to a favorite song.

Table 2 EEG features at various stimulation.

Environment conditions	EEG voltage (μV)	Relative power			
	Mean ± Standard deviation	Alpha	Beta	Gamma	Theta
Phase 1: Easy level					
Control	0.06 ± 266	1430.87	302.68	6.56	4607.37
Favorite song	0.04 ± 256	**1669.74**	**362.16**	8.92	4602.16
Ambient noise	**0.08 ± 272**	1549.38	338.57	**13.13**	**4987.61**
Phase 2: Medium level					
Control	0.05 ± 234	1195.30	246.76	5.83	3696.28
Favorite song	**0.06 ± 248**	**1358.07**	**296.70**	**5.85**	**3965.02**
Ambient noise	0.04 ± 236	1126.43	216.63	5.11	3862.40
Phase 3: High level					
Control	**0.06 ± 229**	1176.02	250.00	6.26	3536.01
Favorite song	**0.06 ± 252**	**1514.48**	**295.11**	**6.43**	3969.84
Ambient noise	0.04 ± 260	1083.05	207.11	5.91	**4630.62**

The subjects feel more comfortable in this state because of their emotion that they like the song. However, it cannot be stated that either it benefits the verbal memory performance or not because it may lead to a loss of interest for the subject in memorizing the words. They may focus more on songs than the required task. The lowest relative alpha power was observed at the control condition for phase 1 and ambient noise for phase 2 and phase 3. This result revealed that the subject's relaxation state was disrupted under control/silent conditions for memorizing easy level assessment. They may feel bored in the control condition because the easy level assessment does not need their full attention to memorization because the words are commonly used. For medium and high level assessment, the subject felt disrupted when listening to ambient noise while memorizing because they needed to split their focus by listening to audio or remembering. Later, the discussion on behavioral data will aid in exact determining the influence of environmental conditions on verbal memory assessment.

Beta activities are related to people's attention, alertness, and arousal level. Table 2 and Figure 4 showed that the highest relative beta power had a similar environmental condition with relative alpha power. The highest relative power of beta activities was observed at favorite song stimulation for all phases. It indicated that the subject needed to focus on the task while listening to the song. The relative power difference for the favorite song was a bit higher compared to the control condition. The percentage difference was 20% for phase 1 and phase 2, and 18% for phase 3. The control condition exhibits the lowest relative beta power for easy assessment, which means less attention and alertness were required to memorize the words. In contrast, the ambient noise gained the lowest relative beta power for both medium and high level assessments. It indicated that lower attention and alertness level was a need for memorizing when listening to ambient noise compared to other conditions when the task difficulty increases. Loading more verbal items to be memorized reduce the attention/alertness in exposure to ambient noise compared to the control condition due to the subject's ability to filter out the noise and give priority to task instead of audio.

Gamma rhythm is associated with higher sensory processing, higher mental activity, and activities that are related to movement. It seems that the relative gamma power obtained the highest value at ambient noise stimulation for phase 1, whereas phase 2 and phase 3 were found at favourite song stimulation. The assessment phases were influenced by audio stimulation more than the control condition. High relative gamma power in audio stimulation occurred due to more sensory information that needs to be processed by the brain. In this case, the sensory information came from hearing (audio stimulation) and sight (verbal assessment). In the control condition, the sensory information was only sourced from sight responsiveness, which led to low relative gamma power. In comparison with audio stimulation, it seems that the favorite song more influenced gamma activities when memorizing items often and seldom used. Among the assessment phases, phase 1 obtained the highest values for all environmental conditions, meaning high sensory information had been processed.

The occurrence of theta rhythm in the brain represents memory formation, information processing, working memory, sensorimotor integration, relaxed and meditative state of mind. Therefore, the brain can determine the success of loaded items to be registered and processed based on theta power. High relative theta power indicated high information had been processed and memory formed. Table 1 and Figure 4 observed that the highest relative theta power was at ambient noise for phase 1 and phase 3, whereas the favorite song exhibited the highest at phase 2. The percentage difference of relative power was 8% for the ambient noise of phase 1, 7% and 31% for the favorite song of phase 2 and phase 3, respectively. Relative theta power revealed that the brain could produce more theta rhythm when subjects memorized the easy and high level assessment under ambient noise stimulation. Meanwhile, high theta activities were observed at the favorite song for medium level

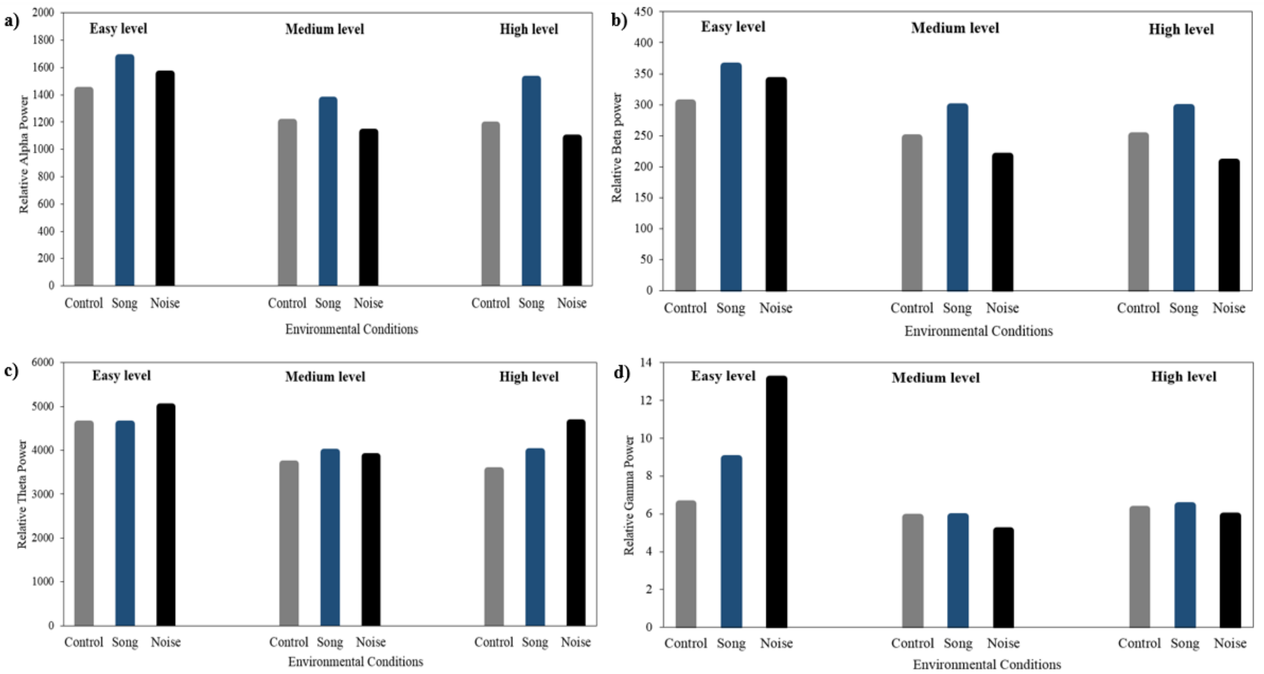


Fig. 4 Relative power of a) alpha rhythm, b) beta rhythm, c) theta rhythm, and d) gamma rhythm at different environmental conditions and assessment phases.

Table 3 Percentage score of verbal memory assessment at different environmental conditions and assessment phases.

Environmental conditions	Percentage Score (%)			
	Easy	Medium	High	Average
Control	98	71	55	75
Favorite song	95	75	59	76
Ambient noise	100	74	65	80

assessment. Therefore, it can be stated that more memorized items can be registered and processed in the brain when subjects were exposing to audio stimulation. This could be related to subjects' arousal, alertness, and emotion, where they felt disrupted by the presence of audio that required them to be more focused and alerted on tasks and filter the audio.

Behavioural data

Table 3 shows the percentage score of verbal memory assessment for control and audio stimulation phases 1, 2, and 3. It seems that different memorizing ability was found at different stimulation. The subjects can memorize better under ambient noise stimulation for the easy and high level of assessment, whereas the highest score was found for the favourite song of medium level. Based on the score result, the easy level achieved the highest percentage compared to the medium and high levels. This could be due to a characteristic of the task that often used words that easily made subjects memorize. The subjects managed to remember all the words under ambient noise, followed by control (98%) and favourite song (95%). Meanwhile, the percentage score of medium and high levels was below 80% due to increased task difficulty. Increasing the number of words to be remembered had reduced subjects' memory performance. However, exposure to audio stimulation can improve memory performance, which means more words can be remembered compared to the control condition. Through the result, it can state that ambient noise was the most appropriate environmental condition for memorizing items related to verbal memory.

CONCLUSION

The work describes the effect of environmental conditions such as control, a favourite song, and ambient noise on verbal memory performance. It had been found that the subjects managed to memorize better under audio stimulation than in control. The most effective condition was ambient noise which obtained the highest mean score. This can be correlated with brain activities. It can be seen that the relative theta power was higher for almost assessment, where this rhythm represents the information processing and memory formation. During listening to ambient noise, more theta rhythm can be found in EEG signal, indicating that the loaded word through visual can be registered and appropriately processed in the brain. Besides, the disruption of emotions and mood when exposed to ambient noise forces subjects to focus more on the task, as can be seen from relative alpha and beta power. Listening to favourite songs reduced the subjects to entirely concentrating on assessment because they were more attracted to the song. Although like that, the memorizing performance of subjects was still better when listening to the favourite song compared to the control condition. Meanwhile, the relative gamma power indicated that verbal information caught by the subject's eyes could be processed better in audio stimulation. The brain rhythms were more affected when exposed to audio stimulation than in the control condition because audio loads more items/information that needs to be processed by the brain. The results indicated that the ambient noise was the most appropriate audio to be listened to for memorizing verbal memory items. The finding from this work can guide researchers in conducting research related to brain behaviour and stimulation influence and propose an environment suitable for learning verbal items. However, this research still requires further improvement, such as increasing the number of subjects, varying the assessment types, extracting more EEG features, and proposing other types of audio stimulation for better comparison.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support provided by the Malaysia Ministry of Higher Education and Universiti Teknologi Malaysia under UTMER grant Q.J130000.3851.20J75, UTMER grant Q.J130000.2651.17J69, and Post-Doctoral Fellowship Scheme Q.J130000.21A2.05E52 for this project.

REFERENCES

Abrahan, V. D., Shifres, F., Justel, N. 2021. Music improvisation enhances neutral verbal and visual memory in musicians and non-musicians alike. Arts Psychother. 48(27), 1-16.

Aube, W., Peretz, I., Armony, J. L. 2013. The effects of emotion on memory for music and vocalisations. Memory 21(8), 981-990.

Ballesteros, S. 1999. Human memory: Research and theory. Psicothema. 11, 785-800.

Bugter, D., Carden, R. 2012. The effect of music genre on a memory task. Mod. Psychol. Stu. 17(2), 87-90.

Cranmore, J., Tunks, J. 2015. Brain research on the study of music and mathematics: A meta-synthesis. J. Math. Educ. 8(2), 139-157.

Dadebayev, D., Goh, W. W., Tan, E. X. 2021. EEG-based emotion recognition: Review of commercial EEG devices and machine learning techniques. J. King Saudi University-Comput. Inf. Sci., 34(7), 1-19.

Daud, S. N. S. S., Sudirman, R. 2017. Evaluating the effect of mozart music and white noise on electroencephalography pattern toward visual memory. Adv. Scie. Technol. Eng. Sys. J. 2(3), 1372–1380.

Daud, S. N. S. S., Sudirman, R. 2022. Effect of audiovisual stimulation on adult memory performance based electroencephalography wavelet analysis. Biomed. Signal Processing Control. 76(103659), 1-14.

Echaide, C., del Rio, D., Pacios, J. 2019. The differential effect of background music on memory for verbal and visuospatial information. J. Gen. Psychol. 146(4), 443-458.

Hatayama, A., Matsubara, A., Nakashima, S., Nishifuji, S. 2021. Effect of pink noise on eeg and memory performance in memory task. In 2021 IEEE 10th Global Conference on Consumer Electronics, GCCE 2021. October 12-15. Kyoto, Japan. 1

Incognito, O., Scaccioni, L., Pinto, G. 2022. The impact of a music education program on meta-musical awareness, logical-mathematical, and notational skills in preschoolers. Int. J. Music Educ. 401, 90-104.

Jackson, A. F., Bolger, D. J. 2014. The neurophysiological bases of EEG and EEG measurement: A review for the rest of us. Psychophysiology. 51(11), 1061-1071.

Lange-Küttner, C., Rohloff, S. 2020. Mozart sharpens and mahler degrades the word memory trace. Adv. Res. Psychol. 1(1), 1-8.

Limyati, Y., Wahyudianingsih, R., Maharani, R. D., Christabella, M. T. 2019. Mozart's sonata for two pianos K448 in D-Major 2nd movement improves short-term memory and concentration. J. Med. Health Sci. 2(4), 930-929.

Martin Gomez, C. 2016. Essentials of human memory. Int. J. Educ. Psychol. 5(1), 108-110.

Moltrasio, J., Detlefsen, M. V., Rubinstein, W. 2020. Activating music improves visual memories in patients with Alzheimer's disease. Neurol. Argent. 12(3), 186-193.

Nineuil, C., Dellacherie, D., Samson, S. 2020. The impact of emotion on musical long-term memory. Front. Psychol. 11(2110), 1-8.

Pecci, M. T., Verrusio, W., Radicioni, A. F., Anzuini, A., Renzi, A., Martinelli, V., Cacciafesta, M. 2016. Music, spatial task performance, and brain plasticity in elderly adults. J. Am. Geriatr. Soc. 64(10), 78-80.

Raouf, M., & Raiesdana, S. 2020. Investigating the effect of music on spatial learning in a virtual reality task. Caspian J. Neurolog. Scie. 6(2), 71-83.

Rashid, M., Sulaiman, N., P. P. Abdul Majeed, A., Musa, R. M., Ahmad, A. F., Bari, B. S., Khatun, S. 2020. Current status, challenges, and possible solutions of EEG-based brain-computer interface: A comprehensive review. Front. Neurorobot. 14(25), 1-35.

Silva, S., Belim, F., Castro, S. L. 2020. The Mozart effect on the episodic memory of healthy adults is null, but low-functioning older adults may be an exception. Front. Psychol. 11(538194), 1-15.

Soderlund, G. B. W., Sikstrom, S., Loftesnes, J. M., Sonuga-Barke, E. J. 2010. The effects of background white noise on memory performance in inattentive school children. Behav. Brain Funct. 6(55), 1-10.

Su, Q., Wang, F. 2010. Study the effect of background music on cognitive memory. Appl. Mech. Mater. 37-38, 1368–1371.

Suresh Manic, K., Saadha, A., Pirapaharan, K., Aravind, C. V. 2014. Characterisation and separation of brainwave signals. J. Eng. Scie. Tech. 32-44.

Tyng, C. M., Amin, H. U., Saad, M. N. M., Malik, A. S. 2017. The influences of emotion on learning and memory. Front. Psychol. 8(1454), 1-22.

Wang, S., Li, Y., Li, J., Wang, L., Yin, N., Yang, S. 2020. Research on the effect of background music on spatial cognitive working memory based on cortical brain network. J. Biomed. Eng. 37(4), 587-595.

Yeoh, J. P. S., North, A. C. 2010. The effect of musical fit on consumers' memory. Psychol. Music. 38(3), 368-378.

Zhuang, T., Zhao, H., Tang, Z. 2009. A study of brainwave entrainment based on EEG brain dynamics. Comput. Inf. Sci. 2(2), 80-86.