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EFFECT OF WHITE NOISE STIMULATION AND VISUAL WORKING MEMORY TASK ON BRAIN SIGNAL

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ABSTRACT

Researcher had claimed that white noise is one of the sound stimulation that is able to improve the human cognitive thinking. This study aims to determine the effect of white noise and visual working memory task on brain signal. The performance of the subject during the task has been analyzed based on the brain signal activation at location Fp1, Fz, F8, Pz, O1 and O2. In achieving the objective of this study, an experiment has been conducted that involving twenty six adult subjects. They are required to memorize the task within two minutes. Electroencephalography (EEG) machine (Neurofax 9200) with 10-20 placement electrodes was used to record the electrical activity of the brain. Two features which are mean and standard deviation has been extracted from the EEG signal by using stationary wavelet transform approach. *T*-test analysis has been done to determine the significant differences between the sound stimulation and control condition. The result shows that there is a significant difference between white noise and silence condition at certain brain locations. Findings from this study show that the location Fp1 and Fz is mostly affected by sound stimulation and visual working memory task.

Keywords: white noise, brain signal, stationary wavelet transform, *t*-test.

INTRODUCTION

Education plays a vital role in a country. It is a form of learning process that involves the teaching, discussion, training and research whether on science, technology, art, engineering and law. Generally, education can be divided into different categories such as pre-school, primary school, secondary school and college or university. Academic achievement is one of the aspect that grade the student performance. Obtaining a good grade is not an easy thing, whether student, teacher and parent should play their role to achieve this objective. There are a few types of modalities that always apply in academic institutions which are musical, interpersonal, intrapersonal, verbal, visual, auditory, logical and kinesthetic (Cowan, 2008). Many of the learning activities that student is engaged within the academic institution, whether related to reading, calculation, memorizing, or other areas impose quite considerable burdens on working memory. Last a few decades much research has been done to determine the relations between sound stimulation and working memory (Soderland, 2010). The cognitive processing is easily disturbed by incompatible environmental stimulation, which distracts attention from the tasks and cause loss of information (Soderland, 2010). Some researchers claim that listening to white noise at specific volume and time able to improve the cognitive process (Soderland, 2010). White noise can be defined as a sound or electrical noise that has a relatively wide continuous range of frequencies of uniform intensity (Soderland, 2010). The human brain is a complex organ in the human body. Each of the input information come from 5 sensory responsiveness (touch, smell, visual, sight and taste) is transfer and process in the brain before pass to the other organs to make a response. Electroencephalography is a modality that able to record the brain signal. This paper aims to determine the effect when people expose to white noise stimulation at medium volume during memorizes the visual working memory task. The brain signal is recorded using electroencephalography modality. It discussed based on the features (mean and standard deviation) that extract from the electroencephalography signal by using stationary wavelet transform approach.

Human brain and working memory

Generally, the brain is approximately three pounds, walnut-like object that consists billions of neurons that communicate which trillions of connections called synapses (Gless, 2005). The input information will be processed whether by right side or left side of the brain. The right side of the brain more concerned about color, dimension, spatial awareness, imagination, daydreaming and rhythm, whereas the left side are focused on logic, word lists, number, sequence, lines and analysis (Glees, 2005). Major regions of the brain are cerebral hemisphere, diencephalon, brain stem and cerebellum. Researcher always interested on the cerebral hemisphere compare to other regions in order to know deeply about how the brain is working (Park *et al.* 2011) . It consists of four lobes, which are parietal, occipital, frontal and temporal (Gless, 2005). Each of them represents their own role. Many brain imaging techniques have been introduced such as computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), electroencephalography (EEG) and etc. However, electroencephalography is the most popular one compare to others. It is a non-invasive techniques, harmless and painless, able to record in milliseconds and low cost. The international 10-20 electrode placement is a recognize method that describes the location of the scalp of the human head for experiment or test purpose (Carr and Brown, 2001). The electrode placement is standardized according to the lobes of the brain where location Fp1,

Fp2, F3, F4, F7, F8 and Fz represent the frontal lobe, P3, P4 and Pz represent the parietal lobe, location O1, Oz and O2 represent occipital lobe and lastly the location T3, T4, T5 and T6 represent the temporal lobe. Figure-1 shows the international 10-20 placement electrode.

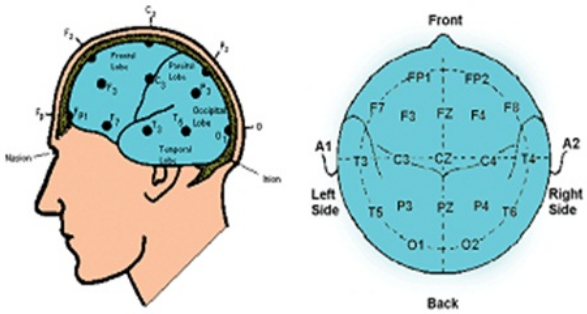

Figure-1. International 10-20 placement electrode (Carr and Brown, 2001).

Working memory or short-term memory is a system in our brain that responsible for temporarily storing and manipulating information (Suprenant and Neath, 2013). Example of activities that involve this system is mental arithmetic, remembering a new phone number, address, pin number or vehicle registration number. The capacity of this system is limited and the stored information easily loss (Suprenant and Neath, 2013). There are three examples of situation that cause the losing of information such as distraction, trying to hold in mind too much information and engaging in a demanding task (Suprenant and Neath, 2013). Having a good working memory is crucial for the student due to everyday they expose to learn a new information. Various models of working memory have been implemented in order to understand the process of this system (Suprenant and Neath, 2013).

According to (Baddeley, 2000) there is three different systems consists in working memory in order to process the information (Baddeley, 2000). Figure-2 shows the model of working memory.

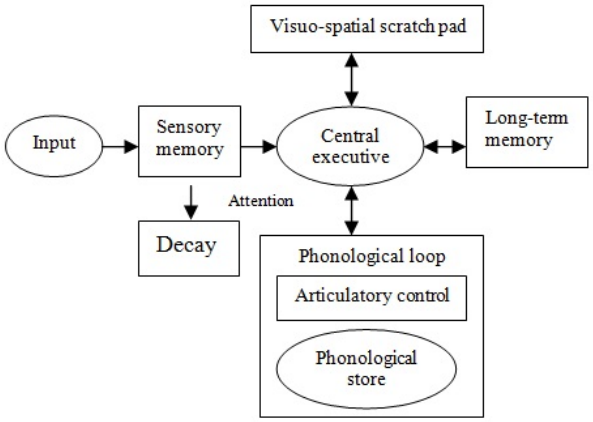

Figure-2. Model of working memory (Baddeley, 2000).

It consists of a central executive, phonological loop (subsystem) and visuo-spatial sketch pad (subsystem). The central executive drives the whole system and allocates the information to the subsytems (Baddeley, 2000). Besides that, it is also dealing with the cognitive tasks such as problem solving, mental arithmetic and memorizing verbal task. The visuo-spatial sketchpad is a subsystem that stores and processes information in a visual or spatial form (Baddeley, 2000). The second subsytem, the phonological loop is deals with spoken and written material (Baddeley, 2000). It consists of two parts which is phonological store and articulatory control process. The phonological loop is linked to speech perception and holds the information in speech-based form within 1 to 2 seconds (Baddeley, 2000). The articulatory control process is linked to speech production and used to rehearse and store verbal information from the phonological store (Baddeley, 2000. There are many researchs has been done with studying various aspects of working memory in the educational and medical field. As examples by using the capacity of working memory capacity to determine cognitive abilities, brain pattern during the task, brain pattern between normal and epilepsy people and the effect of sound stimulation (Park *et al.* 2011; Zhang *et al.* 2009; Schack *et al.* 2002 and Rebsamen, Kwok and Penney, 2011)

Stationary wavelet transform

Wavelet is one of the popular approaches for signal denoising especially for non-stationary signals like EEG (Yasoda and Shanmugan, 2014). It able to change the time domain signal to the frequency domain that important during analyzing stage. The aim of signal denoising is to remove the unwanted frequency of the signal. Electroencephalography (EEG) signal easily corrupted by noise such as muscle movement (electromyography) and eye movement and blinking (electrooculography) artifact. In paper of (Yasoda and Shanmugan, 2014; Mamun, Al-Kadi and Marufuzzaman, 2013; Garg and Narvey, 2013) used this method to remove the artifact from EEG signal and claim that the wavelet transform is the best approach used for signal denoising. The advantages of using this approach compare to discrete and continuous wavelet transform are yet able to maintain the frequency sampling after denoising process, thus the time invariance property is not lost (Palendeng, 2011). Time invariance property is important in signal due to it determine the characteristics of the signal. There are several types of mother wavelet such as haar, daubechies, coifflet, symlet, rbior, bior and dmey. Among the mother wavelet, a study by (Palendeng, 2011) found that Daubechies order 3 (db3) at 5 decomposition level is the best one because it able to remove the electroencephalography and electromyography effectively compare to others.

Related works

Noise is any unwanted sound that cause of the vibration, or a travelling wave. Human hearing is very sensitive to noise, although its volume is low. Usually

sound stimuli have been measured in decibels (dB). Research on examining the effect of sound on human cognition has been discovered long time ago (Hamilton and Copeman, 1970; Weinstein 1974; Nagar and Pandey, 1984). Researchers found that white noise can enhance the human cognitive processing. White noise can define as a sound that is created by combining all audible frequencies in equal amounts. Its sound is like gentle hiss. Study by (Soderland *et al.* 2010) has done an experiment on two different children groups in order to determine the effects of background white noise on memory performance. The attentive and inattentive children were undergoing episodic verbal free recall test in two different noise conditions (low and high volume). They had found that the background white noise, improved performance for inattentive children and worsened performance for attentive children.

In paper of (Soderland *et al.* 2009) investigates the effects of auditory white noise on attention and cognitive performance of a normal population. The findings had shown that, in the dichotic listening experiment there was a significant effect of noise on forced-right ear condition, whereas no significant effect on the visuo-spatial working memory task.

Finding by (Flodin *et al.* 2012) founds that the white noise has a significant effect on young group, but not for old group during verbal memory task and a visuo-spatial working memory task.

In our research, we focused on the effect of white noise during memorizing the visual working memory task at a different difficulty level based on brain signal analysis. An experiment has been done in order to record the brain signal that is used for determine the effect of sound stimulation and visual working memory task based on feature extraction and statistical analysis.

METHODOLOGY

Subject

In this preliminary study, twenty six adult subjects (13 females and 13 males) age ranging 23 to 25 years old were selected based on the mini-mental state examination (MMSE) score. The subject that achieves ≤ 26 out of 30 questions were selected in this research. The aims of MMSE is to determine the normality of people's memory. They also does not have hearing and visual problem.

Visual task working memory

In this experiment the subject requires to memorize the easy and difficult task of visual working memory. The task that used in this experiment is based on (Zhang *et al.* 2009) with some modifications. In our study we use 10 pictures whereas in (Zhang *et al.*) they use 15 pictures. Figure-3 and 4 show the task that uses in this experiment.

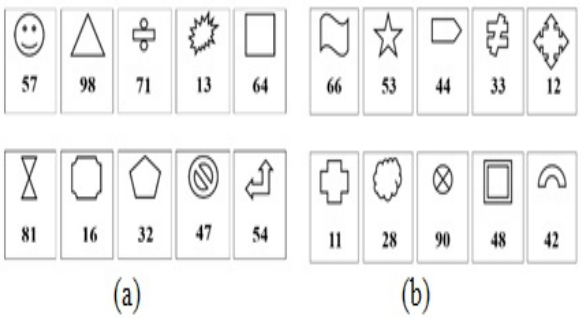

Figure-3. Easy task for experiment (a) Silence condition (b) White noise condition (Zhang *et al.* 2009).

Experimental procedure

The subject was asked to relax in about 5 minutes after entering the laboratory room and fill in the questionnaire. This questionnaire is regarding to their style of study and some basic info about their self. After the subject ready for experiment, they were asked to read the instruction that display on the laptop screen. Then, they were asked to open the program that has been created using movie maker. They were exposed to two different conditions which are silence condition and listening to white noise during memorizing task.

At first they were exposed to silence condition. They were required to memorize the easy task in 2 minutes. After that, they were rested for 30 seconds before recall the task. Then, they were rest 1 minutes before going memorize the difficult task in 2 minutes and rest for 30 seconds before recalling back the task. Lastly, before started memorizing in the white noise condition they were resting with seen the scenery picture that display on the laptop screen.

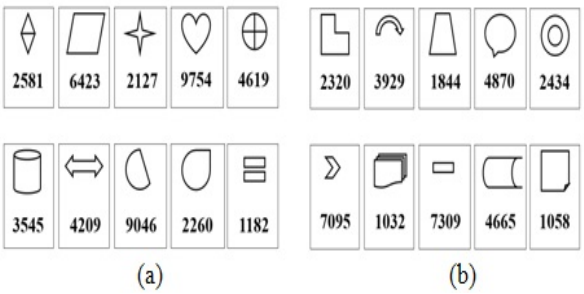

Figure-4. Difficult task for experiment: (a) Silence condition (b) White noise condition (Zhang *et al.* 2009).

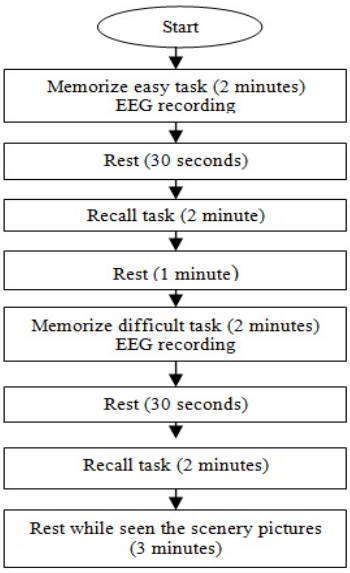

Figure-5. Program flow of data acquisition for silence condition.

The same procedure was used for white noise condition except they need to listen to white noise at first 5 minutes and during memorizing the task. The volume of white noise was controlled at 50 to 51 dB. Figures-5 and 6 show the flow of programs that use for data acquisition. The brain signal was recorded during memorizing time by using electroencephalography machine (Neurofax 9200).

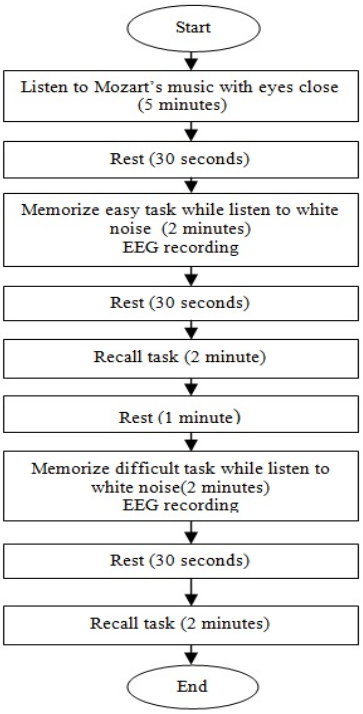

Figure-6. Program flow of data acquisition for white noise condition.

Data processing and analysis

A few steps were involved in data processing and analysis, which are data acquisition, data pre-processing (filtration process), feature extraction, and data analysis in order to achieve the objective of this study. The data acquisition was acquired during memorizing time using international 10-20 placement electrode of EEG machine (Neurofax 9200). However, in this study only six channels were interested that has relations with the sound stimulation and working memory. The channels are Fp1 (attention), Fz (working memory), F8 (emotional expression), Pz (cognitive processing), O1 (visual processing) and O2 (visual processing). Each of them represents the certain brain roles. The raw signal was saved in ASCII format before change to text format. A MATLAB and SPSS 16.0 software was used for data processing and analysis. In MATLAB software the wavelet toolbox is used for signal filtration and feature extraction. Stationary wavelet transform approach with Daubechies order 3 mother wavelet at decomposition level 5 is used due to its ability to remove the EMG and EOG artifacts without losing the time invariance property. Two features are extracted using this approach which is the mean and standard deviation at channel Fp1, Fz, F8, Pz, O1 and O2. Then, the paired samples *t*-test was done to analyze the effect of white noise on brain signal. The normality test was done on the data before proceeding to *t*-test. If the data does not in normal distribution it need to be changed by using some function in SPSS 16.0. Figure-7 shows the stages that involve in data processing and data analysis.

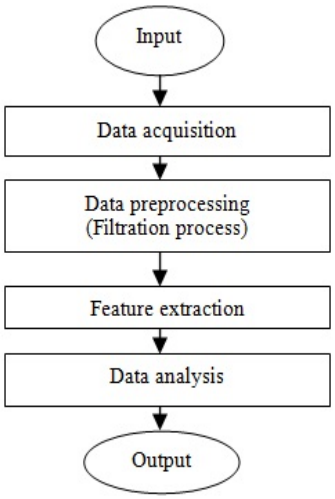

Figure-7. Stage of data processing and data analysis.

Figure-8 shows the EEG signal before and after filtration using db3 mother wavelet of stationary wavelet transform at decomposition level 5.

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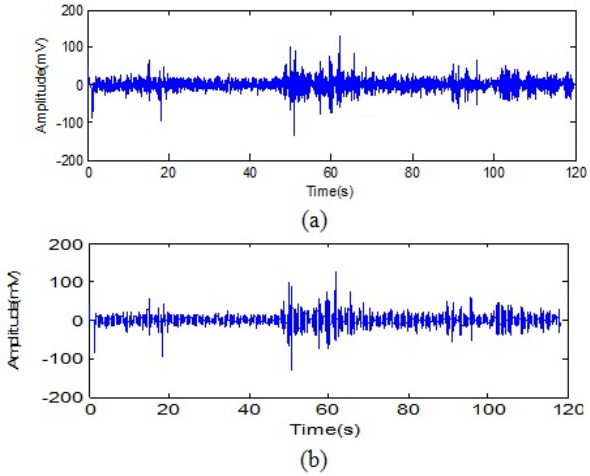

Figure-8. Electroencephalography signal: (a) Raw signal with artifacts (b) Clean signal after filtration.

RESULT AND DISCUSSIONS

The *t*-test analysis was done to mean value that extract from the electroencephalography signal (Fp1, Fz, F8, Pz, O1 and O2) in order to determine the significant difference between white noise and silence condition. Table-1, 2 and 3 show the average mean, average standard deviation and *t*-test value for easy and difficult task of silence and white noise condition for twenty six subjects.

Table-1. Average mean and average standard deviation for easy task of silence condition and white noise condition.

	Silence condition	White noise condition
Channel	Mean (standard deviation) (μV)	Mean (Standard deviation) (μV)
Fp1	0.38 (40.39)	0.22 (37.22)
Fz	0.38 (17.26)	0.26 (18.23)
F8	0.24 (22.25)	0.20 (20.84)
Pz	0.32 (12.71)	0.18 (10.87)
O1	0.29 (11.43)	0.20 (14.43)
O2	0.27 (11.89)	0.17 (12.50)

Figure-9. Average mean of difficult task at silence and white noise condition.

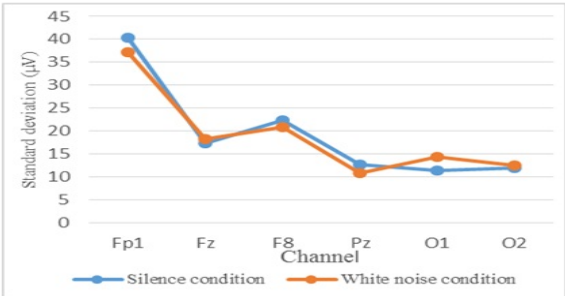

Figure-10. Average standard deviation of difficult task at silence and white noise condition.

Based on Table-1 and Figure-9, the average mean of silence condition (Fp1 = 0.38 μV, Fz = 0.38 μV, F8 = 0.24 μV, Pz = 0.32 μV, O1 = 0.29 μV and O2 = 0.27 μV) is higher than the white noise condition (Fp1 = 0.22 μV, Fz = 0.26 μV, F8 = 0.20 μV, Pz = 0.18 μV, O1 = 0.20 μV and O2 = 0.17 μV) at all channels. It indicates that the brain signal is more complex during silence condition compared to the white noise condition. At silence condition the channel Fp1 (mean = 0.38 μV), Fz (mean = 0.38 μV) and Pz (mean = 0.32 μV) give a higher mean value compare to other channels. Theoretically, the channel Fp1 representing the attention condition, Pz represents cognitive processing and Fz representing working memory action. The channel Fz (mean = 0.26 μV) has higher mean which indicates that the white noise gives more effect on this location compared to others. The brain signal is more active at Fp1 and Fz locations compared to others due to the subject need to be focused on the task during the experiment and the Fz location was involved to process the information from visual sensory. Figure-11 and 12 show the EEG signal at channel Fp1 and Fz that affected mostly during easy task experiment.

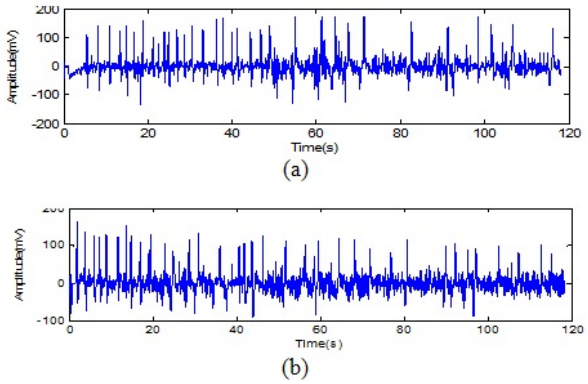

Figure-11. EEG signals at channel Fp1 (a) Silence condition (b) White noise condition.

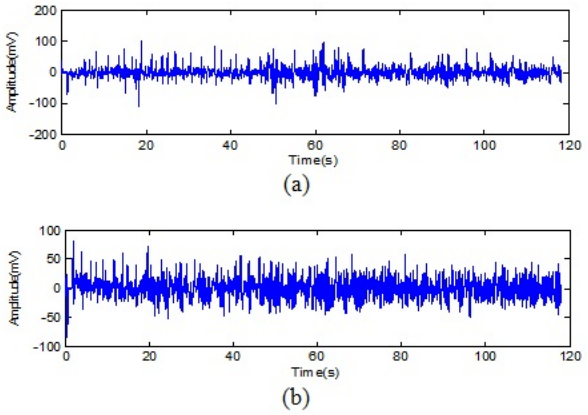

Figure-12. EEG signals at channel Fz (a) Silence condition (b) White noise condition.

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Standard deviation is a parameter that determines the amount of variations among the data. The lower the standard deviation examine that the data points tend to be very close to the mean. Standard deviation at silence condition for easy task is higher at certain locations (Fp1 = 40.39 µV, F8 = 22.25 µV and Fz = 17.26 µV) compared to white noise condition (Fp1 = 37.22 µV, F8 = 20.84 µV and Fz = 18.23 µV). As shown in Figure-10 and Figure-14 the standard deviation at channel Fp1, Fz and F8 is higher compared to others. It indicates that the data point at channel Fp1, Fz and F8 tend to be more spread out compare to channel Pz, O1 and O2.

Table-2. Average mean and standard deviation for difficult task of silence condition and white noise condition.

	Silence condition	White noise condition
Channel	Mean (standard deviation) (µV)	Mean (Standard deviation) (µV)
Fp1	0.55 (41.36)	0.21 (45.40)
Fz	0.51 (18.30)	0.24 (17.35)
F8	0.44 (22.11)	0.19 (18.99)
Pz	0.21 (12.35)	0.18 (12.23)
O1	0.38 (12.56)	0.19 (11.38)
O2	0.42 (10.98)	0.16 (12.29)

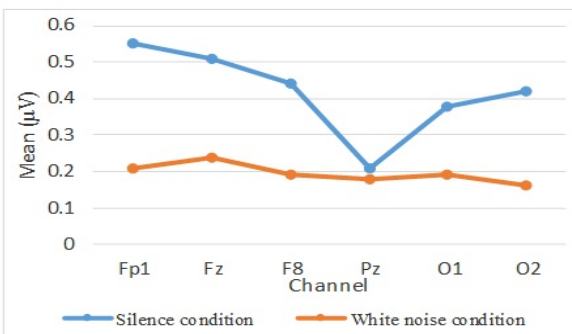

Figure-13. Average mean of difficult task at silence and white noise condition.

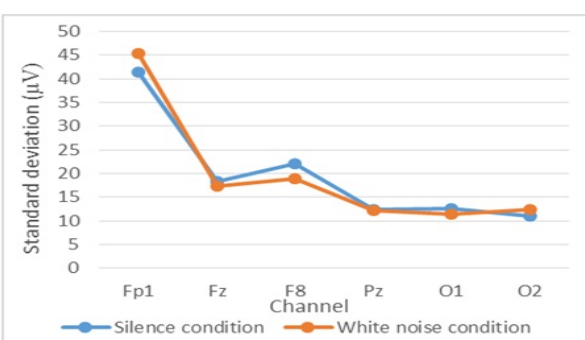

Figure-14. Average standard deviation of difficult task at silence and white noise condition.

Based on Table-2 and Figure-13 it shows that the average mean for difficult task is more high at silence condition (Fp1 = 0.55 µV, Fz = 0.51 µV, F8 = 0.44 µV, Pz = 0.21 µV, O1 = 0.38 µV and O2 = 0.42 µV) compared to white noise condition (Fp1 = 0.21 µV, Fz = 0.24 µV, F8 = 0.19 µV, Pz = 0.18 µV, O1 = 0.19 µV, and O2 = 0.16 µV). The most affected channel is at location Fz (mean: silence condition = 0.51 µV, white noise condition = 0.24 µV) which is for working memory processing region and followed by channel Fp1 (mean: silence condition = 0.55 µV, white noise condition = 0.21 µV). Fp1 location takes a role during the subject give attention in memorizing the task. The brain is more active at these locations due to more items loaded during memorizing. The subjects need to memorize four digit number with picture in difficult task compare to easy task that require them to memorize pictures with two digit number, thus they need to be more focused during memorize difficult task compare to easy task. The result shows that in silence condition the mean at channel Fp1, Fz, F8, Pz, O1 and O2 is higher at difficult task compare to easy task. However, in white noise condition the mean is lower for difficult task compare to easy task. The brain is more active during memorize difficult task compare to easy task in silence condition whereas in white noise condition brain is less active during memorizing the difficult task. It indicates that the subject is stress during memorizing the difficult task in silence condition compare to white noise condition. The sound of white noise is able to decrease the stress that facing by subject in order to memorize the difficult task. Figure-16 shows the EEG signal from one subject at channel Fp1 and Fz which is the most affected brain location.

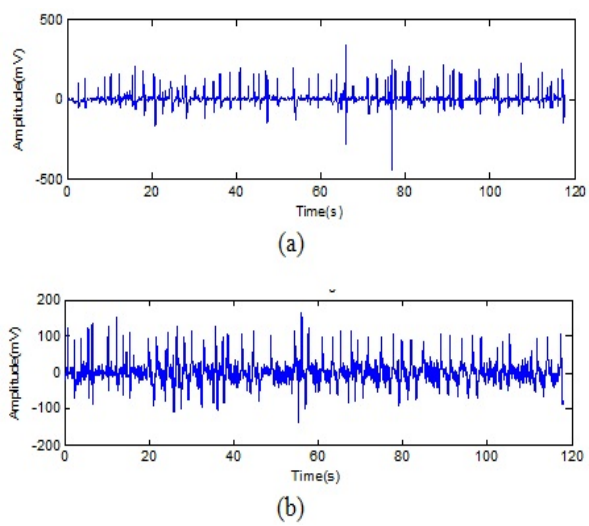

Figure-15. EEG signals at channel Fp1 (a) Silence condition (b) White noise condition.

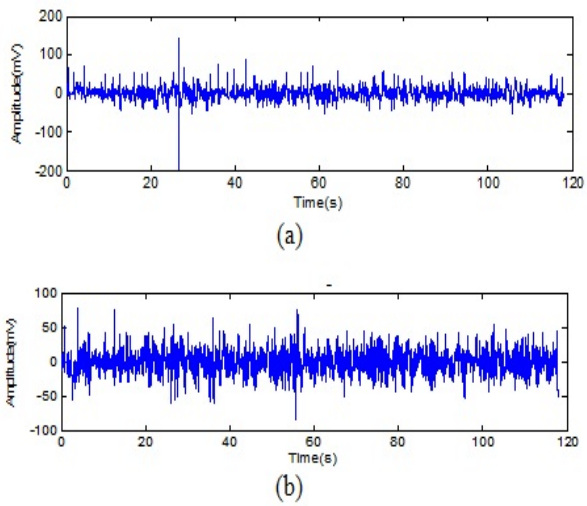

Figure-16. EEG signals at channel Fz (a) Silence condition (b) White noise condition.

A paired samples *t*-test was performed on the mean of silence and white noise condition for easy and difficult task in order to determine the significant difference between them. The aim of this test is to determine whether the white noise has effect on improving the memorizing process which is based on the activation of the brain location. The test value (α) was set to be 0.05 for all analysis performed. The null and alternative hypothesis for this test are:

H_o = There is a significant difference between silence and white noise condition
H_1 = There is no significant difference between silence and white noise condition

The null hypothesis is accepted if the *p*-value is less than the test value ($p < 0.05$) whereas the alternative hypothesis will be rejected.

Table-3. Paired samples *t*-test for the easy and difficult task.

	Easy task		Difficult task	
Channel	t-value	p-value	t-value	p-value
Fp1	2.172	0.041	3.381	0.003
Fz	2.506	0.021	3.080	0.006
F8	0.430	0.671	3.009	0.007
Pz	1.633	0.117	0.330	0.744
O1	1.590	0.128	2.030	0.055
O2	2.493	0.022	2.399	0.026

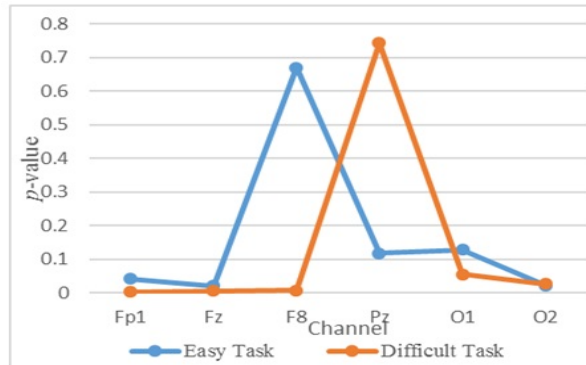

Figure-17. *p*-value of channel Fp1, Fz, F8, Pz, O1 and O2 for easy and difficult task.

There is a significant difference between silence (control) and white noise condition for the easy task at channel Fp1, Fz, and O2, whereas for difficult task at channel Fp1, Fz, F8 and O2 which is less than the alpha value as shown in Table-3. In the easy task, the *t*-value is higher at channel Fz (*t*-value = 2.506), O2 (*t*-value = 2.493) and Fp1 (*t*-value = 2.172) whereas in difficult task the *t*-value higher at channel Fp1 (*t*-value = 3.381), Fz (*t*-value = 3.080 and F8 (t-value = 3.009). Based on this analysis, the white noise has effect on improve the memorizing process especially during memorizing the difficult task. As we can see from the Figure-17, the *p*-value is lower for difficult task that indicate more significance difference compare to easy task. However, there is no significance difference at channel F8, Pz and O1 in easy task. The white noise does not give effect at this three location since the task that use is simple and does not require the brain to process the information hardly. The location Pz does not effect by sound stimulation whether for easy or difficult task since the task that used in this study does not involve the high critical thinking. The subject is able to memorize better and give more attention at white noise condition whether for easy or difficult task.

Based on the resulted mean, standard deviation, and *p*-value we found that there are two channels that affected mostly in this study which are Fp1 and Fz. The reason that the brain is most activate at Fp1 due to visual task that use in this study which require them to focus in order to memorize the items, whereas the Fz location active due to its need to process the information (working memory task) from visual sensory. This result is supported by finding by (Schack *et al.* 2002) which found that the Fp1 and Fz location has functional linking with the working memory.

When comparison made based on the mean value and standard deviation value it indicates that the brain does not work too much during the white noise condition and the subject can perform better during this condition. Study by (Zhang *et al.* 2009) found that listen to the sounds when doing easy task which allows the subject to have available free attention while the influence is less

during difficult tasks which need their concentration as discussed above. The subject is more relaxed during this condition. In paper of (Soderland, Marklund and Lacerda, 2009) has found that the white noise is able to enhance the human cognitive processing. In the easy task, the subject can memorize better since the items that need to be remember is less compare to difficult task which require them to be more focused. Study by (Gevin *et al.* 1997) was found that the energy intensity of Fz and Fp1 increased with increased memory load.

CONCLUSIONS

The present preliminary study investigates the effect of white noise and visual working memory task to the EEG signal at channel Fp1, Fz, F8, Pz, O1 and O2 in terms of feature extraction. The features, mean and standard deviation was extracted by using stationary wavelet transform approach. The channel Fp1 and Fz is the most affected location that found in this study. There is a relationship between left prefrontal area (Fp1) and midline frontal area (Fz) with the working memory and sound stimulation. The more items that need to be memorize increase the activation of brain. The white noise is able to enhance the performance of subjects in memorizing the visual task.

The limitation of this study was the number of subjects is too small and only investigate the effect of white noise has on visual working memory task. In the future works, the number of subjects should be bigger to make the result more validate. Besides that, the mental task should be varied in order to determine the effect of white noise has to enhance the memory performance.

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