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EEG Alpha Oscillation: Handwriting Behavior Toward Working Memory Performance of Normal Children Using Correlation Analysis

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***Abstract*— This study is mainly focused on the Electroencephalography (EEG) of alpha oscillation of normal children's handwriting behaviour and its correlation towards working memory performance. The assessment was presented to five left-handed and five right-handed children who have no records of working memory disability. The EEG signals are recorded using Neurofax-EEG 9200 (taken at channel F7, C3, F4, F8, and C4) during two assessments: Task 1 and Task 2. Raw EEG data is analysed using Discrete Wavelet Transform (DWT) which decomposes signals into different frequency bands. Correlation analysis and *T*-test are used to statistically identify significant interaction which occurs. The voltage activity mean value for Task 1 is 9.664 µV while Task 2 is 5.666 µV. Results showed that there is no significant difference between the working memory average means of left and right handed children. Besides that, there is no significant sensory motor performance difference between the average means of left and right handed children when carrying out the assessments. In conclusion, this study proposed that handwriting behaviour (right-handed and left-handed) does not affect the memory performance of normal children.**

Keywords—Working Memory; Handwriting Behaviour; EEG; DWT; Correllation

I. Introduction

Being right-handed or left-handed is a relatively minor factor affecting the performance and execution of simple tasks or movement. Although muscle activity is essential to both, the primary difference is in the training and usage of the left side and right side muscles [1]. A previous study analyzes normal children who uses left-hand and right-hand for writing to identify the brain activities caused by their handwriting behaviour. The results showed that right-handed individuals affects the amplitude of the left brain, while left-handed individuals affects the amplitude of the right brain [2]. Researches showed that working memory performance is unaffected by the environment but heritability is more likely to contribute towards performance [3][4][5]. The working memory and visual responsiveness of normal and abnormal is also a factor which differentiates children reactions. Therefore, the pattern of EG signals for each child might be different. For example, given a short time, some children with poor working memory may experience difficulties in memorizing and manipulating a given problem, so they will react slower than others.

Electrical excitation generated from the cerebral cortex nerve cell can be recognized by EEG signals. Besides that, the activation sodium ion and potassium ion channels constitute action potential which can be recorded through EEG [6] [7] [8]. Most previous research use the international standard of 10-20 system electrode placements located on various positions of the scalp as shown in Fig. 1 [7 – 9]. The locations of the scalp electrodes consist of F (frontal), C (central), T (temporal) and O (occipital).

The lack of attention in the visual spatial domain is often blamed as the cause of the failure of verbal and visual spatial mental processing. Brain activity occurs in several parts of the brain during working memory task such as at the dorsolateral prefrontal cortex, left ventrolateral prefrontal cortex, right frontal pole, bilateral inferior lobule, junction region of dorsal anterior cortex and medial frontal gyrous, subcortical region at junction left thalamus, caudate and lenticular nucleus [11].

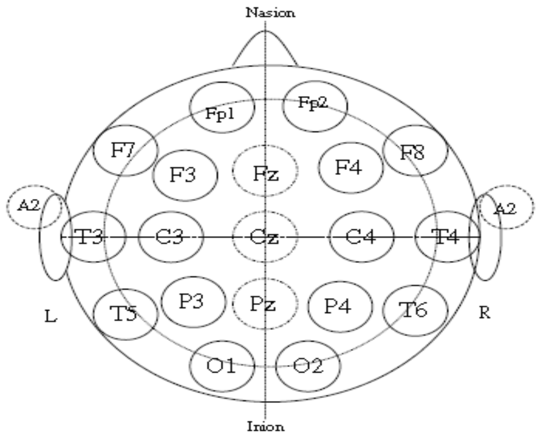


Fig. 1. Electrode placement 10-20 international system [12]

II. Brain Rhythm

EEG inspection can diagnose the brain rhythm generated by neuron activity according to the individual's behaviour. Wave patterns are different according to the age and health level of an individual. The frequency range of brain waves are delta (δ), theta (θ), alpha (α), beta (β) and gamma (γ) [7]. This paper studies the oscillations of alpha, a frequency between 8 Hz to 14 Hz for the extraction of useful parameters to study the correlation between handwriting behaviour and working memory performance. Alpha frequency is suitable for analysing the working memory performance of normal children because it is the most stable frequency among others and has a high degree of reliability for inferences [13]. Besides that, the frequency gives a higher value of power spectrum density than other frequencies hence it was chosen for the whole experimental analysis. Delta frequency (0.5 - 4 Hz) is unsuitable for memory performance studies but it is easy to analyse excessive movement responses because of artefact towards high signal responses from the muscles near the surface skin. Therefore, it generates high signal responses which passes through skull attenuation [12].

A previous research by Raghavachari (2006) which studies the theta frequency (4 to 7.5 Hz) recorded by intracranial electroencephalogram (iEEG) observed that the power of gated theta oscillations in working memory increases from the onset until the offset of a task. The study reveals that the important parts of the brain involved are the occipital/parietal and temporal cortices gates. Results discovered that the working memory function was non-existent in the frontal cortex due to theta synchronization throughout the duration of the task. Moreover, distant gated sites are never coherent [14].

A study conducted by Klimesch (1999) reviews and analyzes the synchronized theta and desynchronized alpha generated by an individual's responses towards a task. He found that in event-related changes, the desynchronized alpha have a positive correlation with the speed of processing information and better cognitive performance. Therefore, increase in alpha power and reduce in theta power produces better long-term memory performance. Theta power increases due to neurological disorders and also in the transitional period from waking to sleeping responses to external stimuli are decreased and alpha power is reduced. From early childhood to adulthood, theta power decreases are related with increasing age as alpha power increases enhance the working memory and cognitive development of the child [15].

The beta frequency in adults ranges from 14 - 26 Hz in awake state which is associated with active thinking, active attention and problem solving [12]. Brain-computer interface (BCI) is used to obtain large discrimination in the sensorimotor area such as the physical movement and motor imagery. Hence, beta band allows reliable performance of human behaviour but do not contribute much towards working memory performance [16].

Other signals involved in brain activities are gamma frequency which oscillates at 30 Hz and above and is used to encode the functional cognitive (perceptual and conceptual information) during electrocorticographic analysis. Neurological patients involved in the experiment are given the task of studying visually presented letters and the gamma band was encoded throughout the attention period. The experiment found that patterns of the viewer's shape of letters were reflected in the occipital region but not in other regions [17]. In addition, gamma frequency is used to demonstrate right and left finger movement but not for assessing working memory performance [12].

III. Materials and Methods

A. Subjects

The subjects for this study are 5 healthy right-handed and 5 left-handed normal school children, aged between 7 to 9 years old.

B. Experimental Task

The subjects were seated on a chair in front of a computer monitor. Then, they were given the task to observe and to remember all assessments within the stipulated time. The two tasks involved are: Task 1 (easy phase study) and Task 2 (moderate working memory).

Task 1: Easy phase study

Fig. 2 shows 4 sample pictures displayed to the subjects. Subjects need to remember and study all the pictures presented to them. Each of the pictures was shown to the subjects for 5 seconds and this process was repeated twice. After that, the subjects were asked by the examiner to recall the sequence of the pictures and the score was recorded. The results of this phase study are recorded using Neurofax-EEG 9200.

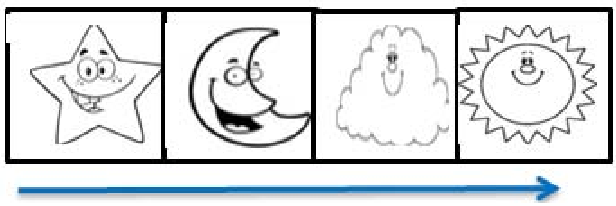


Fig. 2. Phase Study

Task 2: Moderate working memory

The experiment continues with the working memory test phase which includes old (previous) and new (additional) pictures. A delayed match-to-sample task was modified and then conducted in the same way as Task 1. Each memory trial consists of sample target and several test pictures.

Fig. 3 shows each of the test pictures displayed for two times in a given trial. The subjects were given some time and are required to memorize the pictures in the correct sequence. If the subjects can recall the sequences correctly, this implies that they have good working memory is in good condition.

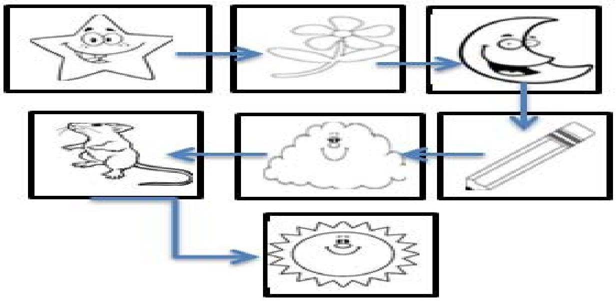


Fig. 3. Working memory

C. Recordings

Neurofax-EEG 9200 is used to record the EEG signals acquired from the scalp electrodes attached to the subjects. The raw EEG signal was saved as an ASCII file and converted into .mat file format for easier data processing and visualizing. The sample frequency of 1000 Hz was selected and the raw EEG signals were decomposed using discrete wavelet transform with mother wavelet: Daubechies 4 (*db4*) at level decomposition of 8.

D. Discrete Wavelet Transform (DWT)

Signal is filtered using low pass filter and high pass filter where it is decomposed and reconstructed by DWT [9] [16] [19]. Furthermore, Finite Impulse Response (FIR) was used to separate the signal into high and low frequencies. High frequencies pass through the high pass filter and low frequencies pass through the low pass filter thereby giving the detail coefficients (cD) and approximation coefficients (cA) respectively [10].

The decomposition of signal into one level sub-sampling is expressed as follows:

$$d_1[k] = y_{high}[k] = \sum_n x[n].g[2k-n] \tag{1}$$

$$a_1[k] = y_{low}[k] = \sum_n x[n].h[2k-n] \tag{2}$$

$$DWT(t,k) = \frac{1}{\sqrt{|2^j|}} \int_{-x}^{x} x(t)\psi\left(\frac{t-2^j k}{2^j}\right)dt \tag{3}$$

Equation (1) is the detail coefficient defined by the scalar product raw signal, $x[n]$ and the scaling function, $g[2k\text{-}n]$. Equation (2) is the approximation coefficient defined by scalar product raw signal $x[n]$ and down-sampling $h[2k\text{-}n]$. In Equation (3), 2^j is the imaginary part to filter the signal. According to previous research, epileptic patients were compared with normal persons using decomposed sub-band DWT and the analytical equations were obtained. The signal passes through a low pass and a high pass filter to produce the output approximation and detail coefficients with a cut-off frequency of one fourth of the frequency sample [20].

Fig. 4 shows the raw EEG signal from one subject before artefacts are removed using wavelet in order to filter the noise.

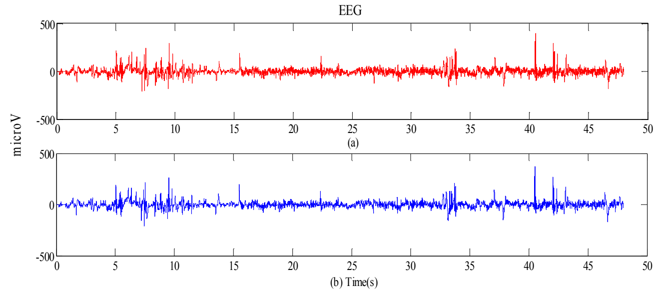
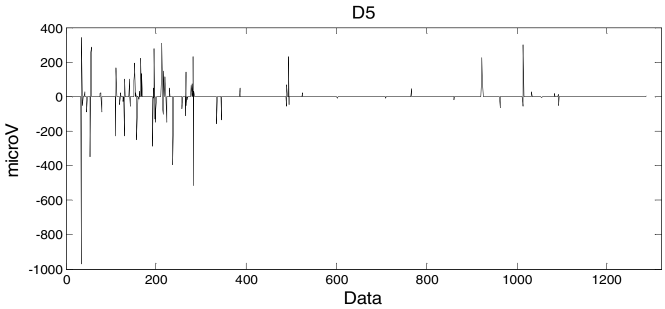
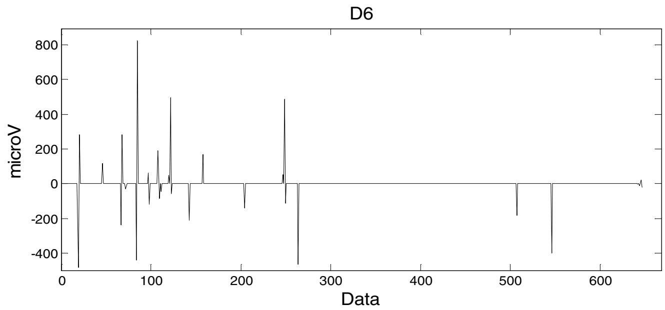


Fig. 4. (a) Raw EEG signal (b) Pre-processing EEG signal of one subject

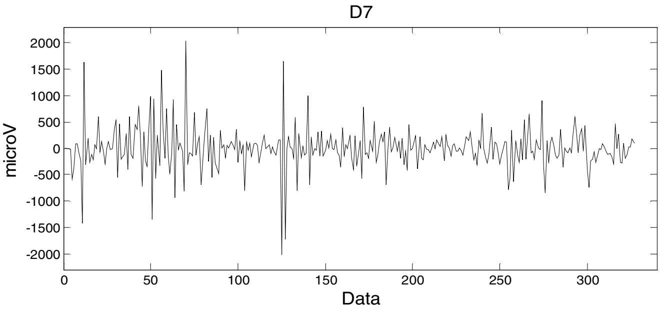
Fig. 5 shows the decomposition by using DWT with sampling frequency of 1 kHz, the signal is decomposed until level 8. The higher frequency bands are detailed coefficients. D5 shows the gamma rhythm, D6 (beta), D7 (alpha), and D8 (theta). Delta rhythm indicated the approximation coefficient (A8). D1, D2, D3, and D4 were ignored due to their higher frequency, also known as noise. Therefore, decomposition level of 7 (D7) was chosen for the next analysis due to its reliable features for alpha oscillation. At D7, the useful parameters: mean and standard deviation, were extracted to identify the performance of the subjects when carrying out the tasks.



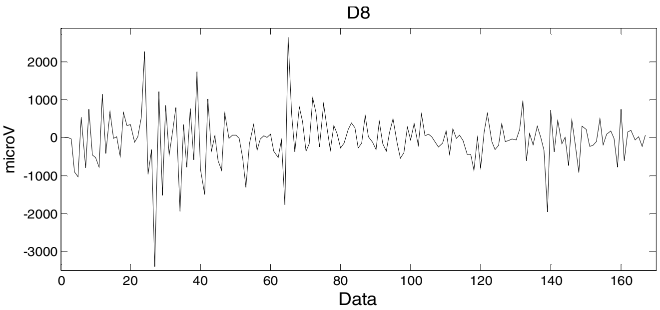
(a) Gamma



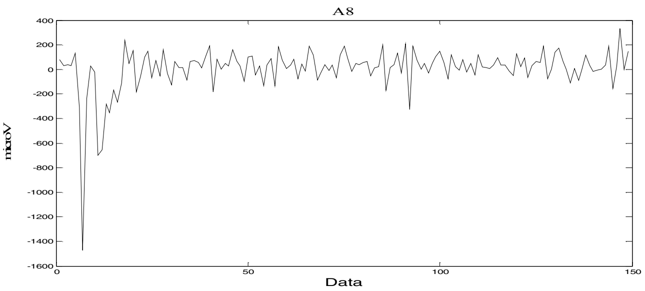
(b) Beta



(c) Alpha



(d) Theta



(e) Delta

Fig. 5. DWT decomposition level from D5 to D8 and A8

E. Data Analysis

The experimental data for Tasks 1 and 2 were recorded. If a participant's answers are all correct, this showed that he or she has good memory. Most subjects (left and right-handed) answered correctly in Task 1. The correct answer boosts the subjects' confidence and they are satisfied with their memory potential. However, in Task 2, the difficulty of the test on their cognitive memory and motor skill signals have increased as the sequences are more difficult to remember. The parameters (mean and standard deviation) extracted from the alpha oscillation are used as input to classify the handwriting behaviour using correlation, *r*:

$$r = \frac{S_{xy}}{\sqrt{S_{xx} S_{yy}}} \tag{4}$$

S_{xy}, S_{xx} and S_{yy} represent the sum of random variables X and Y while r is the sample data number of subjects in each group. The properties of r in element of [-1, 1], r = -1 implies strong negative linear relationship between X and Y variables. Otherwise, r = 1 shows strong positive linear relationship and an r near to 0 shows no linear relationship between X and Y.

T-test is performed to determine the significance of null hypothesis, H_o and alternate hypothesis, H_1 as shown below:

$$T_{test} = \frac{\overline{x} - \mu_o}{s / \sqrt{n}} \tag{5}$$

$\overline{x}$ is the sum of sample, while μ_o is the specified constant and variance, *S* of the population, n [21].

IV. Results and Discussions

In this study, correlation analysis is used to determine the relationship between independent variable and dependent variable from the left handed and right handed subjects. Moreover, *T*-test approach is suitable due to the small number of sample ($n < 30$). Thus, a statistical analysis of *T*-test was done to determine the relationship between the independent variable (handwriting behaviour) and dependent variable (working memory performance) in our hypothesis. The hypothesis is to analyse normal children's memory performance and handwriting behaviour, stated as follows:

H_o: There is no interaction between handwriting behaviour and working memory performance.

H_1: There is interaction between handwriting behaviour and working memory performance.

The mean value and standard deviation comparisons for peak voltage activity for each task are summarized in Table I. The results for Task 1 shows the left-handed mean of 4.837 and right-handed mean of 8.320 with correlation, $r = 0.274$. The results for Task 2 shows left-handed mean of 5.003 and right-handed mean of 5.478 with correlation, $r = 0.319$. Both of the tasks indicated no linear relationship. Based on previous research findings, higher mean indicates lower working memory. In addition, the left brain's channels F3 and F7 indicated more activity for right-handed subjects while channels F8 and F4 are more actively involved for left-handed subjects [22]. In this study, the voltage activity at F8 is 16.208μV and F4 is 8.417μV for right-handed subjects compared to voltage of 5.927μV at F8 and 5.752μV at F4.

TABLE I. Comparisons of left-handed and right-handed children's performance in task 1 and 2

Sensory	Task 1		Task 2	
	Mean, μV	***Standard deviation, μV***	***Mean, μV***	***Standard deviation, μV***
Right-handed	8.320	282.364	5.478	176.346
Left-handed	4.837	217.774	5.003	194.374
Correlation, r	0.274		0.319	

For sensory motor cortex, the mean of peak voltage activity at C3 is greater for left-handed compared to right handed subjects. However, at channel C4, right-handed subjects showed higher mean peak voltage activity when left-handed subjects were supposed to have a higher mean. This was due human error committed by test subjects; environment factors; and the subject's inability to give full attention to the task which affected the test's accuracy. The comparison of means from two independent groups was investigated to confirm the hypothesis. *T*-test was applied on the mean to analyze that if the *p*-value falls from critical region, the null hypothesis is rejected. There was significant difference (p (0.041) < 0.05) in Task 1. Thus, there is a relationship between handwriting behaviour and electrode positions.

Fig. 6 shows the non-linear correlation ($r = 0.319$) between the electrode position and mean voltage activity for left and right handwriting behaviours. The mean of the right brain is F8 (5.979) and F4 (6.190) which are high for left-handed children. This can also be seen in the motor area which is C4 (9.736) and proved that the right and left brain handle movement of the left and right body respectively. The addition of pictures was a factor for the subjects to focus more on the pictures i.e. working memory increases slightly. Besides that, F7 (5.818) and F3 (5.636) show active working memory in the left brain. In addition, motor area C3 (5.139) differs from C4 in terms of location. In regards to Task 2 (p-value = 0.851), where in the critical region ($p > 0.05$), there is enough evidence to support the claim that there is no interaction between handwriting behaviour and electrode positions.

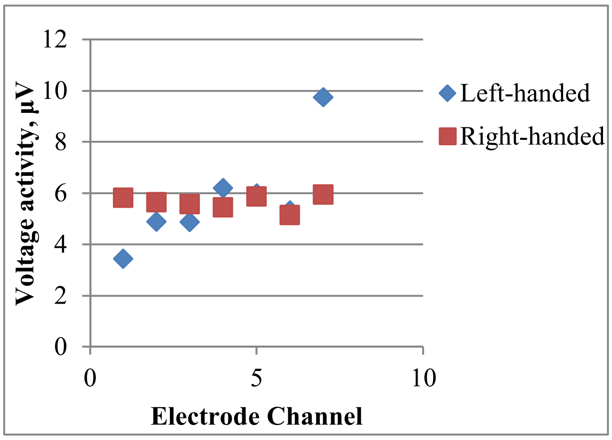


Fig. 6. Average mean for Task 2

The results of working memory and sensory motor tests are shown in Table II. In Task 1 (9.664) and Task 2 (5.666), a higher voltage of activity was measured at the working memory cortex for right-handed compared to left-handed subjects. However, left-handed (7.526) subjects have higher peak voltage activity for sensorimotor cortex. The interaction of working memory performance and sensorimotor for Task 1 and 2 was obtained. Memory performance is focused on channels F7, F3, F4 and F8. Therefore, using α =0.05 degree of freedom, memory performance (T_{memory}= 0.0144 >$T_{criteria}$ - 1.860) is not significantly different between right handed and left handed subjects. In addition, the central sulcus signals involving motor activity at channels C3 and C4 indicated non-linear correlation ($r = 0.190$). Moreover, with a degree of freedom ($\alpha = 0.05$), sensory motor ($T_{motor} = 0.234 > T_{criteria}$) results for Tasks 1 and 2 has no significant differences between the right handed and left handed subjects. The findings highlighted that handwriting behaviour has no effect on memory performance. It has been shown through recent researches that different persons have different motor skill capacity for both, or one hand [1]. There was an interaction in Task 2 between the right handed and left handed subjects which was known as disordinal interaction [21]. In summary, disordinal interaction occurs between the left handed and right handed subjects when the difficulty of memory task increases.

TABLE II. MEAN VOLTAGE OF BRAIN ACTIVITY FOR ALL SUBJECTS: MEMORY AND MOTOR CORTEX

Sensory	Task 1		Task 2	
	Left	*Right*	*Left*	*Right*
Memory, μV	4.664	9.664	5.069	5.666
Motor, μV	5.609	5.584	7.526	5.542

A. Related works

A previous study used the paired *T*-test to analyse the discrimination in motor sequence in performance and errors. 54 university students, (n = 19) male and (n = 35) right-handed participants participated in the experiment. The experiment found that the mean execution rate was faster in SKILLED rather than NOVEL condition (t (53) = 14.75; p < 0.001). Eventually, there are no errors among NOVEL and SKILLED (t (53) = 0.67; $p > 0.05$). However, there was only one observation for each combination of nominal value for the appropriate paired *T*-test [23].

Besides that, the *T*-test method was also used in analyzing the working memory of kindergarten children's achievements in mathematics. 444 kindergarten children with (n = 199) girls and (n = 245) boys participated in the experiment. The *T*-test has been used in a majority of experiments because it is suitable to be used for small sample sizes [24].

V. CONCLUSIONS

This study focuses on the alpha oscillation of normal children's handwriting behaviour towards working memory performance. The useful parameters (mean and standard deviation) to identify cognitive activity between the right-handed and left-handed normal children were determined. The statistical method of correlation and *T*-test were used to prove that handwriting behaviour (right-handed and left-handed) do not affect the memory performance of normal children.

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