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# Wavelet Packet Analysis of EEG Signals from Dyslexic Children with Writing Disability

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*Abstract*— **This paper describes Wavelet Packet Analysis of EEG signal of dyslexic children with writing disability. Two activities were carried out during EEG recordings; relax and and writing letters. EEG signals were collected using biosignal gMobilab system and analysed using Wavelet Packet Decomposition to extract alpha and beta brainwave rhythm. Statistical data such as log energy entropy and standard deviation were used to compare the characteristic of EEG signals from dyslexic and normal children. Result showed that the dyslexic children consumed higher energy at left parietal lobe during writing activity especially those who write incorrectly. The alpha band shows higher log energy entropy for dyslexic children compare to normal children at most channel during relax.**

## I. Introduction

Dyslexia is a neurological impairment known as inability to acquire reading and spelling skills corresponding with the children intelligence, motivation and schooling, which are considered necessary for accurate and fluent reading [1]. It was estimated that 20% of worldwide population is affected by dyslexia where 17% among them are primary school children [2]. The International Dyslexia Association has defined dyslexia as a disorder characterized by difficulties with accurate word recognition and by poor spelling [3].

Previous research has proven that the brain impairment of dyslexic person is due to inability to process rapid acoustic-type (linguistic and non-linguistic) sensorial impulse [2]. From neurological perspective, the dyslexia is originated from the dysfunction in the magnocellular pathway which differs in the temporo-parietal-occipital brain region between dyslexic and nonimpaired children [4]. Neuro-imaging study have shown that individuals with dyslexia shows various anomalies in the activity and functional organisation of different areas which related to the language processing area [2]. In another study, it was reported that the left tempoparietal brain of dyslexic failed to activate during word reading and picture naming [3].

There are several methods used for exploring function of the brain such as Electroencephalogram (EEG), Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI) and others. PET uses the exposure of radioactive injection and MRI which head motion severely degrades the measureable signal. EEG has several strengths as a tool for exploring brain function. First, the time resolution of EEG is very high, down to microsecond that enables brain activity to be tracked more accurately. Other methods have time resolution between seconds and minutes when accessing brain activity. Second, human brain is believed to work through its electric activity and only EEG method can measure it. The EEG is a non-invasive and painless method to record electrical activity of human brain from the scalp surface. Its spectral analysis analyzes the dynamic of large neuronal populations and their interactions. Indeed, there is evidence that the EEG amplitude reflects the state of synchronization within functional visual cell ensembles which can explain why EEG analysis is used to study cognitive processes in human such as language processing and motor activity [5].

The event in the EEG signal can be revealed using Short Time Fourier Transform (STFT), Wigner-Ville distribution (WVD) and time-varying parametric model [6, 7]. However, these methods have limitations. The STFT has fixed time-frequency resolutions trade-off results from windowing of the signal. The existence of the cross-terms that decrease the resolution of the time-frequency characteristics of the signal limits the usage of Wigner-Ville distribution (WVD) in the EEG signal analysis [8]. The variability of the Wavelet Packet Transform can overcome the limitations of STFT and WVD. In addition, in wavelet packet analysis, the frequency spectrum of wavelet can be adjusted according to the brain wave rhythm such as beta and alpha [9].

This paper describes the analysis of EEG signals generated from dyslexic children during writing using Wavelet Packet Decomposition. The purpose of this work is to investigate EEG signal characteristics of dyslexic children with writing disabilities. In this study, frequency spectrum and energy entropy are used as parameters to compare between the EEG signals obtained from dyslexic and normal children.

## II. Methodology

### A. EEG Signal Recording

Four dyslexic children and four age matched normal children were participated in this study. The dyslexic children selected are diagnosed with dyslexia symptoms during their special pre-assessment carried out by Dyslexia Association Center. The dyslexic children were recruited by giving explanation on the purposes and procedure of this study and consent form to their parents. However, normal children

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participated were selected randomly from community. All children were Bahasa Melayu native speaking but use the English language as their second language. Both groups are at primary level aged between 7-12 years old. All participants had normal intelligence except one of the dyslexic was diagnosed with Autistic Disorder. All of them are right-handed writers.

EEG signals were acquired from 8 channels based on 10-20 electrode international system. The EEG signals were recorded using gMobilab EEG system and the signals were transferred to computer using Matlab SIMULINK program. Data were collected from channel C3,C4,P3,P4,O1,O2,T3 and FC5 as shown in Figure 1 [10,11,12]. Data were referenced to the earlobe to create monopolar montage and ground at AFz. A continuous acquisition system was employed and EEG signals were analysed off-line. Here, a sampling frequency of 256 Hz was used. According to the Nyquist sampling theorem, the maximum useful frequency is half of the sampling frequency, which is 128 Hz [13].

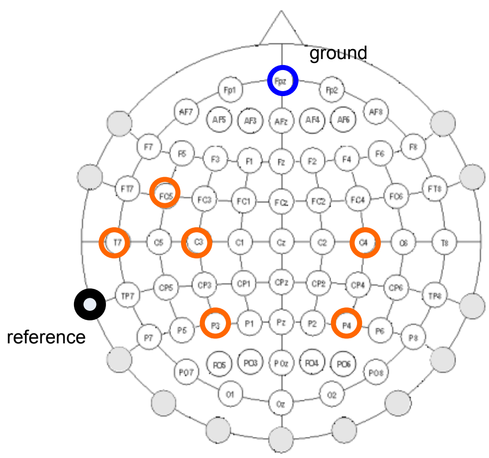


Figure 1. Electrode position at dGamma cap.

### B. *Writing Activities*

During the experiment, the participant was placed in a comfortable sitting position in a sound isolated room with room temperature about 25°C. Participant was asked to minimize their movement as much as possible in order to reduce unwanted noise. Before the writing experiment was commenced, the participant was requested to close his/her eyes, relax their mind while listening to the music played for 2 minutes. Next, after 5s, the participant was asked to recognize the letter displayed on the computer screen and write the recognized letter displayed on the answer sheet. The computer screen was located at a distance of 40cm from the participant eyes. For each writing activity, 8 samples were taken to ensure the EEG signals contain required information. Small letters such as c/e, b/d, o/a, m/w, p/q, s/z and l/I were used in the recognition and writing tasks. All these letters have similar or mirroring pattern which the dyslexic children often get confused. The letters used in this experiment are based on the entry level standard assessment given by Malaysia Dyslexia Association Center.

### D. *Wavelet Packet Analysis*

The first three seconds of each sample was used in the analysis to avoid the contribution of relax condition during their writing task. Wavelet Packet Decomposition was used to separate the required Alpha band and Beta band from the original EEG signal. The Alpha band was selected from node [3 1] in the binary tree shown in Figure 2 and Beta band was selected from node [5 3]. The wavelet packet coefficients at each particular node were measured. Fast Fourier Transform was applied to the selected coefficients to obtain its frequency spectrum. In this study, EEG signals from P3, P4, C3 and C4 were used in the analysis [14]. P3 and P4 are normally associated to the language processing region in the brain specifically at parietal lobe angular gyrus region [15]. And, the C3 and C4 are normally associated to the sensorimotor region for both left and right brain hemisphere. The standard deviation and log energy entropy of EEG signal at alpha and beta bands were then measured.

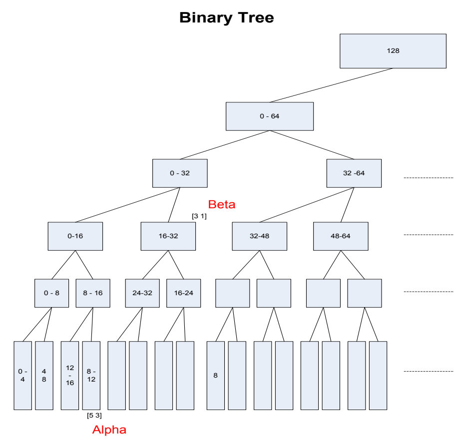


Figure 2. Wavelet Packet Binary Tree.

## III. RESULTS

In this study, it was found that Dyslexic child 1 and dyslexic child 2 response to the task incorrectly. It means while giving the instruction to write letter ‘w’, they write the letter ‘m’ or ‘-‘ on the answer sheet. Unlike these children, Dyslexic child 3 and dyslexic child 4 follow the instruction correctly even though they have been diagnosed with dyslexia. All normal children give correct response during this writing activity. They also gave the impromptu response without any delay after getting the instruction. Even though all normal children were chosen randomly from family members, it is believed that they never show sign of dyslexia based on their education and family background.

### A. *EEG Signals at Beta Band*

As shown in Figure 3, the dyslexic child 1 has the highest EEG signal amplitude for all channels especially at channel P3. This might be due to her struggling during writing. However, the EEG signal amplitude of dyslexic child 2 is different from that of dyslexic child 1 (see Figure 4) even though she writes incorrectly. The EGG signal amplitude is the smallest compare to others which may be due to unconscious state. Other dyslexic children perform tasks correctly during the writing.

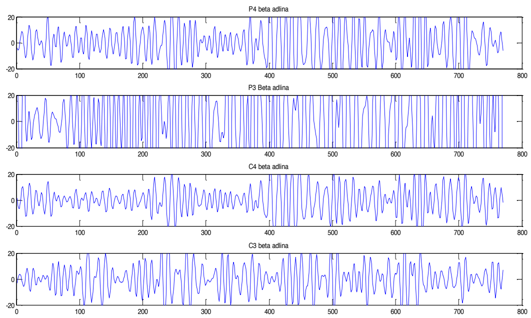


Figure 3. EEG signals of dyslexic child 1 during writing the letter.

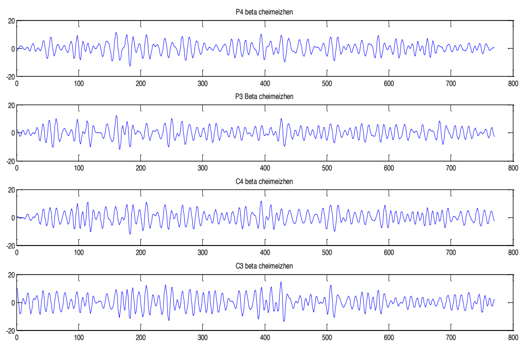


Figure 4. EEG signals of dyslexic child 2 during writing the letter.

### *B. Standard Deviation at Beta Band During Writing*

Table I shows the standard deviation of EEG signals at beta band for all children. Note that the standard deviation of EEG signals from child 1 is higher compared to other those obtained from other dyslexic children. This is because this child writes letters incorrectly. Dyslexic child 2 who also responded incorrectly shows the lowest standard deviation which might be due to Autism. Standard deviation of EEG signals from other dyslexic children has no significant difference. For normal children, there is not much difference in the standard deviation. However, in average, the standard deviation of EEG signals for all normal children is lower than those obtained from dyslexic children. It means that the amplitude changes of EEG signals for normal children are smaller than the EEG amplitude changes of dyslexic children.

### *C. Log Energy Entropy*

The Log Energy Entropies of EEG signals for both dyslexic and normal children during relax are shown in table II. The dyslexic child diagnosed with Autistic Disorder uses the lowest energy in alpha band during relax due to minor movement such as head movement or her finger movement. Other alpha band energy values do not show significant difference between dyslexic children and normal children except for normal child 1. Normal child 1 has the highest energy in alpha band. This might be due to her concentration while listening to the music.

In general, energy of EEG signals from dyslexic children is higher than normal children upon completing the writing activity. As shown in Table III, dyslexic child 1 consumes more energy during her struggling with writing. Dyslexic child 2 who is believed in her sub-conscious mind uses lowest energy during writing. EEG signal of dyslexic child 3 who is always losing focus, has more energy entropy compared to that of dyslexic child 2 who has impairment at language processing region (P4 higher than P3). However, dyslexic child who write correctly and has impairment at sensorimotor region (C4 higher than C3) consumes not much energy compared with dyslexic child 1.

From the theory, the left brain hemisphere is more dominant than right brain hemisphere. From the table, 75% of log energy entropy for normal children is dominant at left language processing and sensorimotor region. However, another 25% of normal children recruited during this research might use the imagination part in the human brain upon completing the writing activity or use the short term working memory region which located in the right side of brain hemisphere instead of using the language processing region since these children already learned the alphabet before performing the writing tasks.

TABLE I. BETA BAND STANDARD DEVIATION DURING WRITING ACTIVITY

| **Participant** | **Standard Deviation for Beta Band** | | |
|---|---|---|---|
| | ***Channel*** | ***Dyslexic*** | ***Normal*** |
| 1 | C3 | 10.81 | 3.91 |
| | C4 | 10.26 | 3.83 |
| | P3 | 35.18 | 3.85 |
| | P4 | 14.47 | 3.80 |
| 2 | C3 | 4.89 | 3.46 |
| | C4 | 4.27 | 4.27 |
| | P3 | 3.88 | 2.90 |
| | P4 | 3.87 | 3.90 |
| 3 | C3 | 5.22 | 2.99 |
| | C4 | 5.36 | 2.90 |
| | P3 | 4.49 | 2.62 |
| | P4 | 6.10 | 2.77 |
| 4 | C3 | 7.43 | 3.23 |
| | C4 | 7.42 | 3.39 |
| | P3 | 8.00 | 3.39 |
| | P4 | 8.28 | 3.62 |

TABLE II. ALPHA BAND LOG ENERGY ENTROPY DURING RELAX

| Participant | Log Energy Entropy for Alpha Band | | |
|---|---|---|---|
| | *Channel* | *Dyslexic* | *Normal* |
| 1 | C3 | 735.39 | 1575.00 |
| | C4 | 874.14 | 1504.50 |
| | P3 | 1226.30 | 1446.30 |
| | P4 | 1340.00 | 1565.40 |
| 2 | C3 | 345.94 | 754.00 |
| | C4 | -172.58 | 638.00 |
| | P3 | 386.00 | 690.00 |
| | P4 | 106.26 | 677.00 |
| 3 | C3 | 648.48 | 588.59 |
| | C4 | 531.21 | 758.64 |
| | P3 | 712.70 | 661.68 |
| | P4 | 679.76 | 577.69 |
| 4 | C3 | 1308.20 | 383.27 |
| | C4 | 1011.90 | 327.84 |
| | P3 | 1283.00 | 499.44 |
| | P4 | 1202.00 | 270.33 |

TABLE III. BETA BAND LOG ENERGY ENTROPY DURING WRITING

| Participant | Log Energy Entropy for Beta Band | | |
|---|---|---|---|
| | *Channel* | *Dyslexic* | *Normal* |
| 1 | C3 | 1303.70 | 567.62 |
| | C4 | 1240.10 | 481.67 |
| | P3 | 2206.90 | 574.93 |
| | P4 | 1526.90 | 503.74 |
| 2 | C3 | 762.67 | 594.59 |
| | C4 | 702.00 | 537.63 |
| | P3 | 544.56 | 430.42 |
| | P4 | 499.54 | 384.79 |
| 3 | C3 | 789.42 | 419.76 |
| | C4 | 777.99 | 280.75 |
| | P3 | 634.05 | 354.00 |
| | P4 | 870.35 | 293.00 |
| 4 | C3 | 956.25 | 440.36 |
| | C4 | 992.58 | 451.63 |
| | P3 | 1050.2 | 432.29 |
| | P4 | 1016.9 | 508.78 |

## IV. CONCLUSION

The results from this analysis have shown that the dyslexic children consumed more energy especially when they have the autism and response incorrectly during writing. The log energy entropy of EEG signals at beta band of dyslexic children who write correctly is slightly lower than that of dyslexic children who write incorrectly. Furthermore, even though they write correctly, the log energy entropy of EEG signals of dyslexic children shows that there is still impairment since they use more energy in the right brain hemisphere. The results found in this study also shows that the Wavelet Packet Analysis is able to reveal the characteristics of EEG signals of dyslexic and normal children and differentiate between the state of writing correctly and incorrectly.

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