Analysis of EEG signals of dyslexic children using Wavelet Packet Decomposition.

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ABSTRACT

This paper describes Wavelet Packet Decomposition of EEG signal of dyslexic children with writing disability. Two activities were carried out by the children during EEG recordings: relax and writing activities as well as letter recognization. EEG signal were collected using biosignal gMobilab system and MATLAB SIMULINK program. EEG collected data were then analysed using Wavelet Packet Decomposition to extract the brain wave rythm especially Alpha and Beta rythm. Statistical data such as log energy entropy and standard deviation also tabulated during the analysis process. Result shows that the dyslexic children consumed higher energy at left parietal lobe during writing activity especially who response incorrectly. Also, the alpha band shows higher log energy entropy for dyslexic children compare to normal children at most channel during relax condition.

1. INTRODUCTION

Generally, dyslexia is a neurological symptom known as inability to acquire reading and spelling skills corresponding with the children intelligence, motivation and schooling considered necessary for accurate and fluent reading[1]. From the study, it was estimated that 20% of worldwide population effected by dyslexia symptom where 17% among them are primary school children[3]. The International Dyslexia Association has defined dyslexia as a disorder characterized by difficulties with accurate word recognition and by poor spelling[2]. Theoritically, previous research proved that this brain impairment is due to the inability to process rapid acoustic-type(linguistic and non-linguistic) sensorial impulse[3]. From neurological perspective, the dyslexia symptom origin from the dysfunction in the magnocellular pathway which differs in the temporo-parietal-occipital brain region between dyslexic and nonimpaired children[4]. In fact, 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[3]. In the Positron Emission Tomograpy (PET) study, it was found that the left tempoparietal brain of dyslexic failed to activate during word reading and picture naming[2].

The dyslexia symptom could be approached from three domain : the behavioral, the cognitive and the biological[2]. From the cognitive perspective, the EEG, Positron Emission Tomography(PET) and Magnetic Resonance Imaging(MRI) were frequently used in most research recently. However, EEG has several strength as a tool for exploring brain function. First, the time resolution of EEG is very high down to microsecond, enabling brain activity to be tracked more accurately when other methods have time resolution between seconds and minutes while accessing brain activity. Second, brain is beliefs to work through its electric activity and only EEG method can measure it. Other methods for exploring function in the brain rely on blood flow using PET. Alternatively, the Magnetic Resonance Imaging(MRI) also could be used to study brain regional activity. However, the PET technique using the exposure of radioactive injection and MRI which head motion severely degrades the measureable signal, which is not suitable for children[5].

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 directly in human. Indeed, there is evidence that the EEG amplitude reflects the state of synchronization within functional visual cell ensembles which can explain why EEG analysis applied to study cognitive processes in human such as language processing and motor activity[6]. Most important, EEG is the variable and complex signal which will reflect the electrical field produced by brain neuron in the cortex and subcortical region[7].

Modern Digital Signal Processing techniques have some attempt to automate the event recognition in the EEG signal. Generally, these three methods were used to analyze the non-stationary EEG signals: the Short Time Fourier Transform (STFT), the Wigner-Ville distribution (WVD) and the time-varying parametric model[20],[24]. But, the STFT has the limitation for EEG analysis which their fixed time-frequency resolutions trade-off results from windowing of the signal. Furthermore, 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 [25]. Hence, the variability of the Wavelet Packet Transform can overcome those limitations by STFT and WVD. In addition, the wavelet packet analysis, the frequency spectrum of wavelet could be adjusted accordance to the brain wave rhythm such as beta and alpha[23]. This paper describes the used of Wavelet Packet Decompostion technique to analyse the EEG signal of dyslexic and normal children.

The aim of this study is to analyse the EEG signals obtained from Dyslexic children with writing disabilities. In this analysis, the frequency spectrum and the energy are used as parameter to compare between the dyslexic children and normal children.

2. BACKGROUND THEORY

a) Brain Processing Path in Writing

From the anatomical perspectives, the brain can be divided into three section: cerebrum, cerebellum and brain stem. “The cerebrum consists of left and right hemisphere with highly convoluted surface layer called cerebral cortex. The cortex is a dominant part of the central nervous system. The cerebrum obtains centres for movement initiation, concious awareness of sensations, complex analysis and expression of emotion and behaviour. The highest influence to elecroencephalogram (EEG) comes from electric activity of cerebral cortex due to its surface position”[18].

EEG activity recorded at the scalp consists of voltage changes of 100μV at frequencies ranging from 0.5 Hz to about 100 Hz[8],[18]. It can be analyzed and quantified in the time-domain as voltage versus time. In the time domain, the magnitude of the voltage change evoked by the presented stimuli[7]. The EEG brain waves can be divided into four major spectral. These are Delta band , Theta band , Alpha band and Beta band [18]. Delta band is the frequency range from 0.5 - 4 Hz which often associated with the deep sleep stage. Theta is the frequency range from 4 – 8 Hz and associated with drowsiness. Alpha is the frequency range from 8 – 13 Hz which normally related to the relax condition. Lastly, Beta band where content between 13-30 Hz. It is the characteristic found when human is active, busy or active concentration[9].

Writing a consistent text or letter can be defined as complex process demanding cognitive operation such as conception, planning, working memory and subjective valuation, in addition to generate a dedicated sensorimotor activity. Furthermore, handwriting is a voluntary motor act which is guided by visual feedback as the writing person observes the appearence of the letter and word she is writing[12]. Generally, the writing process start from the visual processing area or “Visual Cortex” in the Occipital Lobe[13][22]. The information is then pass from visual cortex to the Wernicke are in Parietal Lobe to decode the information and meaning extration. Next, the Broca area (lower part of Frontal Lobe) decodes the meaning into instruction where in this case, the nerves connecting to the motor area and proceed to muscles in the finger and hands. From neuronological perspectives, right handed writing involves the activation of sensorimotor cortex, premotor cortex, left anterior parietal cortex, left supplementary motor area and right anterior cerebellum. However, for children with dyslexia symptoms, the left hemisphere is the neural region expected to be activated during writing event were not functioned[14].

b) Wavelet Packet Decomposition

Wavelet Packet Decomposition is the technique that can provide richer signal analysis since it can interprete the position, scale and frequency of the EEG signal. Also, Wavelet Packet Decomposition can give the equal bandwidth signal filtering without overlapping frequency bands, hence the feature extraction of frequency band is exact[10],[19]. For this study, Wavelet Packet Decomposition were used to extract the alpha rythm and beta rythm which relates to relax and writing activity. Generally, the wavelet packet decomposition splits the wavelet coefficients into approximation coefficient and detail coefficient. Then, each detail coefficient vector also decomposed into next approximation and details. The wavelet transform of a signal s(t) at the scale a and position b is computed by correlating s(t) with a wavelet atom[11]:

$$W_s(a,b) = \int_{-\infty}^{\infty} s(t) \frac{1}{\sqrt{a}} \psi^*\left(\frac{t-b}{a}\right) dt \qquad (1)$$

The main process in the Wavelet Packet Decomposition is filtering where the discrete signals x[n] were convoluted with Low-pass coefficient h[n](1) and High-pass coefficient g[n](2) where h[n] and g[n] are the quadrature filters function associated with the scaling function and mother wavelet function[19],[20].

Low-pass filter

$$C_{j+1}[k] = \Sigma_m c_j[m]*h[m-2k] \qquad (1)$$

High-pass filter

$$D_{j+1}[k] = \Sigma m\ c_j[m]*g[m-2k] \qquad (2)$$

And the relationship between both is:

$$g[n] = (-1)^{1-n} h[1-n] \qquad (3)$$

3. METHODOLOGY

a. Participant preparation

Four children from Malaysia Dyslexia Center and four age matched normal children from public community were participated in this study. The dyslexic children selected are diagnosed with dyslexia symptoms during their special pre-assesment from Dyslexia Center. The dyslexic children were recruited by briefed the parents about the aim, purposes and procedure of this study and gave the written consent form. However, normal children participated were selected randomly from community. The experimental procedure briefed was approved by Faculty of Electrical Engineering, Universiti Teknologi MARA.

All children were Bahasa Melayu native speaking but use the English language as their second language. Both group 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 during writing task.

b. Equipment preparation

EEG data were acquired from 8 channel 10-20 electrode international system using gMobilab EEG system, see in figure 1. From the gMobilab system, data were captured via Matlab SIMULINK program to the computer. Data were collected from channel C3,C4,P3,P4,O1,O2,T3 and FC5 as shown in figure 2[15][17][21]. Data were referenced to the earlobe to create monopolar montage and ground at AFz. A continous acquisition system was employed and EEG data were analyse off-line. From the gMobilab reference, this biosignal amplifier was pre-formatted to 256 Hz sampling frequency. And, according to the Nyquist sampling theorem, the maximum useful frequency is half of the sampling frequency (i.e 128 Hz) [16].

Figure 1 : gMobilab biosignal acquisition equipment

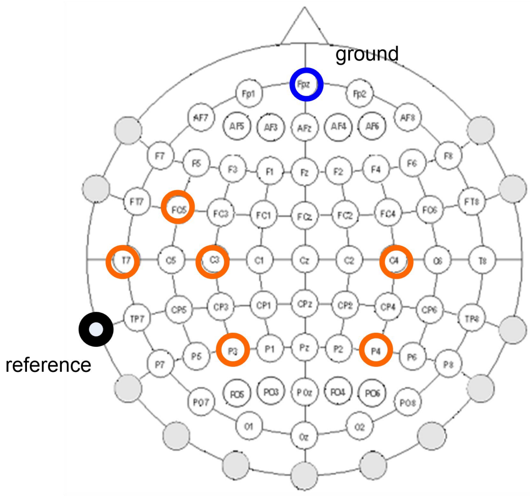


Figure 2: Electrode position at dGamma cap

d. Experimental task

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 or eliminate the EEG signal which contaminated by unwanted noise. Before the writing experiment started, the participant was requested to close his/her eyes, relax their mind while listening to the music played for 2 minutes. Next, after 5 second, the participant was asked to recognize the letter displayed on the computer screen and write the recognized letter on the asnwer sheet. The computer screen was located at a distance of 40cm from the participant eyes. Font Arial Rounded MT Bold and font size 150 were used. Writing experiment were taken for 8 sample to ensure the EEG signal taken are valuable. During the activity, small letter such as c/e, b/d, o/a, m/w, p/q, s/z and l/i were used in the recognition and writing task. All those letter have similar or mirroring pattern which the dyslexic children confused often. The letter used in this experiment are based on the entry level standard assesment given by Malaysia Dyslexia Center.

e. Data analysis

The first 3s of each sample was used in the analysis in order to reduce the impact 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 data. From the binary tree, figure 3, the Alpha band was selected from node [3 1] and Beta band was selected from node [5 3]. The wavelet packet coefficient at each particular node were measured for analyse purposes. Fast Fourier Tranform were applied to the selected frequency band to observe the activity more clearly in the frequency domain. In this study, P3, P4, C3 and C4 were focused for further analysis[18]. P3 and P4 are normally associated to the language processing region in the brain specifically at parietal lobe angular gyrus region[26]. And, the C3 and C4 are normally associated to the sensorimotor region for both left and right brain hemisphere.

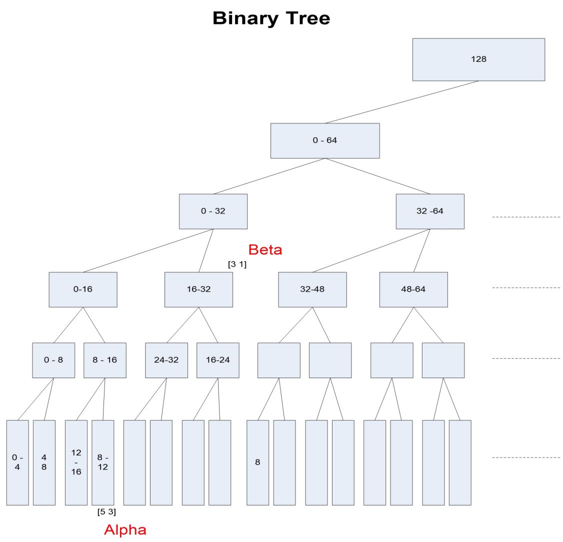


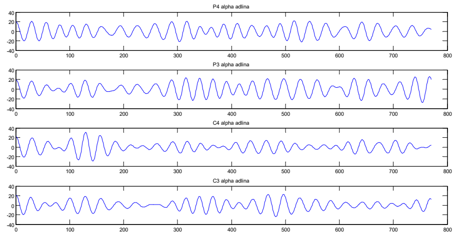
Figure 3: Wavelet Packet Binary Tree

Entropy-based Wavelet Packet Decomposition were used to compute the Log Energy of the selected band rythm[16]. Conceptually, entropy is the amount of information carried in the signal. In other words, log energy entropy is the distribution of energy in the given finite signal. Generally, the log energy entropy for signal s(t) is given by:

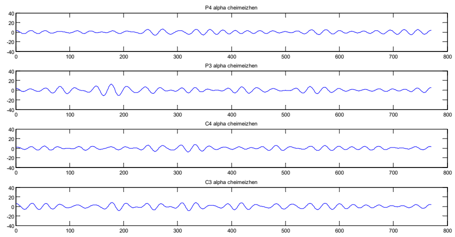
$$E(s(t)) = \mathrm{Log}\,(s^2(t)) \qquad (2)$$

3. RESULT

3.1 Relax Condition



(a) Dyslexic children 1



(b) Dyslexic children 2

Figure 4: Dyslexic Children Alpha band signal during relax

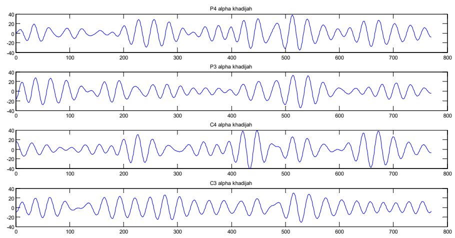
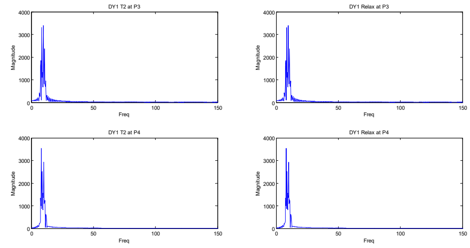


Figure 5 : Normal Children Alpha band signal during relax

From figure 4 and figure 5, there are no significant differences between the EEG signal amplitude in the P3 and P4 during relaxing for dyslexic children 1 compare to . However, the amplitude changes for C3 and C4 for dyslexic children is slightly smaller than normal children. This is because the dyslexic children might be loss the concentration during the relax activity. While, the normal children continuously relax and concentrate towards the end of relax activity. The amplitude changes of dyslexic children 2 is smaller for all channels. This might be due to the Autistic Disorder symptoms diagnosed earlier in this children.



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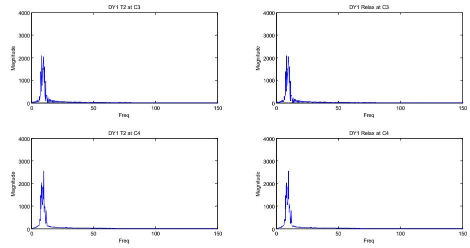

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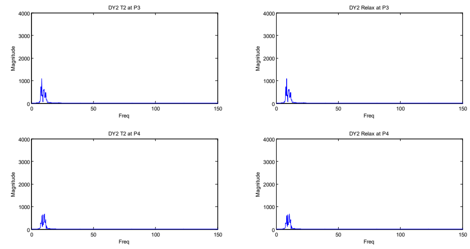

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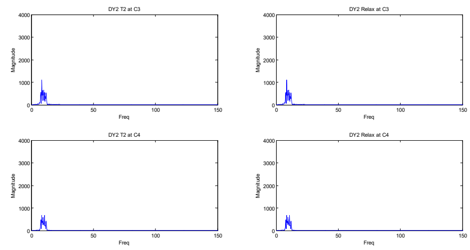
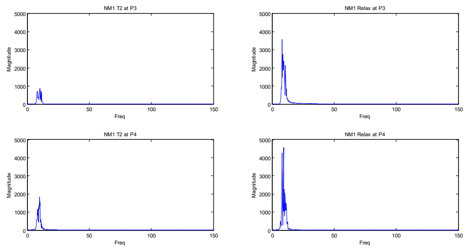
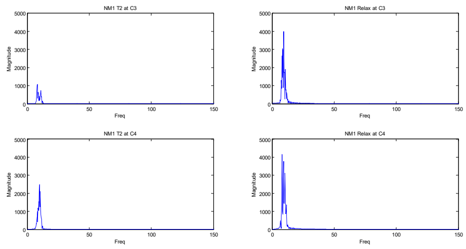


(d)

Figure 6 : Frequency Spectrum of EEG signal obtained from (a) P3 and P4 of dyslexic children 1 (b) C3 and C4 of dyslexic children 1 (c) P3 and P4 of dyslexic children 2 (d) C3 and C4 of dyslexic children 2.



(a)



(b)

Figure 7 : (a) FFT for normal children 1 at channel P3 and P4 (b) FFT for normal children 1 at channel C3 and C4

Figure 6 shows the frequency spectrum magnitude for dyslexic children have similar magnitude in their alpha during writing relax. However, the magnitude for P3 and P4 for dyslexic children 1 is higher than C3 and C4. This is because there is smaller movement occured by this dyelxic children during relax activity. The frequency spectrum magnitude for dyslexia children 2 is smaller than dyslexia children 1 and normal children, figure 6(c) and 6(d). This could because of this children have Autism symptoms. Figure 7 show that the frequency spectrum for alpha band is smaller during writing activity compare with relax activity. It because there are no movement occur for normal children during relax activity and she was concentrated while listen to the music.

Participant	Description
DY1	Dyslexia with incorrect response writing activity
DY2	Dyslexia with Autistic Disorder and incorrect response during writing activity
DY3	Dyslexia with correct response during writing activity.
DY4	Dyslexia with correct response during writing activity.
NM1	Normal and response correctly
NM2	Normal and response correctly
NM3	Normal and response correctly
NM4	Normal and response correctly

Table 1 : Participant response observation

Channel	C3	C4	P3	P4
Children	AI	AI	AI	AI
DY1	725.39	874.14	1226.3	1340
DY2	345.94	-172.58	386	106.26
DY3	648.48	531.21	712.7	679.76
DY4	1308.2	1011.9	1283	1202.6

Table 2 : Log Energy Entropy for dyslexic children

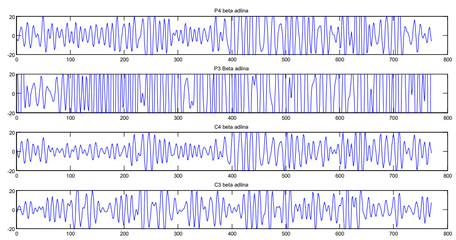
Channel	C3	C4	P3	P4
Children	AI	AI	AI	AI
NM1	1575	1504.5	1446.3	1565.4
NM2	754	638	690	677
NM3	588.59	758.64	661.68	577.69
NM4	866	1149	1198	1271

Table 3 : Log Energy Entropy for normal children

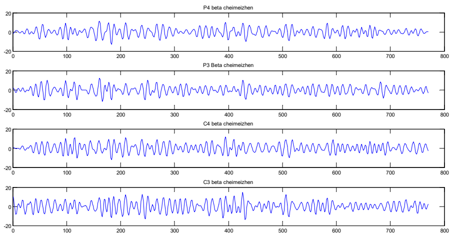
The Log Energy Entropy for both dyslexic and normal children during relax activity have been tabulated in table 2 and table 3. Table 2 shows that dyslexic children diagnosed with Autistic Disorder use the lowest energy in alpha band during relax activity due to minor movement such as head movement or her finger movement.. Other alpha band energy values does not show significant difference between dyslexic children and normal children except for normal children 1. Normal children 1 has the highest energy in alpha band. This might be due to her concentration while listen to the music.

3.2 Brain Processing Path in Writing

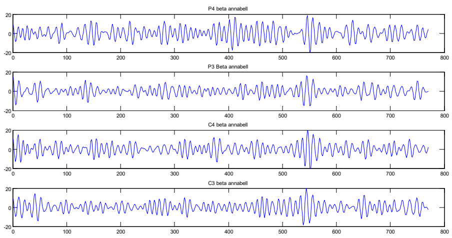
From figure 8, we can observed that the beta band signal amplitude of dyslexic children is higher than normal children for all channels except dyslexic children 2. The beta band amplitude for dyslexic children 1 shows very much different at channel P3. This is because this children perform writing incorrectly. The amplitude value for dyslexic children 2 who has Autistic Disorder is lower compare to other dysexic.



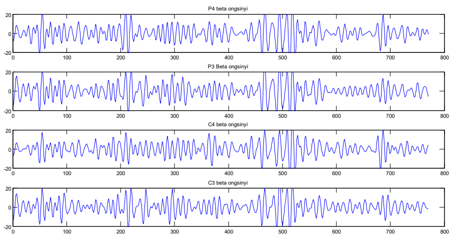
(a) Beta band for dyslexic children 1



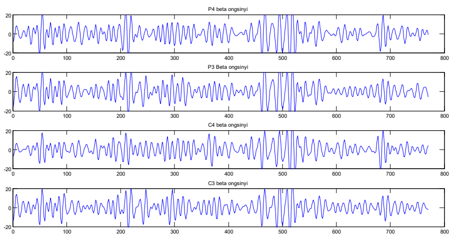
(b) Beta band for dyslexic children 2

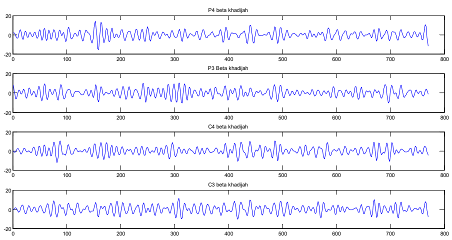


(c) Beta band for dyslexic children 3



(d) Beta band for dyslexic children 4





(e) Beta band for normal 1

Figure 8 : (a) EEG signal at beta rythm for dyslexic children 1 (b) EEG signal at beta rythm for dyslexic children 2 (c) EEG signal at beta rythm for dyslexic children 3 (d) EEG signal at beta rythm for dyslexic children 4 (e) EEG signal at beta rythm for normal children 1.

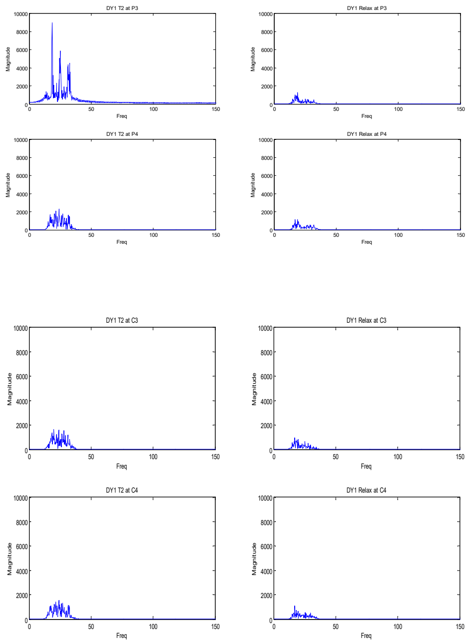
Standard Deviation for Beta Band			
Participant	Channel	Dyslexic	Normal
1	C3	10.81	3.91
	C4	10.26	3.83
	P3	35.18	3.85
	P4	14.47	3.8
2	C3	4.89	3.46
	C4	4.27	4.27
	P3	3.88	2.9
	P4	3.87	3.9
3	C3	5.22	2.99
	C4	5.36	2.9
	P3	4.49	2.62
	P4	6.1	2.77
4	C3	7.43	3.23
	C4	7.42	3.39
	P3	8	3.39
	P4	8.28	3.62

Table 4 : Standard Deviation for Beta Band

Tabulation in table 4 shows the standard deviation for children 1 is higher compare to other dyslexic children . This is because this children perform incorrectly during writing task. Dyslexic children 2 shows the lowest standard deviation for all children. This might be due to this children is diagnosed with Autism symptom. Other dyslexic children have no significant difference at their standard deviation. For normal children, the standard deviation show not very much different between them.

3.3 Writing Task Response between dyslexic

The frequency spectrum show in figure 8(a) indicates strength of channel P3 (angular gyrus at parietal lobe) which consumed more energy during writing activity. This dyslexic children 1 has struggling during the task and respose incorrectly. Other channel for dyslexic 1 show only slightly higher than other dyslexic children. Frequency spectrum for dyslexic children with Autistic Disorder, figure 8(b) show the lowest magnitude compare with dyslexic children who response correctly. For both dyslexic children 3 and 4, figure 8 (c) and (d) show no significant difference in their frequency spectrum.



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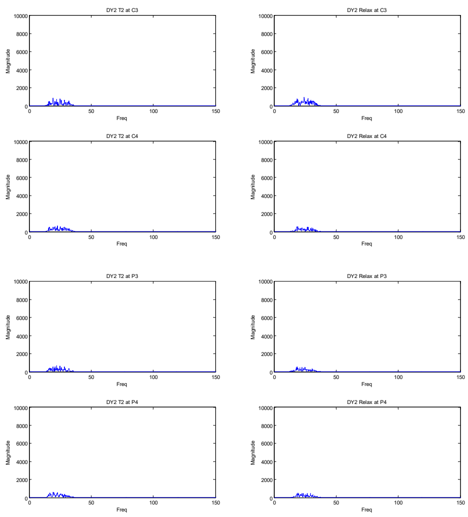

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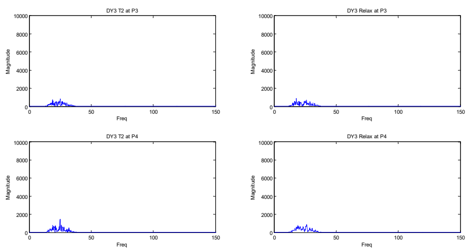

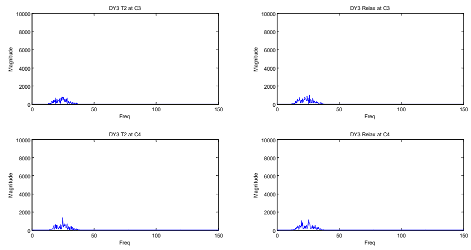

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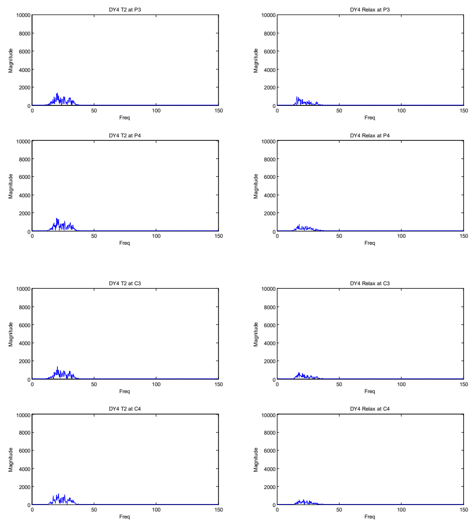

(d)

Figure 8: Frequency Spectrum for Dyslexic children (a) DY1 frequency spectrum (b) DY2 frequency spectrum (c) DY3 frequency spectrum (d) DY4 frequency spectrum

From table 4, it shown that the dyslexic children 1 has the highest energy comsumed for all channel. This might be due to she is struggling during her writing task. However, the dyslexic children 2 shows different value from dyslexic children 1 even she also response incorrectly for the task. The energy consume is the lowest compare to others. This could be due to unconcious state results from her autistic disorder symptoms. All dyslexic children show the energy at C3 is higher than C4 since all of then are right handed during writing except dyslexic 4. It might be because of the impairment occur at sensorimotor area for dyslexic children 4. However, for P3 and P4 channel, neuron activation show the left side of language processing area is higher for all children except dyslexic children 3. It could be due to the impairment affects the left angular gyrus region for dyslexic children 3.

β	C3	C4	P3	P4
DY1	1303.7	1240.1	2206.9	1526.9
DY2	762.67	702	544.56	499.54
DY3	789.42	777.99	634.05	870.35
DY4	956.25	992.58	1050.2	1016.9

Table 5: Log Energy Entropy for Dyslexic Children

4. CONCLUSION

The analysis of dynamic EEG signal for dyslexic children based on the Wavelet Packet Transform has been discussed in this paper. The EEG signal were decomposed into 5 level. The selected band were chosen based on the node sequence produce by MATLAB program. At each selected band, the energy entropy were tabulated for both relaxing and writing condition. From alpha band perspective, there are no specific character to differentiate the normal children and dyslexic children. It is because, during the relax task, the human brain activity is beyond of our control. The neuron activation for particular region such as imagination will affect the outcome of the experiment. Hence, all the results of alpha band for relax activity either normal children or dyslexic children are based on the individual brain activity.

In the beta sub-band, specific character of dyslexic children with writing disability can clearly observe. The standard deviation and log energy entropy can differentiate the changes of beta band among normal children and dyslexic children. In general, standard deviation and log energy entropy for dyslexic children are higher than normal children. The standard deviation can explain whether the dyslexic children response the experiment task correctly or incorrectly. Furthermore, the log energy entropy feature can reveal the specific impairment region between the dyslexic children either the impairment occurs at language processing region or sensorimotor region.

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