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FEATURE EXTRACTION OF ELECTROENCEPHALOGRAM SIGNAL GENERATED FROM WRITING IN DYSLEXIC CHILDREN USING DAUBECHIES WAVELET TRANSFORM

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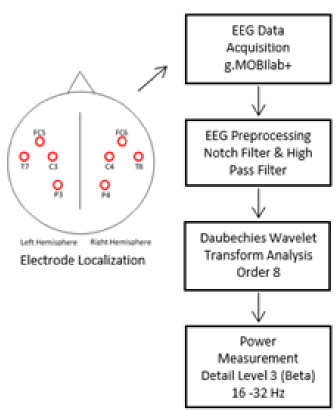
Graphical abstract



Abstract

Dyslexia which causes learning deficiencies in reading and writing is due to a neurological disorder where the brain processes information differently. This paper describes the feature extraction of (EEG) signal using Daubechies wavelet transform. The EEG signals were recorded from capable and poor dyslexic children during writing activities of non-words. Brain learning pathway theories for reading and writing were used to localize electrode placement to 8 positions, namely C3, C4, P3, P4, T7, T8, FC5 and FC6. Daubechies provide the wavelet function shape that represent the type of features in an EEG signal well, detecting variations in frequencies that corresponds to activation of areas in relation to activities. Results showed that capable dyslexic subjects exhibit higher beta band power feature of the frontal (FC6) and parietal (P4) right hemisphere if compared to poor dyslexics, where the normal left hemisphere processing center was utilized. This indicates that the brain of dyslexic is compensating its deficiencies of the left brain with activation of areas to the right.

Keywords: Electroencephalogram, dyslexia, discrete wavelet transform, writing

1.0 INTRODUCTION

Dyslexia is known as a neurological disorder that affects a child ability to properly read or write. Numerous investigations have reported that 5 to 10% of children in a nation is potentially dyslexic [1]. A dyslexic child processes information differently if compared to a normal learner even though they do receive age appropriate education [2]. In a normal child, the brain learning pathway involves the left hemisphere with areas known as Wernicke, located in the temporal lobe, and Broca in the frontal lobe. Broca area is essential in the organization, production and manipulation of language and speech while Wernicke is an area that helps us to understand language [3]. It is believed that the ability to read takes advantage of the language pathway where one's ability in translating word into its phonemes gives them the advantage to be fluent in reading [4].

In neurophysiological studies of dyslexia, phonological theory pointed towards the impairment of the brain's left hemisphere language pathway that affects the child ability to associate sound with word as a possible cause. It is the most supported theory if compared to cerebellar and rapid auditory processing [5]. Poor dyslexics would have an intelligence quotient (IQ) suitable within their age group or in some cases even higher but would struggle to read or write simple word and paragraph. Structurally and anatomically, abnormalities were also found in term of the hemisphere being symmetry or in certain cases, the right hemisphere being larger than the left [6, 7]. Capable dyslexics are those that have shown an ability to properly read and write after undergoing an effective pedagogical intervention program.

Electroencephalogram (EEG) is one of the methods to study brain activities. It records electrical activities in the form of amplitude and frequencies. It has five frequency bands; Delta (1-4Hz), Theta (4-7Hz), Alpha (8-12Hz), Beta (13-30Hz) and Gamma (31Hz and above). Different bands representing different level of activities, ranging from sleeping to concentrating. When compared to magnetic resonance imaging (MRI) or positron emission tomography (PET), it is the most practical and cost effective diagnostic option in the study of brain functionality. Beta band was found to be associated with writing with studies indicating a frequency range of 13 to 29 Hz [8, 9] and finger movements was reported to have a frequency range of 16 to 21 Hz [10]. Thus, the power feature within the beta frequency band extracted during writing activities should be investigated.

Due to the complexity of EEG signals, a suitable signal processing tool is required to effectively extract discriminative feature to distinguish differences between different brain signal activities. Wavelet transform provides the time-frequency representation of EEG signal with the advantage of good time resolution of higher frequencies with an improvement in frequency resolution at lower frequencies. It is suitable in processing and extracting features from a highly non-stationary and non-linear signal such as the EEG. Wavelet transform has been applied in extracting features from EEG signal for the study of mental task [11], emotion [12], motor imagery [13] and seizures [14] to name a few.

In working with wavelet transform, the selection of its wavelet function shape or wavelet families would depend on the features represented by the acquired EEG signal. In a signal whose features is varying in frequency, Daubechies provide the smoothing element that is able to highlight any changes and represent differences between different activities presented to the subject. Daubechies wavelet is also known to be effective in providing good localizing properties in both frequency and time domain.

This paper describes the feature extraction of (EEG) signal of dyslexic children obtained during writing using Daubechies wavelet transform. Analysis was made based on beta band power feature extracted from wavelet transform decomposition of EEG signals during writing tasks for both poor and capable dyslexic. The locations of electrode that were monitored are in accordance to known learning pathway and activation areas related to writing, significantly the Broca and Wernicke areas. Findings would assists the work in providing an assistive dyslexia based assessment system that is capable of producing objective based result and reduce over reliance on skilled therapist.

2.0 METHODOLOGY

The process of extracting features of EEG signals from dyslexic children during writing is shown in Figure 1. Four main stages were carried out; data acquisition, signal pre-processing, discrete wavelet decomposition and feature extraction.

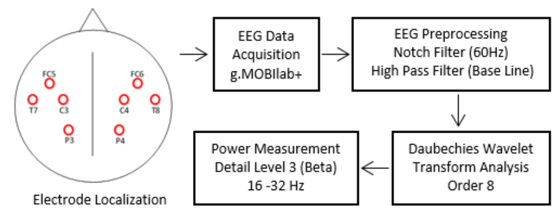


Figure 1 The whole process of extracting features of EEG signals from dyslexic children

2.1 Data Acquisition

EEG signals were acquired from 9 dyslexic children; 4 poor dyslexic children and 5 capable dyslexic children, who are all right handed, based on an existing collaboration with Dyslexia Association of Malaysia. Subjects having an age range of 7 to 11 years old have been put through a screening process to ensure compliance with requirements. Other information such as psychological background, medical history and intellectual quotient (IQ) were also recorded. This was to ensure conformity and uniformity of data as comorbid features or subject at different level or under certain medication, could exhibit different activation pattern and affect results.

Subject was first instructed to sit with eyes closed for a period of 40 seconds as the initial recording during relax was made. For the second task, subject was asked to read a non-word as displayed on a computer screen and writing it down based on an auditory cue. This task consists of 3 non-words per set and is repeated twice, giving a total recording of 6 words of 2 data recording sets. The non-words chosen contained letter that normally a dyslexic child would make mistakes in their writing, i.e. k, l, e and n, with all lower case letters. Video recordings of the full session were also made. Ag/AgCl electrodes were applied on the surface of the subjects scalp at C3, C4, P3, P4, T7, T8, FC5 and FC6, circled in red, as illustrated in Figure 1 based on the international 10/20 system.

The alphabet labelling of C refers to central areas of the brain, with T being temporal, P for parietal and FC for frontal. Odd numbers of 3, 7 and 5 refers to location in the left hemisphere while even numbers of 4, 8 and 6 refers to the right. Motor function primary involves central areas of C3 and C4 while parietal relate to the recognition of words. Wernicke is located close to P3 while Broca around FC5. FC6 and P4 were included to monitor compensatory properties of the brain, looking for the alternate pathway. Temporal areas are involved in the processing of sounds. It was important to localize the electrodes position as it would be time and cost consuming if the full electrode montage of 64 or 128 were to be applied. Placements are tested based on previous fMRI and neurophysiological theories that hypothesized the involvement of the left and right hemisphere of the brain.

In this study, g.MOBIlab+ EEG recording system with 8 monopolar channels were used. The acquired signals were then amplified and sampled at 256Hz. Preprocessing of the EEG signal consists of the removal of power line noise with a notch filter and a high pass filter to eliminate DC baseline drift. After preprocessing, the data were stored in a MAT format for subsequent processing through MATLAB software.

2.2 Discrete Wavelet Transform

The EEG signal were separated at different frequency bands using daubechies wavelet transform by applying two sets of functions, referred to as scaling and mother wavelet. A low pass filter of Equation (1) was used as the scaling function and a high pass filter of Equation (2) was applied as the wavelet function.

$$H_0(n) = \sum_k h_{0\,k}\, e^{-jkn} \qquad (1)$$
$$H_1(n) = \sum_k h_{1\,k}\, e^{-jkn} \qquad (2)$$

As shown in Figure 2, when the EEG signal, x(n) passes through a low pass filter, $H_0(n)$, its approximate coefficient (A(n)) is produced. This resultant signal was then down sampled by two. The resultant signal produced by high pass filter of $H_1(n)$ called the detail coefficient (D(n)) was also down sampled by 2, keeping the even indexed elements.

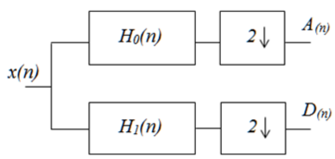


Figure 2 Decomposition of signal using Wavelet Transform

The approximate coefficient was further decomposed into two parts using a similar procedure as per the above by replacing the original signal, x(n) with its approximation, A(n). This was repeated for subsequent level and can be mathematically represented by

$$A_{j-1,k} = \sum_n h_{0\,-\,2k}\; A_{j,n} \qquad (3)$$
$$D_{j-1,k} = \sum_n h_{1\,-\,2k}\; A_{j,n} \qquad (4)$$

for j = j+1, j…., j_0 where $A_{j+1,}\, k = x[k]$, k

Figure 3 shows the signal with a sampling frequency of 256Hz being decomposed to 5 levels using Daubechies wavelet of order 8 that gives the advantage of better feature localization [15, 16].

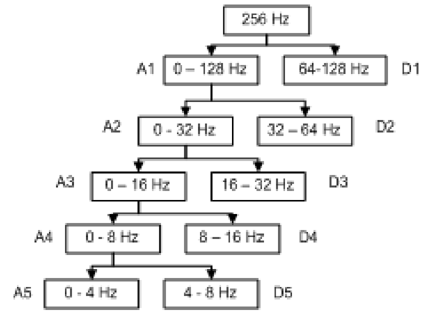


Figure 3 Decomposition of 256Hz EEG signal

Level D1 and D2 represent the high frequency content that can be considered as noise and subsequently ignored. The beta band of the EEG signal at level D3 is of interest as it has been identified as the band that is related to reading and writing as an indication of activation. For the purpose of classification, wavelet coefficients need to be computed into statistical parameters in order to reduce its feature size and proportion. In achieving this, the power feature was selected. The power measurement of the third detail level of decomposition, D3, between 16 to 32Hz, was calculated using Equation 5. The power is the sum of the squared signal values divided by the signal length.

$$\text{Power} = \sum x^2 / L(x) \qquad (5)$$

where x is the signal value and L is the length of the signal

3.0 RESULTS AND DISCUSSION

The overall plots of all 5 levels of electrode position FC5 for poor and capable dyslexics is as per Figure 4 and 5 respectively. By observing the plots, it is not obvious that any conclusion can be derived, although, it can be seen that a poor dyslexic showed a higher level of activities in both alpha and beta band if compared to a capable dyslexic. This could be an indication that the brain is working harder in a poor dyslexic.

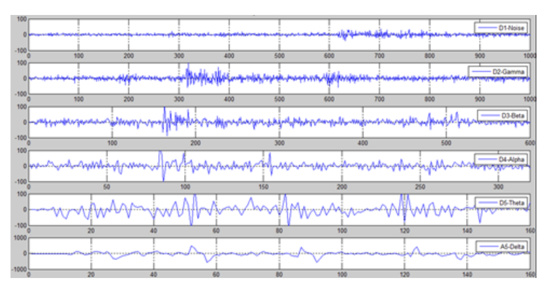


Figure 4 Plot of wavelet coefficients of all level at location FC5 for Poor Dyslexic

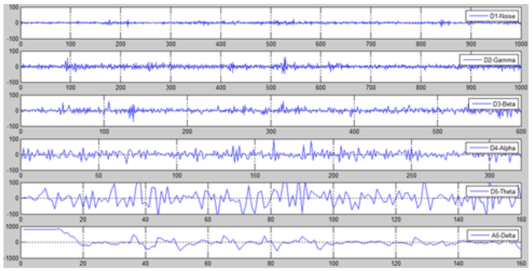


Figure 5 Plot of wavelet coefficients of all level at location FC5 for Capable Dyslexic

The wavelet coefficient plots on all subjects showed a consistent feature with reference to electrodes at frontal and parietal position. This is highly significant as these corresponding locations are where Broca and Wernicke are located. Similar to the overall plots, the beta band of location FC5 and P3 seems to have a higher energy and amplitude on average if compared to location FC6 and P4 in the majority of the time recorded. This is in reversed for the observation of a capable dyslexic where higher amplitude was seen for the majority of the plot in FC6 and P4 if compared to location FC5 and P3. To be definitive, the wavelet power measurement would provide conclusive answers, both in the level and areas of activation. Table 1 shows the power measurement of 4 poor dyslexic subjects during two set of reading and writing tasks. Shaded boxes indicate higher power measurement.

Table 1 Beta band power measurement of poor dyslexic subjects

Subject 1 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	163.6043	C4	156.2956
P3	180.9479	P4	159.2617
T7	234.179	T8	488.7465
FC5	196.0113	FC6	159.2617
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	124.5949	C4	126.7568
P3	133.0402	P4	97.677
T7	175.7396	T8	440.7328
FC5	177.1014	FC6	97.677
Subject 2 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	213.4511	C4	235.9421
P3	204.167	P4	184.6884
T7	463.5545	T8	273.098
FC5	241.0804	FC6	184.6884
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	171.7813	C4	213.884
P3	200.6284	P4	159.9133
T7	334.2723	T8	207.6579
FC5	199.6895	FC6	159.9133
Subject 3 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	87.6116	C4	85.5056
P3	135.1782	P4	64.5668
T7	228.7615	T8	129.1789
FC5	85.5291	FC6	64.5668
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	89.8283	C4	95.8415
P3	138.7247	P4	58.0985
T7	237.7469	T8	192.3862
FC5	93.3282	FC6	58.0985
Subject 4 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	213.853	C4	198.075
P3	249.342	P4	210.039
T7	620.043	T8	1265.3
FC5	251.839	FC6	210.039
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	164.641	C4	148.555
P3	182.047	P4	152.682
T7	482.262	T8	860.893
FC5	255.633	FC6	152.682

It was observed from Table 1 that all 4 poor dyslexic subjects exhibited significantly higher beta band power in the frontal left hemisphere of FC5 and parietal P3. Although there are mixed results with other electrode positions, majority of the activation are located at the left hemisphere. This is in agreement of the normal learning pathway where the left hemisphere is utilized in activities related to reading and writing.

Figure 6 shows the alphabet writings of subject 4 from the poor dyslexic group on the left and its actual answer on the right with errors normally related to signs of dyslexia. Note the inverse b and q, along with w and m. This indicates that although the normal learning pathway is utilized, difficulties in reading and writing tasks are still prevalent.

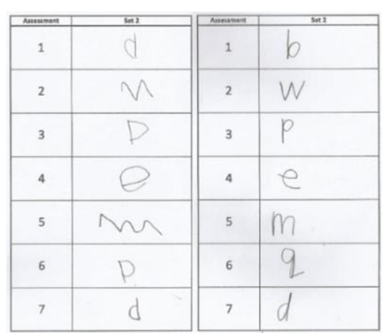


Figure 6 Alphabet writings of poor dyslexic subject 4 on the left with the correct answers on the right

Table 2 Beta band power measurement of capable dyslexic subjects

Subject 1 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	111.8822	C4	104.3847
P3	135.6227	P4	199.3728
T7	116.6934	T8	58.0222
FC5	107.858	FC6	199.3728
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	117.8258	C4	118.4868
P3	143.2137	P4	265.993
T7	115.9878	T8	57.5228
FC5	115.0102	FC6	265.993
Subject 2 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	133.5086	C4	132.7924
P3	149.9758	P4	215.5848
T7	171.3238	T8	150.5574
FC5	209.5004	FC6	215.5848
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	166.5167	C4	170.7378
P3	204.3043	P4	583.3181
T7	373.8787	T8	154.3032
FC5	219.9588	FC6	583.3181
Subject 3 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	209.1273	C4	191.126
P3	237.7886	P4	480.7319
T7	768.9623	T8	313.572
FC5	273.3478	FC6	480.7319
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	196.7522	C4	201.214
P3	220.1731	P4	397.1198
T7	1032.2	T8	468.1374
C5	254.4245	FC6	397.1198
Subject 4 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	102.645	C4	95.6423
P3	104.328	P4	130.478
T7	240.64	T8	99.677
FC5	122.338	FC6	130.478
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	145.634	C4	244.937
P3	179.496	P4	360.701
T7	257.112	T8	154.369
FC5	130.029	FC6	360.701
Subject 5 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	151.64	C4	156.59
P3	239.056	P4	502.662
T7	244.784	T8	135.994
FC5	183.428	FC6	502.662
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	166.666	C4	202.658
P3	272.568	P4	631.963
T7	303.969	T8	154.125
FC5	214.548	FC6	631.963

For 5 capable dyslexics, as shown in Table 2, it clearly indicates a higher activity of the frontal right hemisphere of location FC6 and parietal P4 for all subjects if compared to the left. All capable dyslexic subjects could correctly read and write the non-words that was displayed within a time period that is considered to be normal. This was the opposite for our poor dyslexic subject where the beta band power was reversed. A larger difference in power between the left and right hemisphere of FC5 and FC6 as shown in subject 3, 4 and 5 also relates to their ability to complete the task faster than their colleagues. This could be used to objectively map their performance in learning related activities.

The findings above conforms to the phonological theory of dyslexia that states impairment to the brain left hemisphere for a dyslexic and in an effort to compensate, the brain utilizes the right hemisphere for activities related to learning [17, 18]. As per poor dyslexics, central and temporal areas gave mixed results with further investigation required. Figure 7 compares the writings of a poor dyslexic on the right with that of a capable dyslexic on the left, both are at the same age of 7.

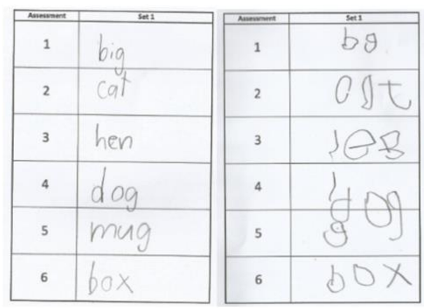


Figure 7 Alphabet writings of poor dyslexic subject 4 on the left with the correct answers on the right

The left hemisphere is known to be an important brain pathway in learning and it has been shown that capable dyslexic is possibly bypassing this area and compensating it with the use of right frontal hemisphere of FC6 and parietal area of P4. Poor dyslexic tends to continuously attempt to engage the left hemisphere as per normal with no significant improvement in learning related activities. This could explain the reason on why they are having difficulties in learning to read or write even if they were to possess an average IQ or even in some cases a higher IQ than the norm. Common pedagogical approaches that are currently being used in mainstream education system favor the left brain which could prove to counterproductive for a dyslexic child. Table 3 represents the power measurement of 2 dyslexic subjects that has undergone 3 months of intervention program with Dyslexia Association of Malaysia. They have been identified by the association as in their intermediate classes.

Table 3 Beta band power measurement of intermediate dyslexic subjects

Subject 1 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	209.1273	C4	191.126
P3	237.7886	P4	480.7319
T7	768.9623	T8	313.572
FC5	273.3478	FC6	480.7319
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	186.6757	C4	171.2103
P3	210.023	P4	173.6547
T7	358.321	T8	323.6265
FC5	242.8937	FC6	173.6547
Subject 2 - Set 1			
Electrode	**Power**	**Electrode**	**Power**
C3	133.9174	C4	120.1305
P3	150.3075	P4	153.3539
T7	210.9332	T8	191.0768
FC5	184.0451	FC6	153.3539
Set 2			
Electrode	**Power**	**Electrode**	**Power**
C3	227.1435	C4	218.2982
P3	243.7699	P4	263.5643
T7	284.1495	T8	243.8662
FC5	263.6782	FC6	263.5643

Results above shows that in an intermediate level dyslexic, the brain is learning to compensate with instances of right brain usage but has not fully utilize its function with the occasional left brain activation of both parietal and frontal. Note that the differences of power measurement are small in the frontal and parietal areas of subject 2 for its left hemisphere activation, also in subject 1 for the second set as the first set are right hemisphere activation. A study have also collaborated these results by indicating that more connectivity of the right hemisphere with an under activation of its counterpart in the left, can be an indicator of whether a dyslexic could and able to overcome their deficits [19].

These initial findings can be used as an objective assessment based system in looking at the progression of a child with dyslexia undergoing an intervention program or in looking at the effectiveness of the invention program itself. Furthermore, the alternate compensating pathway can be identified and used in the design of a neurofeedback protocol in strengthening areas of the right hemisphere by way of facilitating the desired neural pathway. The power measurement could be set as one of the input feature for the classification system on the neurofeedback design.

4.0 CONCLUSION

Daubechies wavelet transform was implemented to decompose the EEG signals into its frequency sub-bands before its beta power feature was extracted. It has been revealed that the technique applied provide the possibility to obtain distinguishable feature in the study of dyslexia. By applying Daubechies wavelet of order 8, its localization capabilities enabled distinguishable features to be identified to differentiate activation pattern in the acquired EEG signals by way of looking into its power measurement. In learning activities related to reading and writing skills, capable dyslexic was seen to bypass the traditional pathway related to learning located in the left hemisphere and compensating its deficiencies by utilizing areas involving the right frontal hemisphere. Poor dyslexic was observed to continuously attempt to engage area to the left, particularly, FC5 and P3. Areas of the brain involving central and temporal, showed mixed results with little variations. The distinguishable feature of FC6 and P4 could be used as an indicator in measuring the progress of a dyslexic children and as an input to a classification system in the design of a neurofeedback system.

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