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Frequency Content Signatures for Letter Writing: Normal and Dyslexic Children

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ABSTRACT

Dyslexia severely impedes specific learning disabilities, reading and writing in particular, owing to impairment of the language processing area located in the left hemisphere of the human brain. It poses a stumbling block to development of an educated competent and competitive society, besides consequences from feeling incompetent. Most previous research examined deficit in reading. Our work attempt to extract signatures of electroencephalogram (EEG) signals to feature writing deficit in dyslexic children. The approach will constitute an objective method to identify children with writing deficits early for intervention programs, if successful. Six children, two normal and four dyslexic, were recruited for our study. EEG signals along the neurological pathway (C3, C4, P3 and P4) for writing are acquired. Fast Fourier Transform (FFT) is applied to transform the EEG in time domain into frequency domain so that signature features in frequency content during letter writing task can be extracted. Results showed that the frequency spectrum of EEG for the normal HighIQ and dyslexic Capable group is trapezoidal and crown shaped. This infers only one major frequency component of neural activity during writing for the former while two for the latter. The frequency spectrum of EEG for both groups is found to exhibit one peak in the alpha-subband and another in the beta-subband. The frequency of peak in the alpha-subband is less than 13Hz, while that in the beta-subband is 13-30Hz, which agrees with previous findings. However, the peak frequency within the beta-subband is found to be 13-20 Hz for the normal HighIQ group while 13-27 Hz for the dyslexic Capable group. This implies that the latter commands higher neural activity in letter writing task.

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INTRODUCTION

Dyslexia is a neurological symptom, which manifests itself as an inability to acquire reading, spelling and writing skill that commensurate with one’s intelligence as per age(Virginia *et al.*, 2008). This is particularly insidious, since a large number of the dyslexics are found to have intelligence above the average and are specially gifted for creative abstract thinking. Accomplished historical figures who had pattern of learning difficulties associated with dyslexia or related learning styles in science and invention are Michael Faraday, Thomas Edison, Albert Einstein; art, design and architecture are Leonardo da Vinci, Auguste Rodin, Pablo Picasso; in athlete are Muhammad Ali, Steve Redgrave, Meryl Davis; in business are Richard Branson, Henry Ford, Sir Peter Leitch; in filmmakers are Walt Disney, Steven Spielberg; in novelists are Agatha Christie, Hans Christian Anderson, Stephen cannel, just to name a few.

A statistical survey by the Ministry of Education of Malaysia has revealed that 5% or 265,210 of a total of 5,304,201 Malaysian students are diagnosed with dyslexic in 2012(Department of Education for Special Needs, Ministry of Education, Malaysia, 2013). A report in 2011 revealed that dyslexia has affected about 80% of children in United States with all specific learning disability (SLD)(Cortiella, 2011). In addition, the National Longitudinal Transition Study-2 (NLTS2) in 2003 from the United States Department established that students with LD are 3.4 years behind their enrolled grade level in reading and 3.2 years behind in mathematic(Cortiella,

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2011). Further research found that the achievement gap between students with LD and those without widens as students progress from one grade to the next. This becomes a hurdle critical to the development of an educated competent and competitive society towards employment chances. A report from the National Center of Learning Disabilities recorded only 54.8% adults with LD, between age 18 to 64, were employed in comparison to 76.4% of those without LD. Based on an United States Survey of Income and Program Participation, 5.7% of adults with LD were unemployed in 2005(Cortiella, 2011). A long term effect as a result of feeling incompetent by these adults with LD is the risk of developing more complex psychopathological disorders that may lead to behavior disorder, anxiety and depression(Gaggi *et al*., 2012). This is a great loss to a nation because their intelligence resides in the upper stratum.

Consensus strongly suggests that a deficit in the language processing area located in the left hemisphere of the human brain causes dyslexia. This language processing area is known to play pivotal role in processing reading and writing activities(Shaywitz *et al*., 2002; Che Wan Fadzal *et al*., 2011; Menon *et al*., 2001). Neuropsychological studies also have established that children with dyslexia face difficulties to express concepts, ideas and notion in both oral presentation and written language; to spell words correctly and to distinguish between letters of mirror images like ‘b’ and ‘d’, ‘p’ and ‘q’, etc.

Dyslexia is usually accompanied by dysgraphia, referring to a disability to acquire the written language, thus makes the act of writing problematic. Dysgraphia manifests itself as poor handwriting as well as repetitive mistakes in spelling of words at schools, which is always misinterpreted by the teachers as defiance in the children to improve(Snowling *et al*., 1986). This causes the children to be ridiculed and prejudiced. A longitudinal design to differentiate between normal subjects and subjects with dysgraphia reveals discrepancies in their writings. Power spectral density analysis on writing from subjects with dysgraphia discovers that it is noisier than the normal subjects proficient in writing, whose writing pattern displays a noise peak in the region of neuro-motor tremor(Smits-Engelsman and Van Galen, 1997). Moreover, subjects with dysgraphia are found to lack behind a year on stroking pattern letters, such as “eee”, “mmm”, “sss” (Smits-Engelsman and Van Galen, 1997), and young subjects can only identify non-complex orthographic patterns(Cassar and Trieman, 1997).

Previous research on diagnosing dyslexia using electroencephalogram (EEG) can be numbered. One elicited wavelet entropy changes in the brainwave during working memory assignment in dyslexic children, majority from electrodes in the frontal-central regions(Giannakakis *et al*., 2008). Another examined the EEG signals during reading tasks and found that the dyslexics displayed an auto-spectral between 16 to 32Hz while the normal subjects exhibited a higher level of energy(Sklar *et al*., 1973). There was also an attempt to extract the EEG spectral features to identify the trait of dyslexic children(Rippon and Brunswick, 2000). However, the writing deficit in dyslexic children has not been explored.

In this paper, an approach to extract signatures to feature writing deficit in dyslexic children is explored. Based on previous studies, signatures in frequency content of the EEG signals will be examined. The approach will constitute an objective method to identify children with writing deficits early for intervention programs, if successful. Our research here is conducted in collaboration with the Dyslexia Association of Malaysia, a non-profit NGO set up to advance the education and welfare of general public, children especially, who are affected by dyslexia and other specific learning disabilities. The dyslexic subjects were recruited and the tasks prescribed in our experiment were from the psychometric test manual for diagnosis of dyslexic from the Dyslexia Association of Malaysia. First, theory to transform EEG signals from time domain at recording to frequency domain is elaborated. Then, demographic information on subject population, data collection, data acquisition, pre-processing and feature extraction are presented in the Methodology Section. Finally, features processed and extracted by Fast Fourier Transform (FFT) from dyslexic and control group are compared and discussed.

Theory:

Fast Fourier Transform (FFT) is widely used in the analysis of EEG signals from subjects with brain related disorders. For example, FFT and Short Time Fourier Transform (STFT) were used to analyze EEG background activity in autism disorders(Behnam *et al*., 2007; Sheikhani *et al*., 2007). FFT was also used to extract features characteristic of epileptic patients(Padmasai *et al*., 2010).

FFT is an algorithm developed to speed up the calculation of Discrete Fourier transform (DFT), described by the following equation, where $X(k)$ is a periodic function with a limited number of distinct values and is evaluated for $0 \leq k \leq (N-1)$.

$$X(k) = \sum_{n=0}^{N-1} x[n].W_N^{nk} \tag{1}$$

Cooley and Turkey introduced the concept of decimation for computing FFT algorithm in 1965(Maslen and Rockmore, 2003). This concept starts with the Divide and Conquer algorithm, which is then expanded further into three different types of FFT algorithms, namely the Radix-2 FFT algorithm, the Radix-4 FFT algorithm and the Split Radix-8 FFT algorithm. Equation (2) and (3) in the following describes the Radix-2 FFT algorithm, which is derived from the Divide and Conquer algorithm and implemented for our research.

First, *n* in (1) of DFT is replaced with 2r for even term and (2r+1) for odd term to produce (2), where *X(k)* is now evaluated from $0 \le r \le ((N/2)-1)$, while *G(k)* and *H(k)* are the even and odd terms.

$$X(k) = \sum_{r=0}^{(N/2)-1} x(2r).W_{N/2}^{rk} + W_N^{k} \sum_{r=0}^{(N/2)-1} x(2r+1).W_{N/2}^{rk} = G(k) + W_N^{k} H(k)$$
$$W_N^{2rk} = e^{-j2\pi/N.(2rk)} = e^{-j2\pi/(N/2).(rk)} = W_{N/2}^{rk} \qquad (2)$$

Next, *N* is set to '2' so that the range of *X(k)* can be simplified to $0 \le k \le 1$ and the Divide and Conquer algorithm in (2) can be replaced with *X(0) and X(1),* as *k* is set to *'0'* and *'1'*, to produce the Radix-2 FFT algorithm as shown in (3).

$$X(0) = G(0) + W_N^{k} H(0) = x(0) + x(1), \text{ k = 0}$$
$$X(1) = G(1) + W_N^{k} H(1) = x(0) - x(1), \text{ k = 1} \qquad (3)$$

Figure 1 shows the Radix-2 FFT algorithm of (3) in butterfly signals flow for 2-point DFT, which illustrates the transformation of signals. Signals *x(0)* and *x(1)* are in time domain while *X(0)* and *X(1)* are signals in frequency domain.

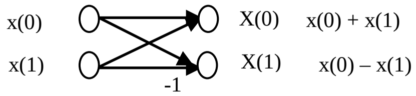

Fig. 1: Radix-2 FFT algorithm in butterfly signals flow for 2-point DFT.

Methodology:

This section elaborates on the subject population, data collection, data acquisition and data pre-processing prior to extraction of significant features with FFT.

A. Subject Population:

Six children in two-sized group, normal and dyslexic, were recruited for our study. The children were of age between 7-11 years old and all right-handed. All of them have healthy medical history. The normal subjects, one male and one female, were denoted as the HighIQ group, based on their scholastic achievement at schools. The dyslexic subjects, three males and one female, from the Dyslexic Association Centre (DAM) of Malaysia, were denoted as the Capable group, based on their achievement in the psychometric test devised by DAM.

Data collection and acquisition were conducted in DAM, with permission. Children who have any history of neurological problems or who were on medication were excluded from our study. Informed consent from parents and patient ethic approval by Universiti Teknologi MARA were obtained.

B. Data Collection and Acquisition:

Figure 2 shows the system that was used to collect, acquire and pre-process EEG data from the subjects. The g.GAMMAcap worn by the subject was connected to the g.GAMMAsys, where EEG signals were sampled and filtered using the g.MOBIlab hardware equipped with low-noise biosignal amplifiers as well as a 16-bit ADC with sampling frequency of 256 Hz, for transporting the EEG signals onto a computer. The computer was equipped with MATLAB program to acquire, store and display the brainwave signals from up to 64 or 128 channels. The EEG signals were recorded using Ag/AgCl active electrodes on the scalp inserted with g.GAMMA gel to improve the electrode skin impedance.

The electrodes on the scalp were assigned based on the International 10-20 System. The reference electrode was placed on the ground ear while the ground electrode was placed on the forehead (Fpz) of the subject. Electrode C3 (central left), C4 (central right), P3 (parietal left) and P4 (parietal right) were applied as they are located on the neurological pathway for reading/writing. They were thought to engage with neural activities during writing. C3 and C4 are associated with sensory and motor while P3 and P4 with word interpretation that registers perception and differentiation activities.

Data acquisition started with the subjects being seated on a chair and made to relax before being instructed to perform six tasks, as dictated in the psychometric test manual of DAM. This paper focuses only on one of the tasks: writing letter 's', 'w', 'j', 't', 'm', 'q' and 'e'. From psychological studies, these letters have been made known to be challenging to the dyslexics.

Then, the subjects were reminded to avoid head movement during data collection that may lead to false data, as the EEG cap with attached electrodes was being put on.

Next, the writing task was executed. The subjects were asked to look at the letter displayed on the screen of the computer and then write the letter on a piece of paper as shown in Figure 3. A screenshot of letters ‘s’ and ‘j’ on the computer screen for the subject to copy is shown in Figure 4.

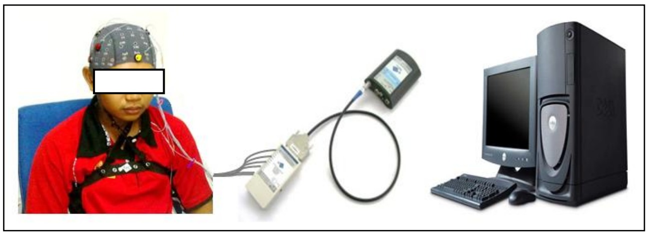
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Fig. 2: System setup that is used to collect, acquire and pre-process EEG data from the subjects .

A recording interval of 40 seconds per letter was allocated, with repetition at every five seconds. This procedure was in full compliance with the EEG procedure to focus on decreasing the anticipatory anxiety in children subjects and desensitizing the children to the components of the task assigned. In this way, the children got to know the data acquisition system and got to practice before performing the task on record.

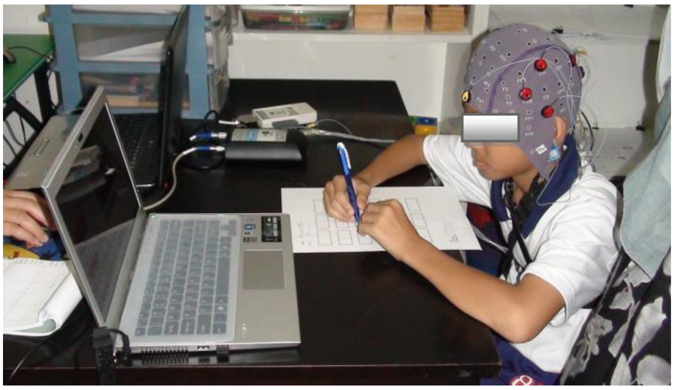
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Fig. 3: EEG recording session for a dyslexic child performing the letter writing task.

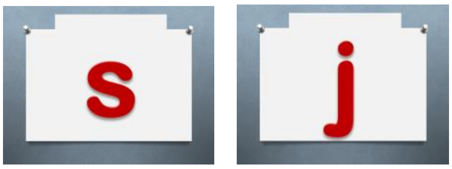

Fig. 4: Screenshot of letter writing task: ‘s’ and ‘j’.

In the signal processing stage, FFT was used to transform the EEG signals recorded in time domain into frequency domain. This is to capture the frequency content of signals from hand movement during writing(Zabidi *et al*., 2012). Initially, raw EEG data were visually inspected for artifacts from electromyogram (EMG) having frequency between 50-3000Hz and electrooculogram (EOG) having frequency between 0.1-10Hz(Description., 2013). The artifacts were first filtered and excluded using a bandpass FIR filter with frequency of interest between 8 to 30Hz. Then, FFT was applied to obtain the spectra of the filtered signals in frequency domain. Both analysis programs were executed using MATLAB.

RESULTS AND DISCUSSION

This section presents results from Figure 5a, 5b, 6a, and 6b, which show the non-segmented frequency pattern of EEG from electrodes C3, C4, P3 and P4 for normal and dyslexic children during writing letters respectively. Based on the psychometric test manual of DAM, seven letters are selected for the writing task: ‘s’, ‘w’, ‘j’, ‘t’, ‘m’, ‘q’ and ‘e’. Due to the constrain of space, only frequency spectra from writing letter ‘s’ and ‘j’, representative of all other letters, are illustrated in detail here. Results on all the letters are summarised in Table 2.

In comparing Figure 5 (normal HighIQ group) to Figure 6 (dyslexic Capable group) in writing letter ‘s’ and ‘j’, it can be seen that the frequency spectrum of EEG at channel C3, C4, P3 and P4 for the normal HighIQ group is trapezoidal. The amplitude scales the highest at low frequency of the spectrum, indicating one major frequency component of neural activity during writing. Amplitudes at all other frequencies are much lower than this. On the other hand, the frequency pattern of EEG signals for the dyslexic Capable group shapes like a crown, with peak at the beginning and end of the spectrum, indicating two major frequency components, one at the low end and one at the high end of the spectrum.

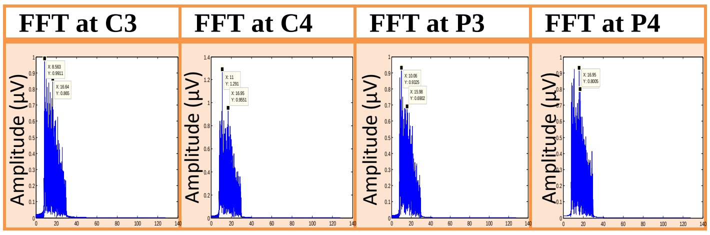

Fig. 5a: Frequency spectrum of EEG signals from normal HighIQ group during non-segmented writing letter‘s’.

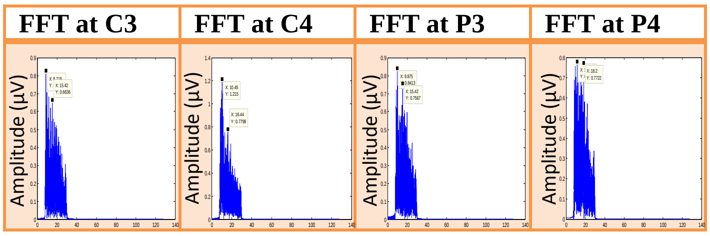

Fig. 5b: Frequency spectrum of EEG signals from normal HighIQ group during during non-segmented writing letter ‘j’.

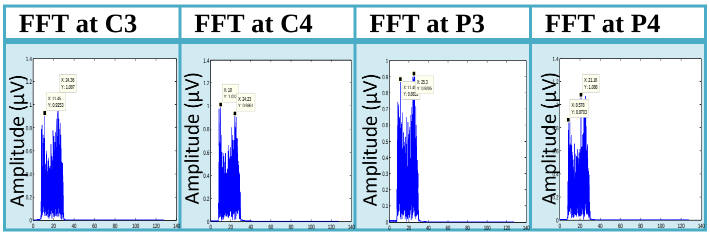

Fig. 6a: Frequency spectrum of EEG signal from dyslexic Capable group during non-segmented writing letter‘s’.

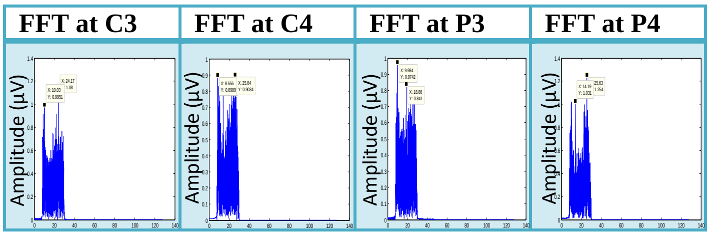

Fig. 6b: Frequency spectrum of EEG signal from dyslexic Capable group during non-segmented writing letter ‘j’.

The frequency spectrum of EEG signals from both the normal HighIQ group and dyslexic Capable group during letter writing task is observed to draw on two peaks, one each in the alpha- and beta-subband (see Figure 5a, 5b, 6a and 6b). These values are tabulated in Table 1. Averaging the frequency content in writing letter ‘s’ and ‘j’, the frequency of peak in the alpha-subband recorded is less than 13Hz, while that in the beta-subband is between 13-30Hz, for all the four electrodes C3, C4, P3 and P4. Interestingly, this coincides with previous findings(Sklar *et al*., 1973; Karim *et al*., 2013). The peak in the alpha-subband is attributed to moments at which the subjects paused during writing. It is also observed that the peak frequencies of the beta-subband are higher for the dyslexic Capable Group than the normal HighIQ Group. This just shows that the former uses more effort is writing letters.

Table 1: Frequency of Eeg Signals In Alpha- And Beta- Subband During Non-Segmented Writing Of Letters: 'S' And 'J'

	Normal HighIQ Gp						Dyslexic Capable Gp					
	Figure 3a 's' (Hz)		Figure 3b 'j' (Hz)		Average		Figure 4a 's' (Hz)		Figure 4b 'j' (Hz)		Average	
	α	*β*	*α*	*β*	*α*	*β*	*α*	*β*	*α*	*β*	*α*	*Β*
C3	8.6	16.6	8.8	14.1	8.7	15.4	11.5	24.4	10.1	24.2	10.8	24.3
C4	11.0	17.0	12.8	17.4	11.9	17.2	10.0	24.2	8.7	25.8	9.4	25
P3	10.1	16.0	9.2	14.1	9.7	15.1	11.5	25.3	10.0	18.9	10.8	22.1
P4	11.0	15.9	10.8	17.1	10.9	16.5	8.6	21.2	10.3	25.6	9.5	23.4

Table 2 shows the frequency range of peaks in the beta-subband for all the four electrodes during non-segmented writing of letters, 's', 'w', 'j', 't', 'm', 'q' and 'e'. It can be noticed that the frequency range for the normal HighIQ group lies between 13-20 Hz while that for the versus group lies between 13-27 Hz. Frequency range for peaks of both the groups falls within the beta-subband for writing activity as documented in previous works(Sklar *et al*., 1973; Karim *et al*., 2013). It can also be deduced from the results that the dyslexic Capable group shows higher neural activity in performing the task in comparison to the normal HighIQ group.

Table 2: Frequency of Eeg Signals In Beta-Subband From Normal Highiq And Dyslexic Capable Group During Non-Segmented Writing Of Letters: 'S', 'W', 'J', 'T', 'M', 'Q' And 'E'.

Electrode	Normal	Dyslexic
	HighIQ group	*Capable group*
C3	13 – 20 Hz	13 – 27 Hz
C4	13 – 18 Hz	13 – 25 Hz
P3	14 – 19 Hz	13 – 27 Hz
P4	13 – 19 Hz	13 – 27 Hz

Conclusion:

Frequency spectrum of EEG signals from the four electrodes (C3, C4, P3 and P4) along the neural pathway for writing for both normal HighIQ and dyslexic Capable group during letter writing task has been compared. It is found that the frequency spectrum of EEG for the normal HighIQ group is trapezoidal while that for the dyslexic Capable group shapes like a crown. This just shows that there is only one major frequency component of neural activity during writing for the former, at low frequency, while two for the latter, one at the low end while the other at high end of the spectrum. Common to both groups, the frequency spectrum of EEG is found to exhibit two peaks - one in the alpha-subband and one in the beta-subband. The frequency of peak in the alpha-subband is less than 13Hz, while that in the beta-subband is between 13 and 30Hz, which agrees with previous findings. A subtle difference is perceived in the peak frequency within the beta-subband: it lies between 13-20 Hz for the normal HighIQ group while 13-27 Hz for the dyslexic Capable group, implying that the latter commands higher neural activity in performing the writing task, to overcome their deficit rendered by dyslexia.

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