Suitability of Neurofeedback Protocol for Children with Dyslexia

Zulkifli Mahmoodin, Wahidah Mansor, Lee Yoot Khuan, and Ahmad Zuber Ahmad Zainuddin

***Abstract*— Dyslexia is viewed as a neurological defect that causes the subject's electrophysiological brain signal to process information differently from that of a normal learner. Subjects exhibit learning disorder in the form of reading and writing difficulties even though they possess an average intelligence quotient (IQ) level among their age group. Current intervention programmes for dyslexia rely on intensive repetitive exercises in phonemic and phonetic awareness which could be counterproductive. This paper looks into the possible application of neurofeedback towards the treatment of neurobiological dysfunction related to dyslexia. Through training or conditioning exercises, neurofeedback practise the control of brain waves in reaching a state most appropriate for a given situation. By understanding the alternate pathway of learning in capable dyslexic learner and looking into its application in various other neurobiological dysfunction, the potential neurofeedback for the treatment of dyslexia are discussed.**

***Index Terms*— eeg, neurofeedback, dyslexia**

I. Introduction

LEARNING disorder in the form of reading and writing disabilities is estimated to be present in approximately 5% of the total population of a nation which constitute to 265,210 from 5,304,201 Malaysian students in 2012 [1]. From that, 80% of those identified suffers from dyslexia which is viewed as a neurological defect that causes the subject's electrophysiological signal of the brain to process information differently from that of a normal learner. Dyslexic has the intelligence and received age appropriate education to succeed in reading and writing but struggle to achieve the desired result [2]. It posts a significant challenge to the nation efforts in improving the literacy rate of students in primary and secondary education. Under the Ministry of Education, there are currently 51 primary schools and 16 secondary schools in Malaysia that are running a specific intervention programme for students with dyslexia in an effort to address the said issue [1].

Looking into programmes and assistive technologies used in approaches towards the education of learning disabled, most take little initiative in understanding the biological aspects of the disorder and approaches it with psychological and purely pedagogical solutions [3], [4], [5], [6], [7]. This scenario lead towards educating students with repetitive and systemic exercises to trained the brain to react in a way perceived to be the most effective for learning to read and write. While the methods may suit normal learner, it could prove to be detrimental to dyslexic as they tend to learn differently. Thus, understanding how a dyslexic brain works should hold the key towards the design of an effective pedagogical intervention programme. To achieve this, an electrophysiological study of the brain is required.

Neurofeedback is a form of behavioural training or conditioning exercise in an effort to normalize the brain's electrical activity or inducing a person to think in a way most suitable to his or her capabilities [8]. It is suggested to compliment the pedagogical intervention programme for dyslexia by providing immediate feedback whether a desired brain state has been achieved during learning activities. The neurofeedback training takes advantage of the brain adaptive features through positive reinforcements; although one needs to be assured of the neural strengthening is of relevance. As dyslexic is thought to process information differently from normal learner, the obvious exercise of normalizing the brain electrical activities could be counterproductive where a reference of capable dyslexic brain activities would be of better significant.

This paper looks into potential neurofeedback protocol that could act as a therapeutic tool for children with dyslexia, in which to improve their learning abilities in reading and writing.

II. Neurophysiology of the Brain

A. Normal Learner

The human brain is divided into left and right hemisphere where there are four main lobes, frontal, parietal, occipital and temporal. Initially, during the early years in a child

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development, both hemisphere are active for reading and speech but as the child progresses, the left brain is found to be responsible for most of the activity in normal learner, where it is believe to be responsible for speech, language processing and reading. It is suggested with neuroimaging that struggling readers have a brain activity that resembles a child's brain that haven't developed [9]. Structurally, the brain of a normal learner is asymmetrical, where the left hemisphere is larger than the right in the same corresponding area [10].

Two main important areas of the brain involved in the process of learning, either in understanding language or in the skill of reading is the Wernicke's and Broca's area. Found in the frontal lobe, the Broca's area is responsible for the organization, production and manipulation of language and speech. The Wernicke's area that is located in the temporal lobe is mainly responsible for one's ability to understand meaning [11].

The ability to speak in a child doesn't require any training and the brain developed the language pathway based on the child's experiences through sight and sound. Learning to read however requires the skill to be taught and to create the brain's reading pathway through rearrangement of neuronal connections is known as neuronal recycling [12]. In the language pathway, the ears receive information through sound which is then sent to the thalamus that provide the identification of it being auditory and pass it to the auditory cortex. The Wernicke's area is then involved where further identification is being done before it is transferred to the Broca's area for processing via the arcuate fasciculus. As the lips and mouth prepare to speak, the motor cortex will be involved [13].

In a normal learner, reading takes advantage of the language pathway where the ability to translate written word into its phonemes or sounds, provide the fundamental basis in the ability to read. The neural pathway for reading started of with the reading of text information through the eyes which is sent to the thalamus and subsequently relayed to the visual cortex. From there, it is pass to the angular gyrus where the relationship from text to sound is made. This information is further process in the Wernicke's area to find meaning and Broca's for understanding of what that is being read [13] as illustrated in figure 1.

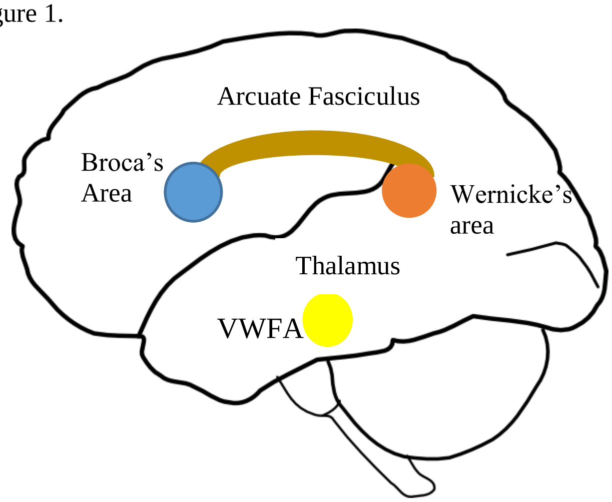

Fig. 1.The Brain's Neural Reading Pathway

In young readers, activation of areas within Wernicke is an indication of their phonological awareness maturation. In addition, fluent readers are also known to engage the inferior temporal gyrus or Visual Word Form Area (VWFA) that recognizes word visually (sight vocabulary) based on its orthography. These are important areas of the brain involved in the process of learning, either in understanding language or acquisition of reading skill.

The ability to read requires knowing the sound of the letters (phonics) at first and the development of sight vocabulary. In early reading, a child would sound out words that they are unfamiliar that would require time, making them slow reader. The longer the time they take to finish a sentence, the child will then have the problem of comprehension, as they have forgotten of what is being read in the beginning. Once the word has been familiarized, it will be memorised and included in what is known to be sight vocabulary. Having a large enough sight vocabulary enables a child to recognize instantly the word without having to sound it first, thus achieving fluency.

The study on neurophysiology of the above indicated the role of left parietotemporal, located between lobes, as responsible for the conscious, effortful decoding of words [14]. This area is particularly active in the beginning of a child's process in learning to read in sounding of words. In experience and fluent reader that utilizes sight vocabulary; the left occipitotemporal is highly active believed to be responsible in the automatic and rapid access to whole words [15], [16]. A study also found that the left occipitotemporal area was activated for speech in during which a child is beginning to read and has low phonics awareness, as they developed their reading skills, the left occipitotemporal area was activated for reading print [17]. This leads to the notion that there are two neural pathways in reading that resides in the left hemisphere, one for early reading and another for fluency. It can also be said that a normal learner brain moves from seeing word to the sounding of the word seamlessly to understand what is being read, taking advantage of the language pathway.

B. The Dyslexic Brain

Looking into the brain of a dyslexic, several neurophysiological studies were conducted that are based on different technology used, ranging from positron emission tomography (PET) scans, functional magnetic resonance imaging (fMRI) and electroencephalography (EEG). Traditionally, researchers focus on the obvious observation of reading difficulties as a result of visual processing impairment [18], [19]. It was found that dyslexic has problems in visual processing of written letters and words originated in the visual magnocellular pathways.

Studies looking into the metabolic activity of the brain using PET suggested that the Wernicke's area is found to be inactive for dyslexic [20] and there are evidences of prefrontal and frontal lobes activities with pattern of being more symmetric while reading that are not normally associated with normal learner [21].

The speed at which the brain processes auditory information were also studied and found that a dyslexic requires time to process a word read due to auditory perception deficit or known as the rapid auditory processing theory [22]. It is found that the auditory processing in reading is 1.5 times slower in dyslexic [23] where the auditory nerves of the left temporal lobe is abnormal as it is smaller in size [24]. Further studies using PET also suggested a reduction in activity of the left hemisphere even though of different countries and learn under different languages [25].

Cerebellar theory looks into the impairment of cerebellum that leads to phonological processing deficits in dyslexia [26]. It is suggested that motor control problem in the articulation of speech contributes towards learning of phoneme important in acquiring reading skills. It is associated with observation that a dyslexic normally has problems in coordination, balance and time estimation. It is found that both right and left cerebellum showed lower blood flow that represents less activity during tasks normally required it to be active.

In the phonological theory of dyslexia, it is suggested that dyslexic suffers from the impairment of the left hemisphere language processing centre which effects sound association skills and thus reading abilities. Currently, it is believe to be the most supported theory among all that have been stated above [27]. An fMRI study of 144 children both normal and dyslexic shows that normal learner have more activation in all the known areas of the reading pathway if compared to dyslexic [14],[28]. Children that are good in the tasks designed, have more activation of the left hemisphere as expected and less in the right hemisphere. Results indicate dyslexic suffers from the impairment of the left hemisphere, particularly in the parietal area which is important for fluent reading. Furthermore, the brain of a dyslexic showed activities in the right hemisphere frontal area that is suggested to be indicative of the brain trying to compensate for the inefficiency of the left hemisphere. This could be seen as an alternate or compensatory reading pathway of the brain for dyslexic. The alternate pathway is in inverse to the normal learner neural pathway that shows strong activation of the left hemisphere. Dyslexic subjects that shows a stronger activation of the left hemisphere remains a poor reader, while those with greater activation of the brain's right hemisphere correlated with increased reading skill. Study on the left occipitotemporal that is required for rapid access to whole word or rapid naming was also found to be under activate in dyslexic [15],[16], making them slow reader and lacks fluency which inadvertedly causes comprehension problems.

Magnocellular theory for dyslexic attempts to combine three theories as per the above, phonological, visual and auditory processing, by suggesting impairment of the magnocellular system [29], [30], [31], [32]. It hypothesizes that magnocellular neurons are responsible for timing function of the brain is genetically impaired in dyslexic. This causes unstable vision and vergence control for visual while mild auditory magnocellular impairments is believe to contribute to a dyslexic lacking in phonological awareness. This theory however has been largely challenged [33].

Structurally, the brain of right handed dyslexic shows a pattern of being symmetry where the right side of the brain is the same as the left side or reverse asymmetry than the norm where the right side is larger than the left [34],[35]. On the corpus callosum, dyslexic exhibits a shallow with little separation with the right hemisphere being larger than the left of the inferior parietal lobe [21], [36].

Brain matter consists of two material being gray and white, where the former is mostly consisted of nerve cells that processes information and the latter composed of connective fibers covered in myelin sheath for fast transmission. In dyslexic, it was found that they have less gray matter in the left parietotemporal area if compared to normal learner that could explain the impairment in phonological processing [37]. The content of white matter was also found to be less in the left parietotemporal in average reader where it is suggested that white matter contribute towards fluent reading as it is critical in inter-communication between brain regions [38].

Most of the above neurophysiological brain studies of dyslexia indicate a failure and abnormal structure of the left hemisphere in the neural pathway of reading by comparing the functional and structural brain differences with that of the norm. One study concluded that the brain frontal regions may compensate for the inefficiency of the posterior area [39]. As the brain being adaptive, it compensate its left hemisphere short comings with the used of the right frontal area in achieving maximum output as shown in capable dyslexic reader. Any recommendation to normalize as per normal learner is forcing the dyslexic brain to use the ineffective part of the brain and can be deemed counterproductive.

The propose neurofeedback protocol suggested in this paper relies heavily on the use of EEG as it is practical and not as expensive as both fMRI and PET. It is also the most used diagnostic tool in the entire field of neurofeedback. Thus, a background on the principle behind the EEG and studies related to findings for dyslexia are further discussed.

As brain function is bioelectric, its activities are based on brain waves of specific frequencies and amplitude. Frequency spectrums of an Electroencephalograph (EEG) consist of Delta (1-4Hz), Theta (4-8Hz), Alpha (8-12Hz), Beta1 (13-21Hz), SMR (12-15Hz), Beta2 (20-32Hz) and Gamma (32 and above) where each spectrum relates to different levels of activity or consciousness as per table 1 [51]:

TABLE I
EEG FREQUENCY SPECTRUMS

Frequency Spectrum	Range	Frequency Description
Delta	0-4	Deep sleep, restorative, regulation of autonomous function
Theta	4-8	Sleep, emotion, creativity
Alpha	8–12	Calm, relaxation, alertness, meditation
Beta 1	13-21	Logical thinking, focus, stimulating effect
SMR	12-15	Mental alertness, physical relaxation
Beta 2	20-32	Anxiety, stress, high arousal
Gamma	32 above	Cognitive functions, higher processing tasks

EEG signal of the brain will be acquired through the international 10/20 system, taking measurements between certain fixed points on the scalp. Dry electrodes are to be applied and acquired signal will be amplified and filtered before subsequently fed to an Analog-to-Digital Converter (ADC) for digitization. The digitized signal will be analysed through a signal processing algorithm that is based on time-frequency analysis that would characterized behaviours of the EEG and provide our basis for the hypothesis on the working of the brain in terms of area activation, coherence of different sites.

EEG relationships are asymmetrical where in normal population, alpha levels drop off from the back of the brain moving to front while beta levels vice versa. Similarly, this relationship follows between the left and right hemisphere where there should be more beta on the left and more alpha on the right. Having a neurological disorder, the subject's brain electrical activities would not conform to the norm and assessment of disorder is possible.

Studies with regards to EEG signature in dyslexia looks into Quantitative EEG (QEEG), coherence, evoked potential and event related desynchronization. Using QEEG, where electrical brain mapping is carried out with a high number of electrodes, has found abnormalities in the left side of the brain, specifically in left posterior area, also right parietal and frontal [40]. Earlier studies found differences in dyslexic during reading where there are marked increases in left temporal and parietal theta activity that normally indicate less active engagement [41] and further research shows a reduced beta activity in the right parietal lobe [42]. Recent suggestions include only difficult reading would activate areas known in the reading path which could be of importance in the design of activities or tasks during any assessment cycle [43].

Studies related to power and coherence indicates an activation pattern of the frontal and temporal lobe for dyslexic [44]. It was previously found that there was a decrease in coherence between multiple sites of the left posterior area [40]. A dyslexic also showed greater coherence within hemisphere if compared to the norm that exhibit coherence between hemispheres [45]. This suggested of an impairment or disconnection between hemispheres. Evidence of impairment in the balance of auditory function between both hemisphere was also found where dyslexic have significantly less lateralization of auditory cortical functioning [46]. In phonological tasks, a lack of coherence was found between the left angular gyrus and related occipital and temporal area for the known critical reading pathway [47].

Of the above EEGs in dyslexic, findings correlate well with results using fMRI and PET. Theta activity of the left hemisphere known to be responsible for reading tasks proves that this area of the brain is under activate and results showing poor coherence further emphasize the reason behind dyslexic having reading difficulties. A beta activity of 15 – 18 Hz is desirable in active reading [43] but a higher beta frequency of 20 Hz and above could also indicate anxiety or other neurological disorders. A delta EEG based study result also supports the phonological deficit theory and suggested the validity of EEG delta band as a clinical measure of dyslexia [48]. A higher activity found in the frontal brain area and that of the right hemisphere for capable dyslexic reader [39] showed that the brain is compensating its efficiencies in order to learn to read.

III. Neurofeedback

Neurofeedback allows the opportunity for a person to practice the control of brain waves and increases the functionality or coherence between different sites of the brain [8], [49]. It gives awareness to a person of the state of the brain and this will allow for them to influence and gradually change its state to reach the desired outcome for a given situation.

Normal individual exhibits EEG with common traits that differ to one with pathological instances such as epilepsy, Attention Deficit Hyperactivity Disorder (ADHD), depression and dyslexia. There are unique pattern that can be found based on EEG assessment of patient with the said neurological disorder as in table 2:

TABLE II
Disorder and Its EEG Characteristics

Disorder	EEG Characteristics
Epilepsy	Excessive electrical activities in the brain with high amplitude EEG waves.
ADHD	Excess of high frequency beta that relates to hyperactivity in the frontal region or excess of alpha or theta.
Depression	Frontal region exhibits excess of alpha or theta especially in the right side of prefrontal cortex or reversal of normal.
Anxiety	Higher amount of beta across the cortex Reversal of normal front to back asymmetry in beta and alpha and left-right asymmetry in beta with higher amount of beta across cortex.
Dyslexia	Impairment in left hemisphere with higher theta activity and higher coherence between regions in the same hemisphere.

Neurofeedback trainings are based on providing immediate feedback once the subject has achieved the desired result, either brain state, coherence or other related parameters that has been set. These feedbacks often run as computer games that are appealing, especially if the subject is children and winning or completing the games are rewards for achieving the desired threshold or parameter.

A session of neurofeedback ranges from 45 to 60 minutes with a repetition of 25 to 50 sessions depending upon the progress of the subject [8]. It is to be noted that additional trainings spread across the length of the neurofeedback sessions are required to transfer the skills in controlling the brain state to actual daily activities or the neurofeedback training itself is based on tasks that they would normally perform in reality, in the case of dyslexia, the transferring of brain state alterations in improving reading and writing skills. It is envisaged that as the brain is adaptive, an adequate training session would alter the brain activity to be able to perform in the desired state without feedback, thus training can be concluded. The factors of the brain plasticity and adaptability in particular with relation to age are of the most concerned in looking into the efficacy of the neurofeedback training.

A. Types of Neurofeedbacks

Several studies have summarize the different types of neurofeedback based on its targeted EEG properties [8], [49],[50],[51] as shown in table 3.

TABLE III
EEG BASED NEUROFEEDBACKS

Targeted Properties	Description
Frequency	The amplitude of one or several frequency bands are increase and decrease based on the need for normalization at the desired electrode position that correspond to certain brain function. Example includes regulation of Alpha/Theta for stress disorder and Beta/SMR to increase alertness.
Slow Cortical Potential (SCP)	Negative and positive SCPs are regulated in an effort to increase or decrease excitation over the sensorimotor cortex. Results in increase attention.
Alpha Asymmetry (ALAY)	Normalize of the left and right hemisphere asymmetry by aiming to reduce left alpha activity. This is targeted as higher right over left activities refers to anxiety or depression.
QEEG	Full brain mapping with the aim of achieving normalization as what is perceive as the best way a brain should work.
Infra Low	Targeting low frequencies as small as 0.01 Hz that is seen to be effective in the treatment of stress disorders.
Comprehensive Adaptive Renormalization of EEG (CARE)	Focusses on training the brain to decrease turbulence of electrical activity that is viewed to effects its functional efficiency. Targeting scalp locations associated with the most brain interconnections, subjects are trained to reduce burst of activities and rewards are given out

Hemoencephalography (HEG) use feedback based on the brain’s blood flow information to allow subject’s to increase or decrease the activity level under the area of the applied infrared based transducer [52], [53]. It works differently from EEG where light shines through tissue and skull and monitors the amount of oxygen in the brain’s blood. As the areas of the brain are work, the faster and redder the blood in the respective area will be. This helps subject to focus and strengthens the function of the frontal lobes that is related to organization, attention and planning skills. It is common for HEG to be used with EEG in neurofeedback studies [54], [55].

B. Studies on Neurofeedback Applications

A list of literatures, as in table 4, looks into the application of various types of neurofeedback and its protocols, targeting the brain’s electrical activity in cases of epilepsy, attention deficit and hyperactivity disorder (ADHD), depression, anxiety, insomnia and drug or alcohol abuse [49]. Included are studies related to improvement of cognitive functions, i.e. memory and enhancement of brain control for brain computer interface (BCI) classification.

TABLE IV
NEUROFEEDBACK STUDIES

Target	Protocol	Author	Result
ADHD	Theta /Beta	Linden et.al. (1996)	Significant average increase of IQ points and reduction of ADHD symptoms.
	Theta /Beta and SMR	Levesque et.al. (2006)	Increase activity in brain areas related to attention, learning and memory.
	Theta /Beta and SCP	Gevensleben et. Al. (2009)	Positive changes in ADHD symptoms.
	Theta/Beta and SCP	Wrangler et al. (2011)	
	Theta/Beta and SCP	Leins et. Al. (2007)	Conclude that SCP gives better result in treating ADHD than Theta/Beta.
	SMR QEEG	Lansbergen et al. (2011)	Double blind procedure showed no improvements after neurofeedback sessions.
	Theta/Beta QEEG	Steiner et al. (2012)	Both neurofeedback and computer based training improve overall IQ and behaviour index.
	Theta/Beta and SMR	Fuchs et al. (2003)	Remediating ADHD symptoms and improvements in TOVA subscales.
Autism	Reduce Theta	Kouijzer et al. (2010)	Improvement in social behaviour but not in executive functioning.
	Theta/SMR	Kouijzer et al. (2009)	Improve social behaviour but not in all subjects.
	Regulating frequencies of 10-13Hz, mu	Jarusiewicz (2002)	Improved autistic behaviour by 26%.
	QEEG and HEG	Coben et al. (2008)	Reducing hyperconnectivity that improved autism symptoms by 40%.
	Mu-reward	Pineda et al. (2008,2014)	Improve autistic symptoms by reducing coherence between hemispheres. Subjects showed increase attention but sensory and cognitive awareness dropped.
Autism and Asperger	Decrease slow wave (3-7Hz), decreasing beta spindling (23-35Hz) and increase SMR	Thompson et al. (2010)	Improvements on measures of attention, autistic core symptoms, achievement, and intelligence. A decrease in difficulties with social functioning.
Epilepsy	SMR	Wyrwicka, Sterman et al. (1968)	Results against cats showed promised.
	SMR	Whitsett et al. (1982)	Upregulation of SMR normalized EEG patterns during sleep

	SCP	Kotchoubey et al. (2001)	Significant reductions in seizures from 3.3 to 2.2 per week.
Insomnia	Z Score	Hammer et al. (2011)	Post comparative study of Z score showed reductions in insomnia disorder.
	Tele-neurofeedback	Cortoos et al. (2010)	Improvement in total sleep time found after neurofeedback
Drug/Alcohol Dependencies	Alpha/Theta	Peniston et al. (1989,1990)	Decrease drinking behaviour, depression and personality changes
	Beta/SMR and Alpha/Theta	Scott et al. (2005)	Only 24% of neurofeedback subjects dropped compared to 46% in controlled group. 77% remained sober after 1 year and have improved personality changes.
Depression	ALAY	Baehr et al. (2001, 1997)	Results showed improvement.
	ALAY	Choi et al. (2011)	Average depression symptoms decreases and showed clinical changes.
Schizophrenia	Increase Alpha amplitude and decrease Beta 2 (20-30Hz)	Nan et al. (2012)	The individual alpha increased 74.73% and beta2 decreased 13.73%. Short term memory was enhanced and mood had a positive change with speech much clearer than before
BCI Classification	SMR	L'opez-Larraz et al. (2012)	Increase in the SMR desynchronization during the execution of a motor assessment after NF application
	Imagination strength information feedback	Xia et al. (2012)	Experiment group achieved 80% average classification accuracy.
Cognitive Performance	Increase upper Alpha and decrease Theta	Hanslmayr et al. (2005)	Only those subjects able to increase upper alpha power performed better on mental rotations.
	SMR, Alpha/Theta, Beta 1	Egner et al. (2003)	Alpha/Theta found to increase musical performance compared to SMR
	SMR, Alpha/Theta	Ros et al. (2009)	SMR improved surgical skills.
	Upregulating peak Alpha	Zoefel et al. (2011)	Improved mental rotation
	Upregulating peak Alpha	Angelakis et al. (2007)	No improvement in memory of subjects with age range of 70 -78 years.
	Alpha/Theta and Heart Variability	Raymond et al. (2005)	Better performance in dancers
	Alpha Synchrony at T3	Landers et al. (1991)	Better performance in subjects that undergone left hemisphere alpha training at temporal if compared to subjects trained on the right.

The research proposed in this paper is to use neurofeedback in enhancing the brain coherence and creating the alternate pathway by making reference to how the brain of a capable dyslexic learner works. This will serve as a benchmark on the desired state to be achieved during the training of a subject in a neurofeedback session.

C. Neurofeedback for Learning Disabilities

Studies on neurofeedback for learning disabilities especially dyslexia are limited, thus the need to propose a suitable protocol that could serve as a recommendation on the way to proceed. Based on QEEG neurofeedback, a study increased slow activity that differed from the norm at T6, increased coherence in alpha/beta frequencies at F7-FC3 and increased coherence T3-T4 [56]. Dyslexic showed improvement in spelling but not in their overall reading ability. It is important to note that the neurofeedback protocol attempt to normalized the brain overall activity similar to that of a normal learner.

A study that focusses on increasing the activity of the left temporal area known to be in the reading pathway showed promised by way of improving the dyslexic reading abilities by two grade level [57]. The study started with analysing the QEEG of subjects, obtaining a reading difference topography, and trained down any abnormalities that are increased (signs of hyperactivity) and trained up those that are underactivated before focussing on the left temporal area. Normalization in this study put the brain into a calming attentive state, reducing any comorbidity that may exist, i.e. ADHD.

The alpha/theta neurofeedback protocol has also been applied in a study of 10 children with learning disabilities [58]. The outcome showed that attention of subjects, their verbal and performance IQ, improved.

Changes in EEG current sources were also studied after neurofeedback treatments that replicate the alpha/theta protocol above [59]. It found that current sources showed little change although subjects exhibit immediate behavioural and cognitive improvements. Only after 2 months had lapsed, it was found that frequencies of current within the theta band in left frontal area decreases and current of frequencies within the alpha band of the right temporal lobe and right frontal regions increases and the same with frequencies within the beta band of the left temporal and right frontal areas. It was suggested that neurofeedback is possibly an efficacious treatment for learning disorder with an abnormally high alpha/theta ratio.

IV. BENCHMARKING CAPABLE DYSLEXIC LEARNER

Understanding the bioelectric aspects of how a dyslexic brain works, would provide a better prognosis on the required treatment [3]. Little studies have been implemented on the electrical aspect of a dyslexic brain and one should move away from over reliance on the development or advocating the use of chemical intervention in correcting brain functionalities. As was discussed earlier, previous studies on the working of the dyslexic brain relies on fMRI that is impractical to be implemented on a larger scale and in non-clinical environment.

Dyslexic brain processes information differently, thus deemed to be creating an alternate pathway in learning to read and write. It would be seen natural to make how a capable dyslexic learner brain works as the benchmark. Capable dyslexic learner bypasses the left temporal area of the brain and seems to process learning related activities such as reading and writing in the right hemisphere [12]. This is thought to be due to the inefficiencies of the left temporal lobe of a dyslexic.

Further studies indicated that dyslexic that showed the highest improvements in reading ability had greater activation in the right inferior frontal gyrus with an under activation of its counterpart in the left side of the brain [9]. The study also states that more connectivity of the right hemisphere is an indicator of whether a dyslexic could overcome their deficits in reading and those that could shift their language function from the traditional left to the right hemisphere is better equipped to succeed. An EEG based assessment could also be designed where improvement of electrical activity on the right hemisphere during reading task could be taken as a sign of progress. This is particularly important as conventional tests of reading and language couldn't clearly indicate reading progress.

The proposed neurofeedback protocol would be based on the alternate brain electrical pathway of a capable dyslexic learner. Normalization of the brain functions as per the normal approach in a neurofeedback protocol would mean to force a dyslexic to use the left side of the brain that is impaired or ineffective. Furthermore, forcing a dyslexic to conform to a normal learner brain activity would seem to be detrimental and counterproductive.

Previous neurofeedback for dyslexic have shown little improvement where the normalization approach was applied [56] and those that achieved success [57], is focusing on training a specific area, mainly the left temporal lobe. Pedagogical intervention programmes that stresses on drilling and exercises repetitive phonic tasks undermine a dyslexic capability of seeing the bigger picture and taking advantage of it. A dyslexic brain of compensating with frontal and right brain areas in learning associated with intellect rather than sounds, gives the advantage for them to have a deeper comprehension of what is being read. This readies the brain to analyse more complex theories and primed for the complexities of learning in higher education level. Thus, it can be argued that although reading ability improved when the neurofeedback is focusing on making the left temporal area more activated (improving phonics), comprehension may suffer.

It can be suggested that a dyslexic learn best through visualization approach by looking into activation of the right hemisphere and frontal brain region and they tend to reinforce these neural pathways. It has been shown that dyslexic that used the normal reading pathway of the left hemisphere remains poor reader [9]. Ultimately, for dyslexic, it is suggested that the neurofeedback protocol focusses on reinforcing neural activity based on the reading pathway of capable dyslexic, focusing on developing intellectual skills rather than forcing to conform to the norm, remediating phonics.

V. Proposed Neurofeedback FR Dyslexic Children

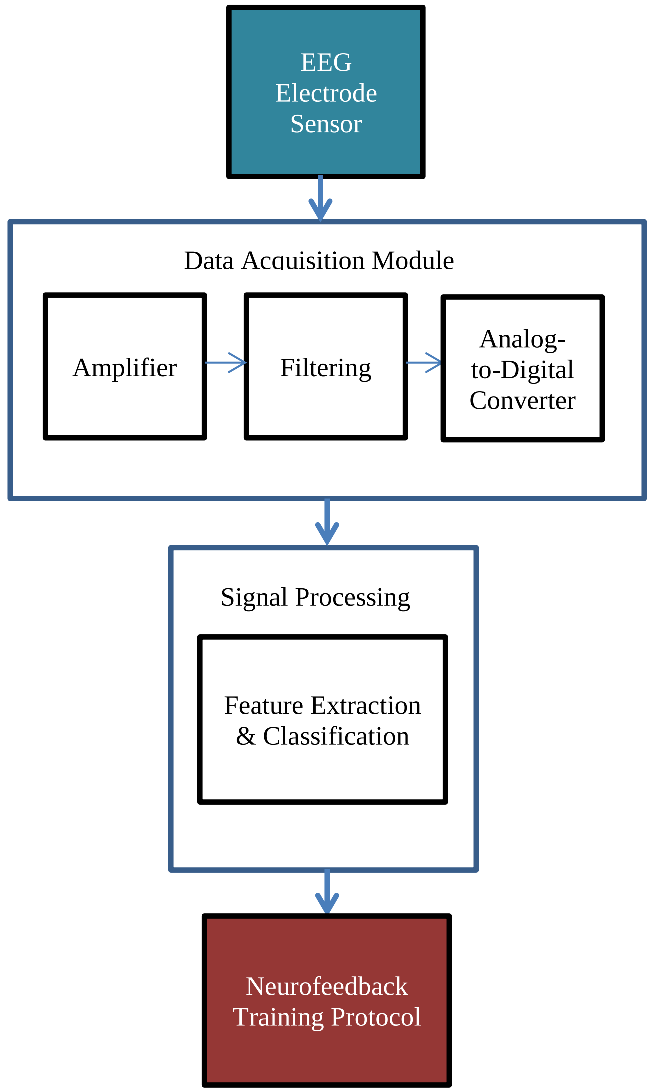

Fig. 2.Components of Neurofeedback

Fig. 2 illustrates the components of the proposed neurofeedback system. EEG will be acquired through specific localization of electrodes and the measured signal subsequently amplified, filtered and digitized, ready to be fed to a computer. The pre-processing of the acquired EEG signal involved the removal of the 50/60Hz power line noise with a notch filter. Any baseline drift, eye movement or muscle signal artifacts were removed with a band pass filter having a lower cut-off frequency of 0.3Hz and upper of 50Hz.

A signal processing algorithm will provide the extraction and classification on the state of the brain activities. Feature extraction would consists of a discrete wavelet transform (DWT) to separate between different frequency bands and is deemed to be suitable based on its matching orthogonal features as the EEG signal and have a localization property that is near optimal to time-frequency. The statistical feature vectors that would be extracted to represent the acquired EEG signal would be the computed beta band power and theta/beta power ratio. These statistical parameters reduce the overall feature size and proportion for an efficient classification process. For classification, Support Vector Machine (SVM) can be adopted to identify the strengthening of the alternate neural pathway and identification of the brain state. The brain state is then converted to visual or auditory feedback to the subject that would give them the awareness to self-regulate. Changes of the brain activities towards the desired goal will be rewarded, as to motivate and compel the subject to strengthen their neural pathway.

Subjects will be from the age group of 7 to 10 years old taking advantage of the neuroplasticity and network development in an adolescent brain. Being more malleable, effective training would hypothetically be more permanent and has better effect if compared to an adult brain. As the focus group is basically children, a computer game based training is desired being fundamentally engaging.

The neurofeedback will be design to work as a one-channel EEG training system as processing a full set of 64 or 128 EEG data would be time consuming and requires a lot of computing resources. Furthermore, a 7 year old child would not be comfortable wearing a full EEG cap and thus affecting reading accuracy. Minimizing this through proper localization of its placement plays an important role in improving the overall performance of any diagnostic system. Similar beta training protocol by applying a one-channel EEG training at location Cz were implemented by Egner and Gruzelier [63] to improve perceptual sensitivity and increase cortical arousal. Vernon et. al. [64] also trained location Cz for enhanced cognitive performance. Attentional performance were increased by training location C4 and C3 also by Egner and Gruzelier and similarly by Fuchs et.al. [65] Treatment of ADHD through neurofeedback utilizes two electrode location, commonly Cz and C3 or Cz and C4 by Heinrich et. al. that shown positive results by enhancing beta and inhibiting theta [66].

Separation of dyslexic into two groups of poor and capable is of interest as it is hypothesized that a poor dyslexic that continues to engage the normal learning pathway would remain a poor learner throughout their life. Therefore, it is best to look into the learning pathway of a capable dyslexic and set that as a benchmark for the proposed neurofeedback protocol. Localization of the electrodes and area of strengthening will be based on the alternate/ compensatory pathway shown by a capable dyslexic reader. It has been argued extensively that capable dyslexic utilizes areas of the brain's right hemisphere compensating the normal neural pathway of the left. The right frontal areas have been particularly identified to have increased activation during learning related tasks, particularly reading and writing. Therefore, it is proposed that 2 electrodes are placed in mirroring positions to that of the left that is equivalent to the locations of Broca and Wernicke, which are FC6 and P4 for research purposes and optimization of the electrode placement would be made to conclude the one electrode location of significant for the design of the neurofeedback training. This is where any proposed neurofeedback that is to provide intervention for dyslexia to focus on. With a large pool of EEG data, localization of placement is important as neurofeedback can be targeted properly and the desired state to be achieved can be identified.

Normalization of the dyslexic brain to replicate the neuronal pathway of a normal learner will be to force the brain to utilize the left hemisphere known for language processing. This has been exhaustively argued by which studies has suggested the area to be impaired and to train is to be counterproductive and might prove to be detrimental.

It is however suggested that the overall brain activities that showed over activation or under activation that contribute towards being attentive, similar to that experience by ADHD sufferers, needs to be regulated prior to localization. A disruption in attention mechanism has been suggested to contribute towards reading difficulties and to treat this factor would be an effective complimentary treatment [60]. A higher than normal theta and beta values need to regulated prior to the strengthening of araes corresponding to the alternate pathway. These findings can be behind the success in earlier neurofeedback dyslexia treatment that also focusses on normalization of overall brain activities related to attention [57]. The complimentary treatment focusses on training the brain to be quiet at rest and active while learning.

Exercises during training will be based on available pedagogical approach that enhances the intellectual part of right and frontal parts of the brain with a reward system that is game based, either moving a car or navigating through space, whichever that could excite. Right brain pedagogical approach would include visual and multisensory activities that includes using pictures and multimedia material, drawing mind maps, using different colours, visual software programmes and creating alphabets using sand or plasticine. Phonological exercises should not be drill or offered repetitively, but can be integrated into the overall training, allowing dyslexic to learn naturally.

Trainings are suggested to be entirely focused on neurofeedback at first to strengthen and facilitate neural pathway. Trials without feedback can then be administered sparsely throughout the remainder of the training in ensuring the transfer of regulating skills in actual learning environment. The progress shown by the brain electrical activities could also be viewed as progression of a dyslexic in their ability to read. Assessment methods of pre and post treatment are to be administered and IQ performance recorded.

It is suggested that the proposed neurofeedback treatment would improve a dyslexic ability to read and increase language processing. Brain activities should exhibit enhance neural pathway of the right hemisphere and increase activity in the frontal lobe. As they became fluent, left occitotemporal lobe whould also showed increase activation. Both normalization (the brain being put in an attentive state) and compensatory effect (alternate pathway) is expected.

VI. Design And Protocol Considerations

Screening procedures needs to be properly categorized and manualized as to be ascertain that all subjects are at the same level before the start of the trainings. References of their IQ level and reading abilities shall be based on standardized assessments of recognition. Subjects at different level or under medication for example, could exhibit different activation pattern and effect the reliability and validity of data collected. On another note, comorbidity should also be screened at first, as this would also exhibit different neural profile and would require additional or a different neurofeedback protocol.

The unique nature and individualism of brain activities based on subject has to be properly investigated. Certain neurofeedback trainings are based on individual neural profiles [61] and proved to be successful. These requires practitioner of a very high standard to be able to diagnose and advice treatment. The proposed neurofeedback advises the dyslexic to first be normalized in terms of being attentive. It is hope that this is sufficient before localization took place.

The study looks to take advantage of the neuroplasticity of the brain by having child subjects, knowing that a child brain is more acceptable to changes and susceptible to be trained. In early childhood, the development and expansion of neural pathways is consistently evolving, where connections that are not utilized will undergo the process of pruning that would explain why the brain at birth has twice as many neurons if compared to young adults [62]. The pathways that are strengthened will be kept while others that are underutilized will be pruned. This is why it is important to apply the neurofeedback proposed here to a child that has yet to reach adolescent. Neurofeedback in this sense can be fundamental towards helping in the organization of a child brain pathway and prevent any neural disorder from developing.

VII. Summary

In summary, common neurofeedback protocol focusses on normalizing brain activities to conform to a known average brain benchmark. This approach holds true in several neurological disorders, particularly ADHD, giving desirable results. For dyslexia, forcing the neural pathway towards that of a normal learner can be seen as counterproductive and even detrimental, as they will be utilizing parts of the brain that has been shown to function differently and has discrepancies structurally. It is ineffective and furthermore, dyslexic that continues to utilize these normal pathways has been suggested to remain poor reader. Capable dyslexic reader relies on compensatory right frontal areas, making them think analytically and relies on more intellectual thinking. It is proposed that a neurofeedback system for the dyslexic should set the benchmark based on capable dyslexic reader alternate pathway as the target goal.

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