Resting state EEG signal analysis in Indian Dyslexic children

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***Abstract*—Developmental Dyslexia is the most common learning disability associated with the difficulty in reading skills even with normal intelligence. The present study analyzed the resting state (eyes closed) 19 channel EEG recordings in 15 Indian dyslexic children and 15 normal children. Node strength for each electrode location for all major EEG bands (delta, theta, alpha, and beta) was calculated for both groups and compared. Results showed increased (p<0.05) delta/theta node strength in temporal, parietal, frontal and occipital regions during rest in the dyslexic group. Also, the dyslexic group showed decreased (p<0.05) alpha/beta node strength at right temporal, prefrontal and left central brain areas. The control group showed decreased (p<0.05) delta/theta node strength at temporal, parietal, occipital and frontal regions and increased (p<0.05) alpha/beta node strength at the right parietal and frontal regions. The present study concludes with the finding of increased theta activity during rest condition (eyes closed) as a strong biomarker for the existence of resting-state functional abnormalities in dyslexic children at temporal, parietal and occipital regions.**

***Keywords*—learning disability, dyslexia, resting state, EEG, wavelet component energy, signal processing**

I. Introduction

Developmental Dyslexia (DD) is a neuro-developmental disorder related to difficulty in reading skills despite normal intelligence[1][2]. DD is a most common learning disability and termed as a core deficit in phonological processing and awareness[3], in addition to this impaired in attention[4], visuospatial attention deficit[5] and arithmetic (mathematical) deficit[6] in dyslexic individuals were prominent. DD has a worldwide incidence of 15-20% in the total population[7] and in India, DD incidence is believed to be 15% in total children population.

Several functional magnetic resonance imaging (fMRI) studies [8] have shown the functional abnormalities in the dyslexic brain in the left hemisphere (in language processing areas). But in the present study, authors have employed electroencephalography (EEG) technique to study the brain nodal activations, as it provides high temporal resolution compared to imaging techniques and appropriate for identification of synchronization among different EEG frequency bands (delta, theta, alpha, and beta)[9]. EEG is a non-invasive technique of measuring brain electrical activity produced by similarly oriented groups of cortical neurons under the scalp. C. Spironelli[10] found inefficacy of the left hemisphere to regulate theta oscillation in dyslexic children compared to the control group during phonological processing. In another study, C. Spironelli[11] analyzed the theta and beta band hemispherical asymmetry during the linguistic task and found increased activation of theta/beta band in the left frontal hemisphere for control groups, whereas dyslexic group showed increased activation at the right frontal area. Based on the previous literatures, it may perhaps recognize that dyslexic children had shown abnormalities in left hemisphere during phonological processing.

The present study aimed at examining the resting state nodal behavior between Indian dyslexic children and normal children using EEG signals. Resting state EEG recording is a capable tool to analyze and understands the brain activation and information transfer rate during wakeful rest[12]. G. Fein[13] studied resting state EEG in nine dyslexic and control children and found no significant difference in absolute delta and theta band power and decreased beta power at central, mid-temporal electrodes. G. Fraga[14] examined the resting state connectivity in children with dyslexia and found less integrated connection between nodes in theta band of dyslexics compared to control group. E. A. Papagiannopoulou[15] detected abnormal linguistic networks in dyslexic children by analyzing hemispheric power asymmetry using resting EEG.

In this study, we state the differences in node strength (regional activation) of major EEG bands at all 19 electrode locations in dyslexic children compared to normal children during resting condition.

II. Methods and Materials

A. Selection of subjects

Total of fifteen dyslexic children (aged 8-16 years) were recruited from special schools for learning disabilities. All dyslexic children have been assessed by a school based psychologist and all had non-verbal IQ above 80 were participated in this study. The control group was 15 normal children (aged 8-16 years) recruited from primary schools with no history of reading difficulties. Both group (Dyslexic and control) had no sensory, visual or hearing impairments, had no history of seizures. In addition all the participants were assessed by mini mental state examination (MMSE) and child behavioral checklist in order to make sure that they had no cognitive impairment (had MMSE score greater than 24) and other behavioral disorder. This study was approved by the Institutional Ethical Committee, NIT Raipur (NITRR/IEC/2019/02) and all the parents or guardian had signed the consent form before starting the experiment.

B. Recording procedure

Recording instructions have been clearly explained to the participants and to their parents before starting the recording procedure. Children were comfortably sat on a chair in a uniformly illuminated, and soundproof room. The researcher and one medical staff were present with the children during entire recording protocol. EEG electrodes were placed on children's head scalp (see Fig.1) with respect to 10-20 electrode placement system. 2 minutes rest EEG signals with eyes closed condition were recorded from 19 different locations of brain using RMS Superspec system with sampling rate of 256 Hz. The contact impedance between electrode and scalp were kept below 5k ohm.

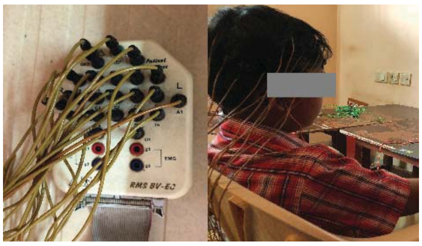

Fig. 1. Experimental setup and electrode placement.

C. Data processing and feature extraction

All channels EEG data was processed through offline analysis using LabVIEW 2017. Fig. 2 shows the raw EEG signal recorded from the children. All channels EEG data was first preprocessed using moving average filter with rectangular window of width size 3. The moving average filter removed the high frequency noise and power line interference (50 Hz) from the recorded EEG but still eye blink artifacts were present in the signal. This eye blink artifacts were then removed using threshold based wavelet denoising techniques, as it gives best result on eliminating eye blinks since it is independent on electrooculogram reference signal[16]. Db9 was used as a mother wavelet with 6 decomposition levels and SURE thresholding rule with multiple level rescaling was used for wavelet denoising[16]. Fig. 3 shows the eyeblink detected from the recorded EEG signal and Fig. 4 shows the artifacts-free EEG signal which was used for feature extraction.

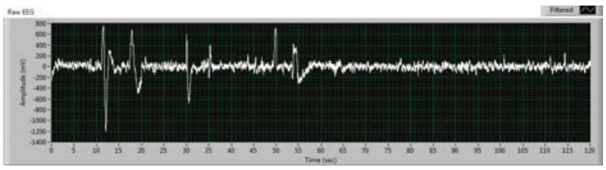

Fig. 2. Raw EEG recording during rest condition.

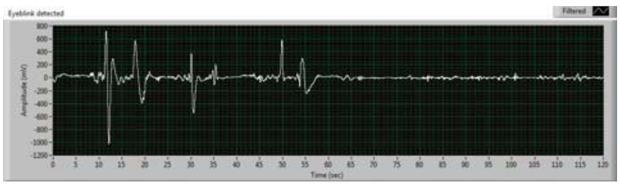

Fig. 3. Eyeblink detected from raw EEG recording.

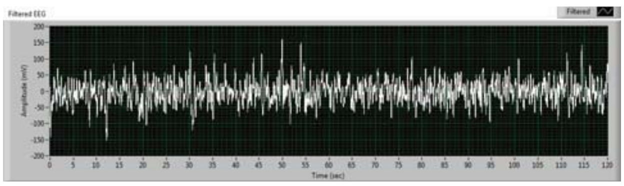

Fig. 4. EEG recording after eyeblink removal.

Different bands of EEG signal were extracted using wavelet packet decomposition method. Db9 was remained as mother wavelet for wavelet packet decomposition and applied to both approximation and detail components. The EEG total bandwidth (0-32 Hz) at decomposition level 3 in approximation coefficient A (3,1), similarly beta band (16-32 Hz) at level 4 detail coefficient D (4,1), alpha band (8-12 Hz) at level 6 approximation coefficient A (6,2), theta band (4-8 Hz) at level 6 detail coefficient D(6,1) and delta band (0-4 Hz) at level 6 approximation coefficient A (6,1) were extracted using wavelet packet decomposition. From the extracted EEG bands, band component energy has been calculated for all bands and the relative component energy (E_{rel}) for each EEG band has been estimated by dividing each band (delta, theta, alpha and beta) component energy (E_{band}) with total component energy ($E_{total\ (0\text{-}32\ Hz)}$) of EEG for all channels as in (1).

$$E_{rel} = E_{band} / E_{total\ (0\text{-}32\ Hz)} \quad (1)$$

Spearman correlation was calculated from the derived relative component energies at 19 electrodes (for all EEG bands) in order to estimate the node strength (or degree) at each electrode locations. Node strength or degree is obtained by adding each column (or row) values from the 19x19 correlation matrix and served as a feature for statistical analysis.

D. Statistical analysis

All the measured features were tested for normality using Shapiro-Wilk Test and the test result shows that the data is deviating from normal distribution ($p<0.05$). Hence Mann-Whitney U test, a non-parametric alternative to the independent t-test was used to study the group differences in measured parameters (node strength of delta, theta, alpha and beta band) during rest condition at 19 electrode locations (Fp1, Fp2, C3, C4, Cz, F3, F4, F7, F8, Fz, P3, P4, Pz, T3, T4, T5, T6, O1 and O2). The alpha value was set to 0.05. All the statistical analysis were performed on SPSS version 20. Fig. 5 illustrates the flowchart of methodology followed in the present study.

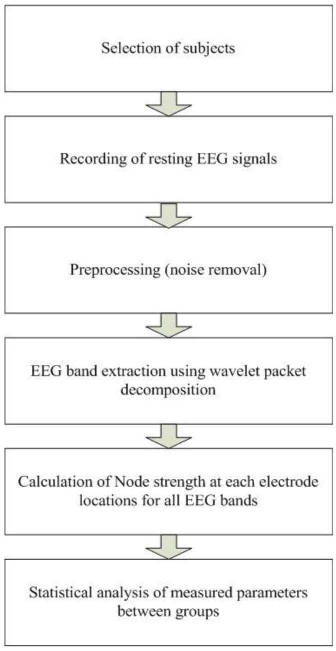

Fig. 5. Flowchart of entire methodology.

III. RESULTS

The node strengths at 19 EEG electrode locations for all 4 EEG bands were calculated during resting condition for both the groups and compared statistically for significant differences. Fig. 6 represents the delta band node strength distribution across all electrode location during rest condition in dyslexic (Fig. 6a) and control (Fig. 6b) group. In dyslexic brain, the delta node strength found to be significantly high (see Fig. 7) at T5 (z=-3.15; p=0.001), T4 (z=-2.84; p=0.004), P4 (z=-3.76; p<0.001), P3 (z=-3.56; p<0.001), Pz (z=-3.03; p=0.002), Fp2(z=-2.27; p=0.02), Fp1 (z=-2.61; p=0.008), F7 (z=-3.85; p<0.001) and F4 (z=-3.09; p=0.001) electrode locations compare to control group during rest condition. The delta node strength was dominant at tempo-parietal and frontal region in dyslexic group compared to control group.

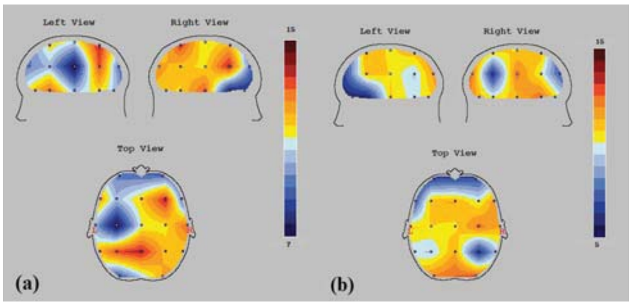

Fig. 6. Topographic plot of delta band node strength during rest a) Dyslexic group b) Control group.

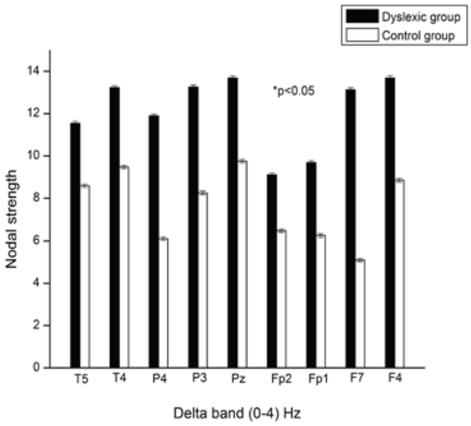

Fig. 7. Delta band significant electrode location between groups.

Fig. 8 represents the theta band node strength distribution across all electrode location during rest condition in dyslexic (Fig. 8a) and control group (Fig. 8b). In dyslexic brain, the theta node strength found to be significantly high (see Fig. 9) at T6 (z=-2.30; p=0.02), T5 (z=-3.02; p=0.002), T4 (z=-4.02; p<0.001), T3 (z=-2.20; p=0.02), P4 (z=-4.26; p<0.001), P3 (z=-3.70; p<0.001), O2 (z=-4.08; p<0.001), F8 (z=-2.45; p=0.01), F7 (z=-2.87; p=0.003), F4 (z=-3.82; p<0.001) and F3 (z=-3.32; p=0.001) electrode locations compare to control group during rest condition. Like delta band, theta node strength also found to be dominant at tempo-parietal and frontal region in dyslexic group compared to control group during rest.

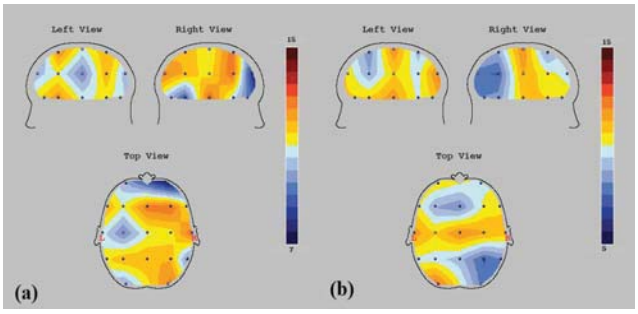

Fig. 8. Topographic plot of theta band node strength during rest a) Dyslexic group b) Control group.

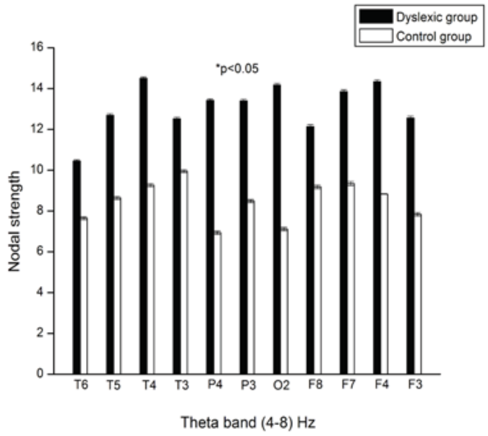

Fig. 9. Theta band significant electrode location between groups.

Fig. 10 represents the alpha band node strength distribution across all electrode location during rest condition in dyslexic (Fig. 10a) and control group (Fig. 10b). In dyslexic brain, the alpha node strength found to be significantly high (see Fig. 11) at P4 (z=-3.56; p<0.001), F8 (z=-2.20; p=0.02), and F4 (z=-3.13; p=0.001) electrode locations compare to control group, whereas the control group showed significantly high node strength at T6 (z=-3.00; p0.002), Fp2 (z=-2.02; p<0.04) and C3 (z=-2.70; p<0.006) electrode locations during rest condition. Control group showed dominant alpha activity at left tempo-parietal regions and in central region and this was not noted in dyslexic group during rest.

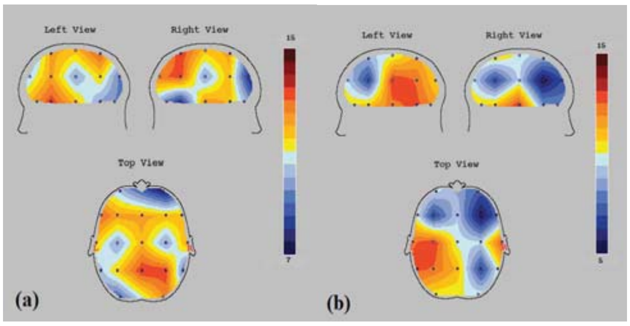

Fig. 10. Topographic plot of alpha band node strength during rest a) Dyslexic group b) Control group.

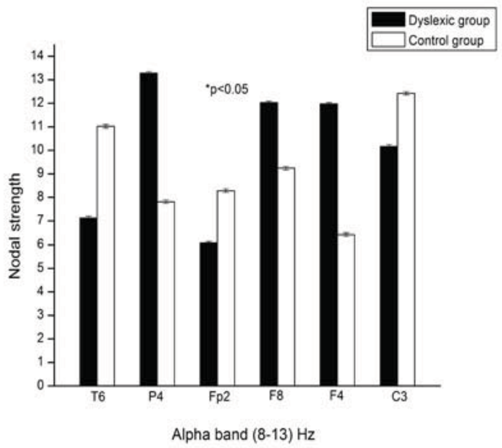

Fig. 11. Alpha band significant electrode location between groups.

Fig. 12 represents the beta band node strength distribution across all electrode locations during rest condition in dyslexic (Fig. 12a) and control group (Fig. 112b). In dyslexic brain, the beta node strength found to be significantly high (see Fig. 13) at P4 ($z=-2.68$; $p=0.006$) and F8 ($z=-3.51$; $p<0.001$) electrode locations compare to control group, whereas the control group showed significantly high node strength at T6 ($z=-2.04$; $p<0.04$), O1 ($z=-1.95$; $p=0.04$) and C3 ($z=-2.92$; $p=0.003$) electrode locations during rest condition. Control group showed dominant beta activity at left temporal-parietal-occipital (TPO) regions and at central region, whereas the dyslexic group showed dominant beta activity at right TPO regions during rest.

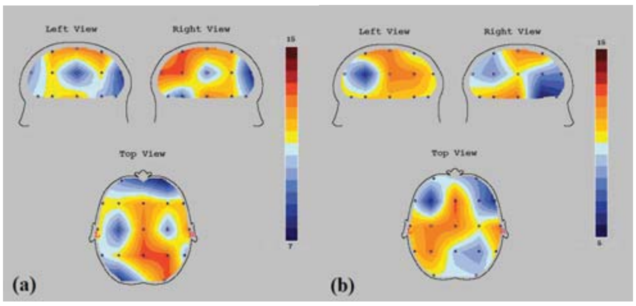

Fig. 12. Topographic plot of beta band node strength during rest a) Dyslexic group b) Control group.

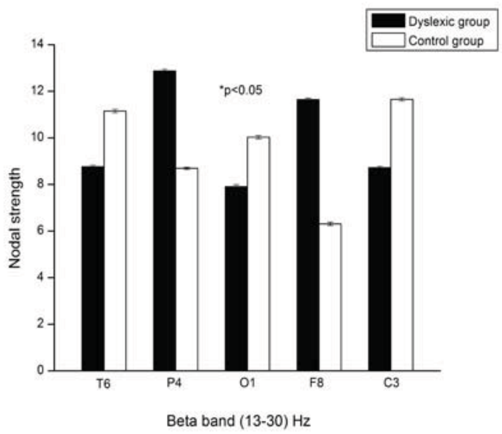

Fig. 13. Beta band significant electrode location between groups.

IV. Disscussion

The overall aim of the present study was to evaluate the differences in brain activity between dyslexic and normal children during rest condition (eyes closed). Wavelet packet decomposition technique was employed to extract all EEG bands and relative component energy for each EEG band was calculated. From the derived relative component energies, Spearman correlation matrix was estimated across 19 electrode locations and node strength was calculated for each electrode location for each EEG band served as the main feature. Node strengths were examined at all electrode locations across prefrontal, frontal, central, parietal, temporal and occipital brain regions. The results revealed that increased delta/theta node strength in temporal, parietal, frontal and occipital regions during rest in dyslexic group. Also, dyslexic group showed decreased alpha/beta node strength at right temporal, prefrontal and left central brain areas. The control group showed decreased delta/theta node strength at temporal, parietal, occipital and frontal regions and increased alpha/beta node strength at right parietal and frontal regions. Many structural and functional studies have shown the abnormalities in dyslexic brain language processing areas particularly at left hemisphere [8]. The present findings are consistent with previous research findings showed significant increase in delta[17] and theta[15] at temporoparietal and frontal regions in dyslexics, which are areas essential to processing of language associated information. Delta band activities are well known in early developmental phases and in slow-wave sleep are frequently interpreted in developmental disorders and pathological situations[17]. Study[17] shown increase in delta activity in dyslexic group compare to normal during phonological task suggested delayed maturation/ immaturity of brain development in dyslexic children. However, in the present study, increased delta activity was observed during rest hence the authors interpret the present findings on delta activity as a delayed maturation/brain development immaturity. Considering theta band, previous research[18], has stated that the theta band activity increases with the increase in task demands for successful encoding new information. , this was noted in the control group showed decreased theta activity at rest (absence of any cognitive stimuli) which is expected to be normal in the absence of cognitive load, but the dyslexic group showed a significant increase of theta activity at temporal, parietal, frontal and occipital regions during rest. This activity of theta synchronization at rest (without any cognitive stimuli) suggests the functional abnormalities at resting state in dyslexic group. The study concludes with the finding of increased theta activity during rest condition (eyes closed) as a strong biomarker in dyslexic children for the existence of resting state functional abnormalities at TPO regions. Further, future study is required to examine the difference and correlation in brain activity between groups while performing cognitive task and at rest.

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