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Detrended Fluctuation Analysis of EEG in Detecting Cross-modal Plasticity in Brain for Blind

M. Kalaivani and Dr. G. Ravindran

Abstract—**Cross-modality is the development of cross link between the modalities in the brain following sensory deprivation in the early stage. Cross modality analysis was previously done with fMRI, MEG and PET images for studying the changes in cerebral activities. Instead of these imaging techniques, this work involves in deriving self similarity parameter using Detrended Fluctuation Analysis of EEG from blind and blind folded normal individuals. This paper presents a novel technique of nonlinear spectral analysis to extract the information from electro encephalograms of humans for the detection of cross- modality existence in blind subjects.**

I. Introduction

Cross-modal plasticity is the existence of cross link between the modalities when any one of the modality is deprived of its function in early stage. In early blinded people it has been shown that there is a link between the auditory modality and visual modality which is the affected modality. Due to this reason the brain has the capability to reorganize itself following the sensory deprivation of one modality or brain damage in early stage [1]. Similarly in deaf subjects, cross-modal network is existing between affected or damaged auditory region and normal visual cortical region and this cross-modal plasticity depends on extent of hearing loss[2]. Due to the existence of cross- modal link between the modalities in brain the stimuli in one modality cause the response not only in the corresponding modality but also in affected modality. Human studies also have shown that sensory deprivation in one modality can have striking effect on the development of the remaining modalities [3].

Recent studies of deaf and blind humans have also provided convincing behavioural, electrophysiological and neuroimaging evidence of increased capabilities and altered organization of spared modalities using MEG studies and change in cerebral blood flow shown by fMRI and PET images[4].

This paper describes a novel technique for the detection of cross-modal plasticity in blind using EEG data analysis in nonlinear domain using Detrended Fluctuation Analysis(DFA) which is one of the Fractal analysis techniques. Detrended fluctuation analysis is a new scientific paradigm that has been used successfully in many domains including biological and physical sciences.

Linear analysis such as FFT spectral analysis would not be suitable for brain as the brain itself is quite complex and nonlinear system. The EEG signal with linear analysis leads to misconception of neuroscientists. So the EEG waveform generated by brain should be analyzed using nonlinear methods to extract the useful information [5]. Previous works have explained that DFA method is fit for analyzing the EEG signals under normal and epileptic conditions and in analyzing sleep EEG of depressed man [6],[7].

Using fractal DFA, it is possible to analyze and classify EEG signals during various brain activities like relaxation, concentricity, problem solving etc. Fractal features represent the morphology of the signals. These morphological differences can be picked up and used by several applications like analyzing depth of anesthesia and in finding out EEG background activity in Alzheimer's disease[8],[9].

This work focuses on extracting the self similarity parameter using DFA technique to show the cross-modality existence in blind and that has been compared with the normal subjects. As DFA is an efficient technique for the analysis of EEG signals, that is adopted here for bringing out the details of activity of affected modality(visual area in the case of blind) for the stimuli applied to other modality(stimuli to auditory modality).

II. Methods and Materials

Experiments were conducted in the Neurology department of leading medical Institute with 10 blind subjects and 10 blind folded normal subjects in the age group of 20-30 years old. The neurons in the visual cortex of the early blinded person are activated by auditory stimuli.

To achieve that, a train of click sounds (70db) was given with 1 second interval. Simultaneously EEG signal was recorded from visual cortex and auditory cortex for evaluating the evoked response. This was done with blind (n=10) and blind folded normal subjects (n=10). For visual response the signals from Oz and for auditory response the signals from Cz were used. EEG from these areas were used to extract the response of the auditory stimuli which was the train of click sounds.

The signals were recorded with thousand samples per second and with 0.01mV as the sensitivity of the recording instrument. Interfacing and processing of the signal were done in the LabVIEW environment and the DFA was carried out using MATLAB programming. The effect of 50Hz noise was removed using suitable filter design and artifacts were

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M. Kalaivani is Research Scholar in Anna University, Chennai, India-600 025 in the Centre for Medical Electronics. (phone: 0091-044-22462615; e-mail:kasudha@yahoo.com).

Dr. G. Ravindran is Professor and Chairman of Information and Communication Engineering, Anna University, Chennai, India-600 025 (e-mail:raviguru@annauniv.edu).

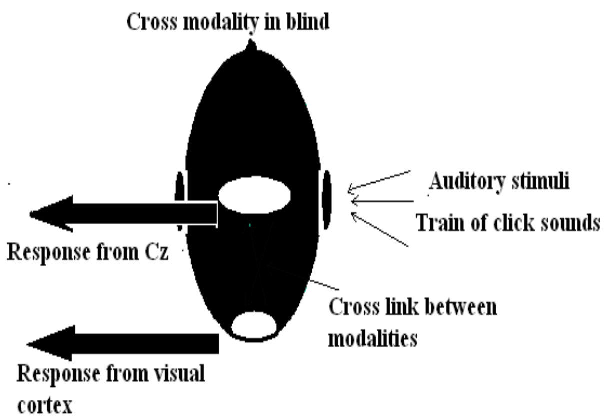

Fig. 1. Schematic diagram of Cross-modal plasticity in blind

eliminated by asking the subjects to restrict their movements. Also no significant difference has been observed between the recordings from female and male subjects.

III. DATA ANALYSIS

The EEG samples obtained from both auditory and visual cortex upon the application of train of pulses are used for FDA techniques. For applying detrending operation, EEG recorded as time series of eight thousand samples is first considered. This number is denoted as N.

To improve the stability of spectral estimates the data recorded over entire time series are first subtracted from the mean of the data series which is shown in (1)

$$X(k) = \sum_{i=1}^{N} X(i) - X_{ave} \quad (1)$$

Where X(i) is the i^{th} sample and x_{ave} is the average of all the 8000 samples and X(k) is the resultant sequence. And difference between each and every sample and average of the sample is integrated for its total length.

The second step of DFA technique is measuring the vertical characteristic scale of the integrated time series. For that the integrated time series is divided into B number of windows of equal length, n. Each window is labeled as b(b=1,2…..B). In each window of length n, a least square line is fit to the data. This line obtained with least square is the 'trend'. The y coordinate of the corresponding window is denoted as $X_b(k)$.

The third step is the detrending process which can be achieved by subtracting the local trend $X_b(k)$ from the integrated time series X(k) of that particular box or window . For a given box size n, the characteristic size of fluctuation for this integrated and detrended time series is calculated by

$$f_b(n) = \left[\frac{1}{n}\sum_{k=(b-1)n+1}^{k=n+(b-1)n} (X(k) - X_b(k))^2\right]^{\frac{1}{2}} \quad (2)$$

The resultant value $f_b(n)$ is averaged over B windows to yield F(n) using (3).

$$F(n) = \frac{1}{B}\sum_{b=1}^{B} f_b(n) \quad (3)$$

This computation is repeated for different values of window sizes with different n values [10]. The F(n) values and n values are used to plot log(n) and log(F(n)) values to get the linear relationship on a double log graph. Linear curve fitting is used to find out the slope of the line which shows the relationship between F(n) and n This slope of the line determines the scaling exponent, which is also known as self similarity parameter, α(alpha).

We explored the characteristics of electroencephalogram (EEG), recorded from blind and blind folded normal subjects while getting same auditory stimuli. The results show that mental EEG exhibits long-range power-law correlations by calculating its scaling exponents (α), which can reflect the kinds of mental responses. The scaling exponents of blind individuals are compared with that of blind folded normal subjects.

IV. RESULT AND DISCUSSION

For the measurement of trend the entire time series is divided into box size of various n values. Fig. 2 shows the values of 2000 samples of integrated time series X(k) after first step of the DFA algorithm. The trend which is the straight line drawn with least square algorithm in each box and that is shown in Fig. 3. which is the Xn(K) signal, for the window size of n=50 samples.

The averaged value of difference between the integrated

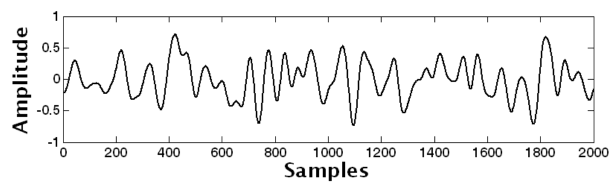

Fig. 2. Integrated time series X(k) which is obtained after subtracting mean value from the obtained EEG signal

time series X(k) and Xn(k) for all the windows is the size of fluctuations F(n). This F(n) is calculated for increasing values of n. The n values are chosen from 80 to 1000 samples per window.

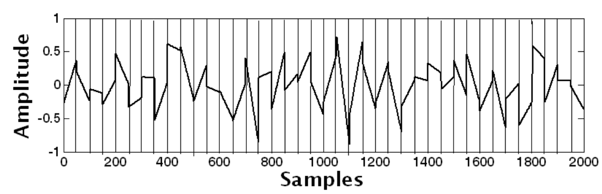

Fig. 3 Least square line fit $X_b(k)$ of the integrated EEG with the window size of 50 samples which shows the straight line representation of EEG data in each window

The plot of log(F(n)) and log(n) is shown in Fig. 4. This is the plot of natural logarithm of F(n) against the natural logarithm of n values. After plotting the values using linear curve fitting method a straight line is drawn. The slope of the line drawn using linear curve fitting is the scaling exponent of the DFA technique.

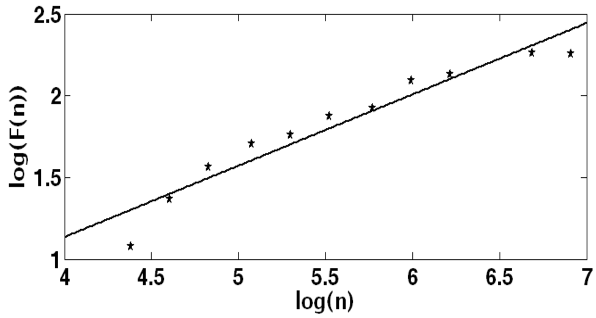

Fig. 4 Linear curve fitting of log-log plot of F(n) and n for finding out the slope which is the scaling exponent

Similar curves are drawn for all the EEG signal obtained from Cz and Oz of blind and blind folded normal subjects. The range of scaling component values for 10 blind and 5 normal subjects are shown in Table .I.

TABLE I
SCALING COMPONENETVALUES AT DIFFERENT ELECTRODE POSITIONS

Nature of the subject	Blind Subjects		Blind folded normal subjects	
Electrode	Cz	Oz	Cz	Oz
Scaling component(α) for 10 subjects	0.65±0.05	0.56±0.04	0.51±0.06	0.38±0.05

We have analyzed the slope values for 10 blind subjects and 10 blind folded normal subjects. It is noted down from the values of the slope that there is significant difference between the scaling exponent values between normal and blind subjects.

All the slope values for signals from different electrode positions are plotted in the bar graph as shown in Fig.5. The graph clearly shows that the slope values or self exponent value α is greater than 0.5 for both Cz and Oz in the case of blind. But for the blind folded normal person the value of α is greater than 0.5 for signals recorded from Cz and α value is less than 0.5 for signals recorded from Oz . This clearly indicates the existence increased cortical activity in both occipital and central cortex for the applied stimuli in the case of blind.

In the normal blindfolded person there is no activity increase in the occipital region when the auditory stimuli are applied. This is due to the fact that there is no cross network or plasticity between the auditory and visual modalities in

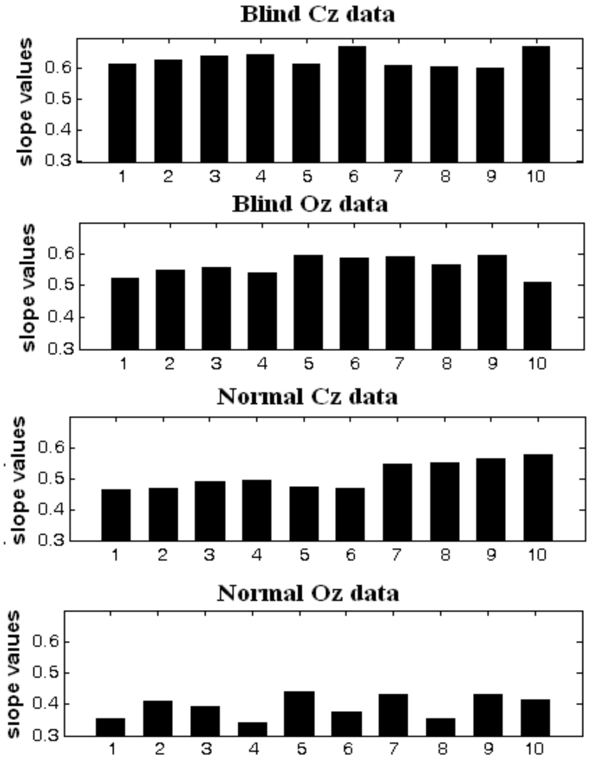

Fig. 5. Scaling exponent values which is the slope of log-log plot of F(n) and n of EEG recorded from Cz and Oz regions of Blind and Blind folded normal individuals.

normal sighted individuals. This shows the clear indication of cross-modal plasticity in blind.

V. CONCLUSION

Experimental results confirm that the DFA on raw EEG data obtained from visual cortex can clearly discriminate between the blind and blind folded normal subjects on the application of auditory stimulus. The α values clearly shows that the there is response to the click sound in both auditory and visual cortex for blind subjects.

The self component values derived from DFA can be utilized for cross modality analysis. This cross-modality analysis can be used in deaf persons also. Thus for the quantification of fluctuation in EEG, the self exponent derived from DFA technique can be utilized and the same thing can used in different cross modality analysis.

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