CHAPTER 1

INTRODUCTION

1.1 WHAT IS CROSS-MODAL PLASTICITY IN BRAIN?

The integration of the functions of two or more sensory systems in the brain due to the adaptive reorganization of neurons, is called cross-modal plasticity. This sort of the reorganization of neural network occurs, following brain damage at an early age or long term sensory deprivation. Thus, cross-modal plasticity is the existence of the cross link between the modalities, when any one of them is deprived of its function at an early stage, like congenital blindness or pre-lingual deafness. In such cases, cross-modal plasticity can strengthen the other sensory systems or modalities, to compensate for the lack of the affected functions like vision or hearing. Cross-modal plasticity in brain causes a modality-specific brain area that is deprived of its normal sensory input and becomes responsive to the stimulation of other modalities. Thus the brain re-organization and behavioral compensation that occur following sensory deprivation is cross-modal plasticity (Theoret, 2004).

The investigation of cross-modal plasticity has expanded rapidly over the past 25 years and has uncovered a remarkable capacity of both the young and the adult brain to be shaped by environmental input. Due to this cross-modal plasticity, inputs to one sensory modality will be processed by the deprived modality. In other words, the ability to respond to, the stimuli presented in another sensory modality is called as cross-modal processing. (Charles et al, 2009).
The burgeoning literature on this topic indicates that plastic changes vary widely across brain systems, giving rise to highly specific alterations as a function of the nature of the altered experience, its timing and the brain systems involved. The nature of altered experience can vary widely between modalities.

In the work of Burton, 2003 it was shown that even if the blind people are no longer able to see, the brain area which is involved in the processing of visual signals is still in active use due to existence of cross-modal plasticity. Simply stated, the loss of vision does not lead to a permanent inactivation of the visual cortex. The investigation of cross-modal plasticity has expanded over the past ten years, and has uncovered the capacity of the human brain to adapt to cross-modal plasticity based on environmental inputs. There is compelling evidence from the literature (reviewed in Noppeney 2007) that blind subjects activate their visual cortex when performing tasks that involve somatosensory or auditory inputs, suggesting a reorganization of the neural pathways that transmit sensory information to the visual cortex. Due to the existence of cross-modal plasticity, the auditory and visual cortices are much more interconnected in the early blind than in the normal sighted people. Due to the cross-modal effect in the blind, the spreading of auditory information processing between the auditory and visual modalities takes place.

Due to the enhancement of auditory processing in the case of the blind, blind persons are able to perform auditory tasks better than people who can see (Hugdahl et al 2004).

Figure 1.1 shows the effect of cross-modal plasticity in the blind. In the case of blind people, if the auditory stimuli are given, the processing will be done by both the visual and auditory modalities.
Figure 1.1 Schematic diagram of cross-modal plasticity in the blind

A variety of studies have demonstrated cross-modal responses within occipital cortex as a result of early blindness. Animal studies too have shown enhancements in processing within the remaining modalities with the reorganization of brain areas following early sensory deprivation. Rauschecker (1996) have shown the response of the visual cortex to auditory inputs in visually deprived animals. Cross-modal plasticity between the auditory and visual regions of ferrets was explained by Laurie et al (2000).

The evidence for cross-modal plasticity, the areas involved in the cross-modal reorganization and the behavioral enhancements in processing within the remaining modalities in deaf and blind people, had been explained by Bavelier and Neville (2002).

Similar to the auditory cortex, the somatosensory cortex is able to utilize the visual cortex to assist with tactile sensation. Cross modal plasticity reworks the network structure of the brain, leading to increased connections between the somatosensory and visual cortices. Furthermore, the somatosensory cortex acts as a connecting region of nerve connections in the
brain for the early blind but not for the sighted. This was shown by Shu et al (2009) with the help of the diffusion MRI data. With this type of cross-modal networking, the early blind are able to react to tactile stimuli with greater speed and accuracy, as they have more neural pathways to work with.

The brain imaging studies described by Burton et al (2002) and Norihiro et al (2002) revealed visual cortex activity in blind people during nonvisual tasks such as Braille reading, hearing words or sensory discrimination tasks.

Congenitally blind human subjects, trained to discriminate the orientation of a stimulus applied to the tongue via an electrotactile device, show the activation of their visual cortex, whereas trained blindfolded controls show only the activation of the somatosensory cortex representing the tongue (Ptito et al 2005). Kujala et al (1995) have dealt with somatosensory and auditory ERPs of blind and sighted subjects, which were recorded when subjects were instructed to attend to stimuli of one modality and to ignore those of the other. In the sighted, deviant stimuli of the attended modality elicited N2 type of deflections (auditory N2b and somatosensory N250) over the lateral scalp areas. In contrast, in the blind, these ERP components were centroposteriorly distributed, suggesting an involvement of posterior brain areas in auditory and somatosensory stimulus discrimination. In addition, the mismatch negativity, elicited by deviant auditory stimuli even when the somatosensory stimuli were attended, was larger in the blind than in the sighted. This appears to indicate enhanced automatic processing of auditory stimulus changes in the blind. Thus, this work suggested that several compensatory changes in both auditory and somatosensory modalities after the onset of early visual deprivation. At the same time, in the work done by Kujala et al (1999) it was shown that cross-modal reorganization may occur
even in the mature human brain. This result was contradictory to his previous work.

In deaf subjects, a cross-modal network exists between the affected or damaged auditory region and the normal visual cortical region; and Lambertz et al (2005) have revealed that the cross-modal plasticity depends on the extent of hearing loss. In the work by Finney (2001), it was shown that in deaf people, the auditory cortex was activated by visual stimuli due to the existence of cross-modal plasticity. Due to the existence of the cross-modal link between the modalities in brain, the stimuli in one modality cause a response not only in the corresponding modality but also in the affected modality.

1.2 HYPOTHESES

The study cross-modality in blind individuals provides insight into the brain re-organization and behavioral compensations that occur following sensory deprivation. The functionality of the sensory cortices can be profoundly changed by sensory experience, especially during early postnatal development.

Based on the above discussions, the following hypotheses were tested in this research context.

- Analyzing the cross-modal plasticity in blind using a simpler technique like EEG analysis.

- Deriving a quantitative approach for determining the extent of cross-modal plasticity.

- Understanding the role of cross-modal plasticity in late and early sensory deprivation subjects.
• Correlation between the ERP components obtained from auditory and visual cortex for the train of click sounds.

• Scaling exponent values derived from detrended fluctuation analysis of EEG signal obtained from both auditory and visual cortex of blind

The present work deals with analysis of cross-modal plasticity in blind, using EEG data analysis by conventional ERP (Event Related Potential) method and fractal methods.

1.4 CROSS-MODALITY ANALYSIS USING ERP COMPONENTS

An event related potential (ERP) is any measured brain response that is directly the result of an electrophysiological activity initiated due to internal or external stimuli.

Event related potentials obtained in response to auditory, visual or somatosensory stimuli from blind or deaf individuals could be used for the cross-modal analysis. Blind people rely more than sighted people on auditory input in order to acquire information about the world. Kujala et al (1992) had studied the cross-modality in the blind by the ERP components of the auditory stimuli and found that the ERP components were distributed in the scalp posterior to those in the sighted controls. Roder et al (1999) had described in his work about the amplitude change of the ERP in blind humans with the change in the interstimulus interval of auditory stimuli.

The distribution of the ERP components for both auditory and somatosensory stimuli over the posterior scalp regions, by which the
involvement of the posterior brain areas in auditory and somatosensory stimuli discrimination was determined, was studied by Kujala et al (1995).

An evidence for cross-modal sensory reorganization in the blind using ERP components was given by Liotti et al (1998), and it was also shown that the plasticity changes in the blind had a progressive recruitment of the parietal, and then, the occipital regions. By analyzing the distribution and the amplitude components of the ERP Brigitte Roder et al (2000) described that blind people process auditory language stimuli faster than sighted people.

Leclerc et al (2000) had showed in their work the scalp distribution of components N1 and P3 of auditory evoked potentials during a sound localization task in four totally blind subjects who had previously shown better performance than sighted subjects. Both N1 and P3 waves peaked at their usual positions while blind and sighted individuals performed the task. However, in blind subjects these two components were also found to be robust over occipital regions while in sighted individuals this pattern was not seen. From this result, it was concluded that deafferented posterior visual areas in blind individuals are recruited to carry out auditory functions, enabling these individuals to compensate for their lack of vision.

In this work, ERPs, from two brain locations were obtained and used for the cross-modality analysis in the brain. Instead of analyzing the amplitude components and the distribution of the ERP in the various brain locations, the ERP components obtained at two different locations were correlated to derive the parameters, to analyze the cross-modal plasticity in the blind, and blind-folded normal controls.
1.4 CROSS-MODALITY ANALYSIS USING FRACTAL METHODS

The fractal analysis technique is a new scientific paradigm that has been used successfully in many domains, including the biological and physical sciences.

Fractal analysis is the modeling of data by fractals. It consists of methods to assign a fractal dimension and other fractal characteristics to signals, datasets or objects which may be sounds, images, molecules, networks or other data. Fractal analysis is now widely used in all areas of science.

The fractal description of an EEG signal can be a useful tool for extracting important features effectively. Fractals are objects which possess a form of self scaling. Parts of the whole can be made to fit the whole by shifting and stretching. Fractal features represent the morphology of the signals. These morphological differences can be used in many applications. There are several features based on the fractal theory, that can be extracted from a usual signal.

The fractal dimension has been proven to be useful in quantifying the complexity of dynamical signals in biology and medicine. Fractal dimensions are measures of the self similarity of the signals (Jelinek and Jones 1998). Fractal dimensions have their value as a fractional number; hence, this dimension is referred to as a fractal.

Electroencephalogram (EEG) - the recorded representation of electrical activity of the brain contain useful information about the state of the brain. Nonlinear methods can extract valuable information from neuronal dynamics. The dynamical properties of EEG signals of healthy subjects with epileptic subjects were being compared using nonlinear time series analysis
techniques by Kannathal et al (2004a). Applications of non-linear models are useful for understanding complex physiological phenomena such as abrupt transition and chaotic behavior. The electro encephalogram can be considered as a chaotic process.

EEG signals are highly complex in nature, and are highly subjective with a random nature in the time scale. Therefore, the EEG signals should be analyzed by non-linear methods to understand its chaotic behavior and to extract the information hidden in it.

The electroencephalogram is a representative signal containing information about the condition or various states of the brain. The shape of the wave may contain useful information about the state of the brain. However, the details cannot be monitored directly. So the EEG signal analysis, carried out using non-linear and fractal methods, yields better results than the linear methods.

Vladimir Kulish et al (2006) have stated in their work, that a linear analysis such as the FFT spectral analysis, would not be suitable for the brain as the brain itself is quite complex and nonlinear. An EEG signal subjected to a linear analysis leads to misconceptions by neuroscientists. So the EEG signals generated by the brain should be analyzed, using nonlinear methods to extract the useful information.

In this work, two fractal methods were also used along with the conventional ERP method to analyze the EEG to study the cross-modal plasticity in the brain. They are:

i) The Detrended Fluctuation analysis (DFA)

ii) The Hurst analysis
1.4.1 Detrended Fluctuation Analysis

The Detrended fluctuation analysis (DFA) is a method for determining the statistical self-affinity of a signal. With the detrended fluctuation analysis, the dynamics of the human brain electroencephalogram can be investigated. Long-range temporal correlation and scaling behavior can also be observed.

Lee et al (2007) had found that the application of the detrended fluctuation analysis, one of the well established fractal analysis techniques, can demonstrate the electrophysiological correlation with a hypnotic influence on cerebral activity.

The electroencephalogram (EEG) data from two specific conditions (of eyes-closed and eyes-open) were analyzed using the non-linear method, detrended fluctuation analysis, by Tingting Gao et al (2008). The characteristics of Alzheimer’s diseases were revealed with the help of the EEG analysis using the DFA method by Pan et al (2004).

In the work of Ping Zhou et al (2007) and Hwa and Ferree (2006), it was described that the Hurst exponent method is fit for analyzing the EEG signals under normal and epileptic conditions, and Leisted et al (2007) used the DFA to analyze the sleep EEG of depressed men.

Using the 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 were picked up and used by Jospin (2008) for analyzing the depth of the anesthesia, and the same technique was used by Abasolo et al (2007) for finding out the EEG background activity in Alzheimer’s disease.
In the present work the EEG recorded from two different electrode positions was analyzed using the DFA technique. The entire EEG obtained from the blind and normal subjects during the application of auditory stimuli was divided into windows of equal size, and the scaling exponent values, which give the amount of the fluctuation of any non-linear time series, were calculated. From the values of the scaling exponent, the study of cross-modality was carried out.

1.4.2 Hurst Exponent

The Hurst exponent is also used to measure and evaluate self-similarity. The Hurst exponent is the measure of the smoothness of a fractal time series, based on the asymptotic behavior of the rescaled range of the process.

The EEG contains information about the state of the brain. The nonlinear dynamics theory is a better approach for the EEG analysis. So the Hurst Exponent is one of the nonlinear measures. Kannathal et al (2004b) had shown that the Hurst exponent can also be used for the EEG analysis under various mental states. The complexity of an epileptic EEG signal was evaluated by estimating the Hurst Exponent (H) by Indiradevi et al (2009).

Differences in the characteristics of normal subjects with eyes open and closed, epileptic subjects during seizure and seizure free intervals, had been shown by the Hurst exponent by Nurujjaman et al (2009). Also, the nonlinear analyses of various sleep EEG signals were carried out using the Hurst and other non-linear methods by Rajendra et al (2005). So, the Hurst exponent can be used for analyzing the EEG to study the different states or conditions of the brain.
The present work focuses on extracting the self similarity parameter using the Hurst exponent, to show the cross-modality existence in the blind; that has been compared with the normal subjects. As the Hurst exponent is an efficient technique for the analysis of EEG signals, it has been adopted in this work for bringing out the details of the activity of the affected modality (visual area in the case of the blind) for the stimuli applied to another modality (auditory).

1.5 OUTLINE OF THE WORK

Thus, the present research work attempts to analyze the existence of cross modal plasticity in the blind and blind-folded normal subjects by analyzing the EEG obtained from the electrode positions of the Cz and Oz for the train of click sounds. The obtained EEG has been analyzed using the following methods:

- ERP based cross-modality analysis
- Fractal methods
- Detrended Fluctuation analysis
- Hurst Exponent analysis

The first method is based on averaging the EEG signal to obtain the ERP components, and analyzing the cross-modality in the blind. The other two methods are fractal methods called as the detrended fluctuation analysis and the Hurst exponent method.

In chapter 2, previous works in the fields of cross-modality analysis in the brain, and analysis of the EEG using fractal and nonlinear methods are dealt with.
The objective of the present work, and the need for a cross-modality analysis, and the need for analyzing the EEG using fractal methods and the method adopted in this work to carry out the cross-modal analysis, have been discussed in chapter 3.

The next chapter, i.e. chapter 4 deals with the cross-modality analysis using the conventional ERP techniques, and the correlation of the ERP components obtained from two different locations, and the methods to derive three parameters using ERP components are discussed.

In chapter 5, the detrended fluctuation analysis of the EEG, deriving the scaling exponent values from the EEG and an analysis of the cross-modal existence in the blind using scaling exponent values are discussed.

The algorithm and application of the Hurst exponent for the EEG analysis of cross-modality in the brain are mentioned in chapter 6.

The conclusions of this research work in cross-modal analysis in the blind, and the scope for future works in cross-modal analysis, have been described in chapter 7 and chapter 8 respectively.