Investigation of P300 sources using varied sensory modalities

A

Project Report

submitted in partial fulfillment of the

requirements for the award of the degree of

MASTER OF TECHNOLOGY

in

ARTIFICIAL INTELLIGENCE AND ARTIFICIAL NEURAL NETWORKS

by

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CANDIDATE'S DECLARATION

I/We hereby certify that the project work entitled **"Investigation of P300 sources using varied sensory modalities"** in partial fulfilment of the requirements for the award of the Degree of MASTER OF TECHNOLOGY in ARTIFICIAL INTELLIGENCE AND ARTIFICIAL NEURAL NETWORK submitted to the Department of Computer Science & Engineering at Center for Information Technology, University of Petroleum & Energy Studies, Dehradun, is an authentic record of my/ our work carried out during a period from **December**, **2015** to **April**, **2016** under the supervision of Dr. **Manish Prateek, Professor and Associate Dean, CIT**.

The matter presented in this project has not been submitted by me/ us for the award of any other degree of this or any other University.

(Siddharth Talwar)
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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date: _____2016

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ABSTRACT

P300 wave has been studied in the past but whether to categorize it as a part of the perceptual process or decision making process is still inconclusive. Although, it has found its use into BCI application immensely, little is still known the reason it is elicited and whether the elicited wave can be different due to different stimuli. To determine this, it is necessary to study the presensory networks arising from external stimuli. To mark the networks, it is significant that the sources of P300 are first realized, so that the network can be later realized.

This thesis includes acquisition of EEG under varying stimuli modalities but essentially, the oddball paradigm is used. It deals with the preprocessing of the data and source localization techniques in order to find the specific sources for different sensory modalities i.e. Visual, Audio and combination of the two kinds.

Cross modal P300 have not been researched deeply in the past. Thus, this thesis also tries to compare cross modal data with regular auditory, visual, auditory-visual to determine if the sources and hence, the network arising due to each stimuli are different or similar to each other.

This thesis also present source localization using sloreta and fieldtrip, both compatible with MATLAB. The results of this thesis are not final as many more subjects are required to validate the observations.

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CHAPTER 1

INTRODUCTION

Cognitive neuroscience is a field concerned with the scientific study of biological substrates underlying cognition, with a specific focus on the neural substrates of mental processes. It addresses the questions of how psychological/cognitive functions are produced by neural circuits in the brain. Cognitive neuroscience is a branch of both psychology and neuroscience overlapping with disciplines including physiological and psychology, and neuropsychology.[1] Cognitive neuroscience relies upon theories and hypothesis in cognitive science along with evidence from computational and neuropsychology modeling.

To provide and analyze data for computational modelling and hypothesis creations, many software and toolboxes exist in the market today which supplies the needs of different applications in this department. Some of them include Fieldtrip, sLoreta, Chronux etc. The common modality of usage for using these tools is through MATLAB which provides an easy user interface and a platform to inculcate different functions on experimental data.

The topic of study is the comparison source localization of P300, from the EEG complex, elicited due to different stimuli. Event related potentials evoked from visual, audio and audio visual stimuli have been studied in great detail over the years, in different subjects and environments. They are also being used in Brain Computer Interfacing actively, for example, the P300 speller, mouse controller etc. Source Localization is a sought out subject, which has recently become easier using fMRI, but due high resolution of EEG, unlike fMRI, source localization using EEG and MEG data is being done and studied by scientists all around the world. It is also co-registered later on with fMRI studies so as to affirm the process. This thesis discusses and compares the sources of P300 in different paradigms, so as to understand the pre sensory networks in detail.

The method applied in this project is EEG, which is explained further. The following deals with the understanding of basic neuroscience, EEG and its modalities, data acquisition and recording, preprocessing, analysis on Event Related Potentials and source localization of P300. A summary of fundamentals required to perform this study is given as following.

CHAPTER 2

LITERATURE REVIEW

2.1 EEG

Electroencephalography is one of the most widely used non-invasive techniques to measure electrical activity along the scalp i.e. non-invasive technique. Hans Berger, a german physiologist and psychiatrist recorded the first human EEG in 1924. Since then, it has proved to serve as a diagnostic mechanism in clinical practice and answer different problems related to the functionality of the brain. Clinical applications include diagnostic application of EEG in case of epilepsy, coma, encephalopathy and brain death.

EEG is recorded using small silver/silver chloride sensors or electrodes with a radius of about 5mm. One can also use conductive gel or saltwater to reduce impedance between scalp and electrodes. Primary way to attach the electrodes is using an electrode cap on which the sensors are attached to the headset. For example, other types of sensors such as emotive epoch don't use caps. They have individual electrodes arising from the mainframe which can be worn on the head.

The EEG electrode placements and names are standardized by the International 10-20 System. The International 10-20 system is an internationally recognized procedure to label and put the location of scalp electrodes in the context of an EEG acquisition or experiment. [2][3] This system was developed to ensure that the standardized reproducibility of any subject who has undergone through an EEG system, could be compared over time and subjects could be compared to each other. This system is based on the relationship between the location of an electrode and the underlying area of cerebral cortex. In Fig 3.1 "10" and "20" refer to the fact that the actual distances between adjacent electrodes are either 10% or 20% of the total front-back or right-left distance of the skull.

EEG signals are of very small potential differences (0 to 100uV) between different areas or the electrodes at different positions. Due to this, signal processing and conditioning are of the utmost importance. Due to the volume conduction in the cerebrospinal fluid, the skull and and the scalp also, signals are spread to distant electrodes from a local collection of neurons. Thus, the signals

measured with EEG are thought to be mainly an effect of information processing primarily at the pyramidal neurons located in the cerebral cortex of the scalp [2]. The potentials caused by the activity of a local collection of neurons also spread to distant electrodes. In EEG, the effect of the tissue barrier between the electrodes and neurons is practically invisible. This makes it a global measurement of brain activities. Therefore, it can be difficult to use only EEG for inferring the activities of small brain regions. The activity of single brain neurons, thus, becomes close to impossible.

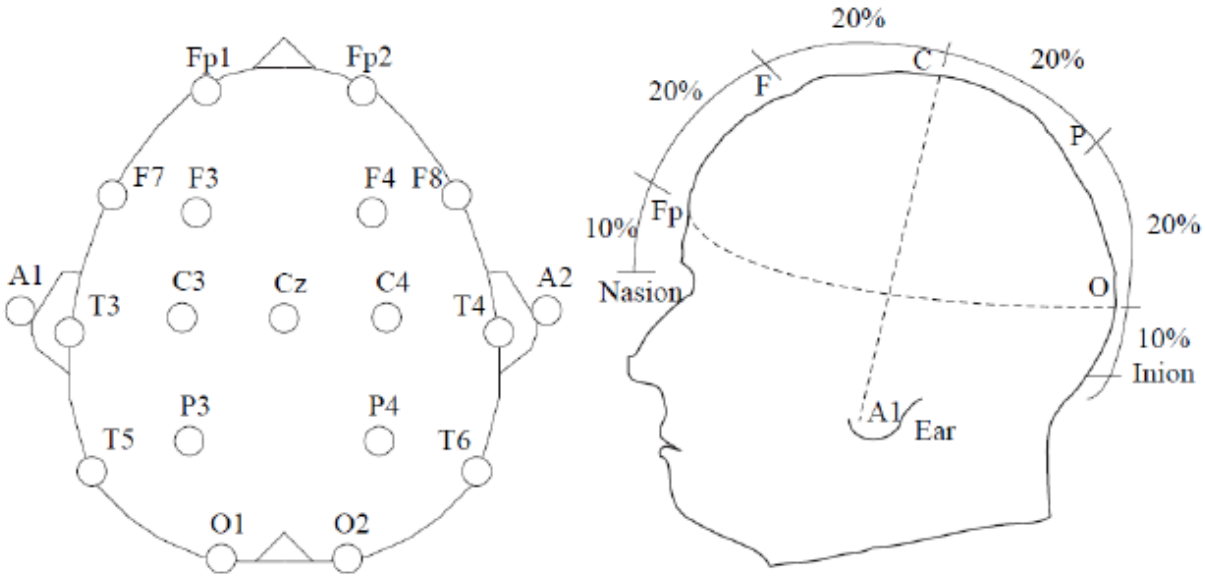

Fig 2.1

A big drawback of EEG also states the sophistication due to the presence of different artifacts which may physiological or non-physiological. Physiological sources include eye movements and eye blinks, heart activities, muscle activities and slow potential drifts due to transpiration. Non-physiological artifacts include main power supple line noise (50 to 60 Hz), noise generated by unexpected changes in the setup of electrode scalp interface and noise due to the amplifiers. These artifacts seem to have much larger amplitudes compared with the same of the signal of interest. Thus, artifact removal and filtering procedures have to be carried out before any EEG signal analysis can be applied.[2] Irrespective of the drawbacks, EEG remains one of the most widely used methods for measuring brain waves.

Frequency bands that include most of the useful neurophysiological signal information are classified as shown below:

Band	Frequency (Hz)
Delta	1-4
Theta	4-7
Alpha	7-13
Beta	13-30
Gamma	30+

Table 2.1

2.2 Physiology

The electric and magnetic fields generated by the cortical neurons pass many layers of tissues with different conductivities and a complex geometry. Thus, the recorded signal is attenuated and transformed image of the cortical sources. The distortion is more in case of EEG as different layers like skull, cerebrospinal fluid etc. have different conductivities, but these tissues surrounding brain have constant magnetic permeability and thus less influence on MEG signals.

The frequency of these signals is below 100 Hz and thus we can use quasi-static approximation of Maxwell's equations written as follows: [4][5][6]

$$\nabla . \mathrm{E} = \rho / \varepsilon \varepsilon_0 \quad (1)$$

$$\nabla \times \mathrm{E} = 0 \quad (2)$$

$$\nabla . \mathrm{B} = 0 \quad (3)$$

$$\nabla \times \mathrm{B} = \mu_0 J \quad (4)$$

B and E are the Electric and Magnetic fields; J is the conductivity, is the charge density and is Electric permittivity and magnetic permeability. The continuity equation can be written as follows:

$$\nabla . J + \frac{d\rho}{dt} = 0 \quad (5)$$

The total current can be expressed as a sum of primary current and a secondary current. The Secondary currents are caused due to the electric fields created by primary currents.

$$J = J^P + \sigma E \quad (6)$$

Where σ is the conductivity profile of the head tissues. Since the curl of Electric field turns out to be zero, we can rewrite the field as the negative gradient of electric scalar potential.

$$E = -\nabla \Phi \quad (7)$$

Also the net current entering the head volume is zero

$$\nabla . J = 0 \quad (8)$$

Combining the above equations, we can write:

$$\nabla . (\sigma E) = -\nabla . J^p \quad (9)$$

For a specific set of neural current sources, we can find the scalp potentials from the previous equations using proper boundary conditions.

$$J_{1n} = 0 \quad (10)$$

$$\nabla . E_{1r} = E_{2r} . J^p \quad (11)$$

Using Biot-Savart's law, we can calculate the magnetic field values at the scalp. Considering head to be a set of regions of isotropic conductivities (σi), we can write the magnetic field as a sum of contributions from primary and volume currents.

$$B(\mathrm{r}) = B_0(r) + \frac{\mu_0}{4\pi}\sum_{if}(\sigma_i - \sigma_f)\int_{S_{ij}} V(r')\int \frac{\mathrm{r}-\mathrm{r}'}{|\mathrm{r}-\mathrm{r}'|^3}\times \mathrm{dS}'_{if} \tag{12}$$

Similarly we can write an expression for Electric potentials at the scalp as:

$$(\sigma_i + \sigma_f)V(r) = 2\sigma_0 V_0(r) - \frac{1}{2\pi}\sum_{if}(\sigma_i - \sigma_f)\int_{S_{ij}} V(r')\int \frac{\mathrm{r}-\mathrm{r}'}{|\mathrm{r}-\mathrm{r}'|^3}\times \mathrm{dS}'_{if} \tag{13}$$

$$V_0(r) = \frac{1}{4\pi\sigma_0}J^p(r').\frac{\mathrm{r}-\mathrm{r}'}{|\mathrm{r}-\mathrm{r}'|^3}\,dr' \tag{14}$$

$$B_0(r) = \frac{\mu_0}{4\pi}J^p(r').\frac{\mathrm{r}-\mathrm{r}'}{|\mathrm{r}-\mathrm{r}'|^3}\,dr' \tag{15}$$

B(r) and E(r) are due to primary current sources only. The generalized equations for Electric potentials and Magnetic fields have analytical solution only for certain simple geometries and must be solved numerically in other cases.

Since we are concerned with the potentials which can be picked up, the brain activities are classified based on different paradigm or characteristics. Some of them are given as follows:

a) Oscillatory Brain activity

It is a sinusoidal like activity that can take place in many areas of the brain. For example, between aware and idling or wake and sleep between, thus, changing according to the state of users. Oscillatory activity in EEG is classified into different frequency bands. Typically it is observable in the alpha delta, theta, and mu, beta and gamma rhythms.

b) Sensorimotor rhythms

Mu rhythms oscillations are observable over the sensorimotor cortex. This can only happen when a user doesn't act the movement. One needs to imagine the movements of body parts or performed,

the amplitude of these oscillations is decreased. Additionally, imagined or performed movements of the body parts lead to changes in beta rhythm amplitude. [2] The changes in the mu and beta rhythm are located over the part of the sensorimotor cortex corresponding to the moved body part. So when, the imagined movements of moving the right hand corresponds to a decrease in mu rhythm amplitude over the left sensorimotor cortex, the imagination of moving the left hand corresponds to a decrease in the amplitude over the right sensorimotor cortex. [5] Classification algorithm usually cannot sense the sensorimotor rhythms in people who are untrained, as they are not high enough, rendering training of high priority.

c) Other oscillatory activity

Cognitive task which are other than motor imagery, could also be used to trigger changes in oscillatory brain activity. Examples of such tasks can be auditory imagery, mental calculations, imagining of rotating geometric objects or spatial navigation imagery. The classification accuracy for such cognitive tasks is comparable to that achieved with motor imagery. Additionally, preferences of alternative or other cognitive tasks can be easier to perform the motor imagery, depending from user to user.

d) Slow cortical potentials (SCP's)

These are slow voltage changes in EEG signals. They occur in the frequency range of 1 to 2 Hz. Positive SCPs correspond to a general increase in the cortical excitability, while negative SCPs correspond to a general decrease in the cortical excitability.[5]

2.3 Event-Related Potentials (ERPs)

Event Related Potentials are referred to as spatiotemporal patterns of brain activity, occurring time-locked to an event. For example, after presentation of a specific stimulus, before execution of a movement, or after the detection of a surprising stimulus [7]. Typically, EEG is used to record ERPs and these have been used in neuroscience for studying the different stages of perception, apprehension, cognition, and action. Primarily, ERPs can be divided into two classes; exogenous and endogenous ERPs. Endogenous ERPs are the due to later and more comprehensive processing of stimuli. These basically, have the properties that mainly depend on the stimulus context, i.e. on

the stimuli, the subject pays attention to and the task that was given to the subject. Exogenous ERPs occur when the initial and automatic processing of stimuli takes place and they have a latency, amplitude, and topographic distribution. These usually depend mainly on the physical characteristics of stimulus. An endogenous ERP that has gained much attention in both, the neuroscientific and medical research fields is the P300.[7] The P300 is a common research topic these days due to the reliability in its measurement and the characteristics of its waveform, such as amplitude and latency. Also, these can be influenced by various factors, and its eliciting nature. Since the discovery of the P300 by Sutton *et al*., experiments are conducted by many researchers to discover the neurophysiological and psychological meaning of the P300 wave by changing ways of stimuli presentations and modalities and consequently, observing the corresponding changes in the waveform of the P300. Also, different subjects have been taken under account so as to compare the neurophysiological studies. Many other studies have linked the characteristic of the P300 wave to some specific factors of subjects such as gender, age, or brain diseases, for example Alzheimer or schizophrenia. A graph based on P300 is given below:

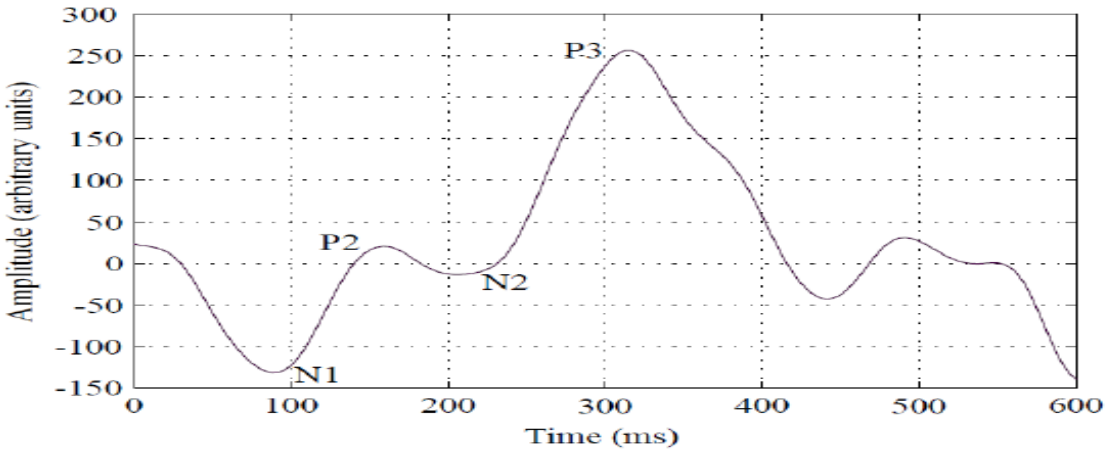

Fig 2.2

Different stimulus modalities and paradigms can be used to elicit the P300 wave by the user. For the stimulus modality: auditory, visual, tactile or other stimuli can be used. Although, for some practical reasons, many a time visual, auditory, or both the stimuli are used in most studies in the literature. Therefore, five paradigms are inculcated in this thesis, so as to understand the behavior of the P300, depending on the paradigms.

By defining the oddball paradigm, two different stimuli are used; a target (or oddball) stimulus and a non-target stimulus. 2 stimuli are used and arranged randomly. One is the frequent stimuli which is shown to the subject multiple times. The other is the oddball or the deviant stimuli which is shown 15% to 20% of the total time of the session. For example, in this experiment, for visual task, rectangle is the frequent or standard stimuli and the triangle is the oddball. Thus, a P300 can be elicited when the target appears only, that is the triangle.

There also exists a three-stimulus paradigm also known as modified oddball paradigm. In this a so-called distracter stimulus appears infrequently in the sequence of target (oddball) and non-target (standard) stimuli presentations. The subjects have no information about the distracter stimulus when being given the instructions making the subjects surprised when the first distracter appears in a sequence. This can also elicit a P300. Several unique distracter stimuli are used to increase the surprise and each distracter stimulus is presented only once. The distracter stimuli should be different from both the target and non-target stimuli perceptually. For example, one can use random noises which are very different from other stimuli or some other environmental sounds can also be used as distracters.

When users do not pay attention to stimuli, in the classical oddball paradigm, the target stimuli in the oddball paradigm evoke a different type of P300 also known as P3a. The P3a has a latency of approximately 200-400 msec and can be detected mostly over frontal-central regions of the brain. P3b is elicited when the target stimuli comes up. The P3b wave has a latency of approximately 300-500 msec. It can be detected mostly over central-parietal regions. The P3b appears only if users pay attention to stimuli and it will disappears if they do not pay attention to stimuli. The target stimuli also elicit a P3b in the three-stimulus paradigm. However, the distracter stimulus can evoke a P3a. [7] The relations between the different paradigms and the P3a and P3b are summarized in Fig 2.3

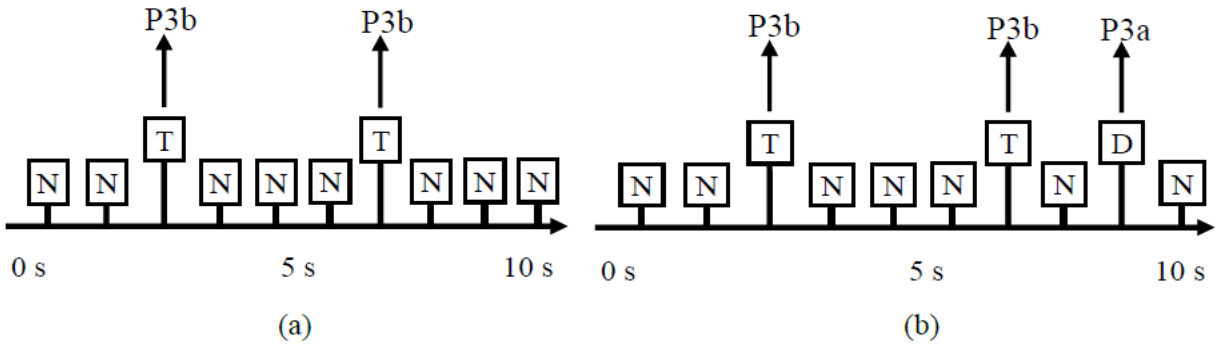

Fig 2.3

2.3.1 Factors Influencing the P300

Many other factors also affect the P300, in addition to its dependence on different paradigms which are noted previously above. Since P300 is dependent on so many factors, it cannot be declared as a fixed phenomenon, but better can be described as a variable phenomenon occurring in some sources in the brain. It is occurring in situations in which infrequent, rare or task-relevant stimuli have to be processed or perceived. Following are some important factors that can alter the P300:

a) Target Probability

The probability of an eliciting stimulus is inversely proportional to the P3b amplitude. Lesser the probability of the target stimulus, more activation of high amplitude P3b waves. The low amplitude P3b waves are evoked only when the probability of the target stimulus is high, stating vice versa of the statement. Practically, the probability for target stimuli is usually set to values about 15 % maximum in order to reliably obtain the P300 wave. The amplitude of the P3b is also dependent upon the local target probability in addition to the effect of global target probability. This means that amplitude of the wave will be high when an oddball stimulus is preceded with many standard stimuli and that the amplitude will be low if a deviant stimulus is preceded with a small number of standard stimuli.

b) Inter stimulus Interval

The amplitude of the P3b wave is directly proportional to the inter stimulus interval, that can be defined as the amount of time between two consecutive stimuli. The longer are the ISIs, the higher the amplitudes and the shorter the ISIs, the smaller are amplitudes.

c) Attention

The amplitude of the P3b wave is mainly altered by the attention that users pay to stimuli infront of them during the presentation and on the concentration exerted by the users. Actually, the P3b wave disappears fully if the users are not actively engaged in their task. On the contrast, the P3a wave doesn't get affected by changes in users' attention and can be observed even if subjects entirely ignore the stimuli.

d) Habituation

The amplitude of the P3a is known to habituate. After many distracter stimuli are presented, these stimuli become familiar to the subjects and P3a amplitude thus, decreases. For the P3b, its amplitude is mostly unaffected, if the stimuli is repetitive in nature.

e) Task Difficulty

The amplitude of the P300 (P3b) is inversely proportional to the difficulty of the task. The latency of the P3b wave is directly proportional to the difficulty of the task being processed. If the oddball stimuli in the experiment are very different from non-target or the standard stimuli, it would lead to higher P3b amplitudes than oddball stimuli that are similar or not very different from non-target or the standard stimuli. For the P3a, the effect of task difficulty is different. If the difficulty of determining oddball and standard stimuli in a three-stimuli paradigm is increased, it will lead to high P3a amplitudes. Therefore, the P3a also seems to be related to perceptual discrimination difficulty between standard and deviant stimuli. In such a paradigm, the P3b amplitude decreases as expected.

Conclusions can be drawn about the psychological and physiological meanings of these ERPs after the review of the paradigms used for eliciting P300 (both the P3a and P3b waves) and the factors on which the shape of these waves is influenced by. Usually, the P3a is mainly related to frontal lobe function and evoked by the set of stimuli that require attention and subsequent processing. Specifically, it has been stated that the P3a wave is a part of the so-called orienting response, i.e. the response of the human body to rare, surprising or potentially threatening situations, consisting of rapid changes in heart rate, skin conductance, and other physiological

parameters. Contrary, immediate responses to a stimulus and the P3b are thought to be part of high-level, meta-control processing. In summary, more investigations and experiment need to be conducted about the role of P3a and P3b in human information processing.

2.4 Source Localization

It is widely known that there are primarily two types of electric current. Firstly, the primary currents, which are the impressed neural and microscopic passive cellular currents and secondly, the secondary current, also known as volume currents which are a result of macroscopic electric field. Source localization in general, means deciphering the source of the electric fields which are measured by EEG or MEG. This problem can be solved by answering either of the two different problems: [9]

The forward problem refers to determining the currents and fields which are produced from the primary sources. The inverse problem refers to estimation of the sources or location by obtaining and reconstructing the currents and fields.

The major problem with source localization are the infinite solutions to any current. The current system in the brain can be said to act as diploes. If there is activation of a neuron or a set of neurons, there is also inhibition of a different neuron or a set of neurons. Since there are millions of neurons which can be activated or inhibited at a particular time, the number of solution tends to infinity. Thus, any field potential vector can be consistent with an infinite number of possible dipoles. The possibilities will only increase with tri-poles or quadra-poles and further. This the solution becomes very complicated. [10]

In the forward problem, one computes the EEG or MEG from the sources by using permutation and combination of these predefined sources, as a template in accordance with the experimental data obtained. When each combination of source vectors are stored in conjunction with field vectors and these field vectors are analysed with the experimental data, is called the inverse method, and thus, the sources are selected. Therefore, the forward model is going from sources to the data obtained, and inverse model is vice versa.

Source localization often gets difficult due to Numerical instabilities due to errors (finite precision of the method, noise). Some small errors in the measured data, can lead to much larger errors in the source localization (also known as ill-conditioned). Although, there is a perfect solution for every unique field obtained. Thus, the inverse method is also called the dipole fit method. In the forward model, modeling the head as a volume conductor becomes difficult.

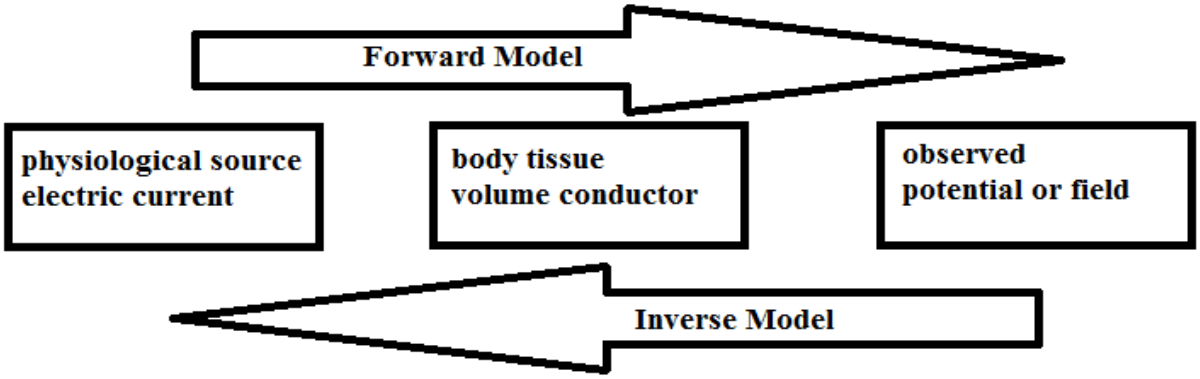

Fig 2.4

2.4.1 Source Modelling

Superposition of source activity states that if we take any two random sources in the brain, the different EEG of MEG (electrodes) will pick up the activity of the sources. The nearest electrode may pick up the maximum activity as power of the signal picked up is inversely proportional to the square of the distance of the source from the electrode. The most distant electrode will also thus, pick up the activity, but of a lesser amplitude. These two sources are also associated with a time course. The time course is super positioned at the scalp level, thus making each electrode pick up the activity. The reconstruction is not only of the sources but also the time course and the source waveform (used to make connectivity matrix). [11]

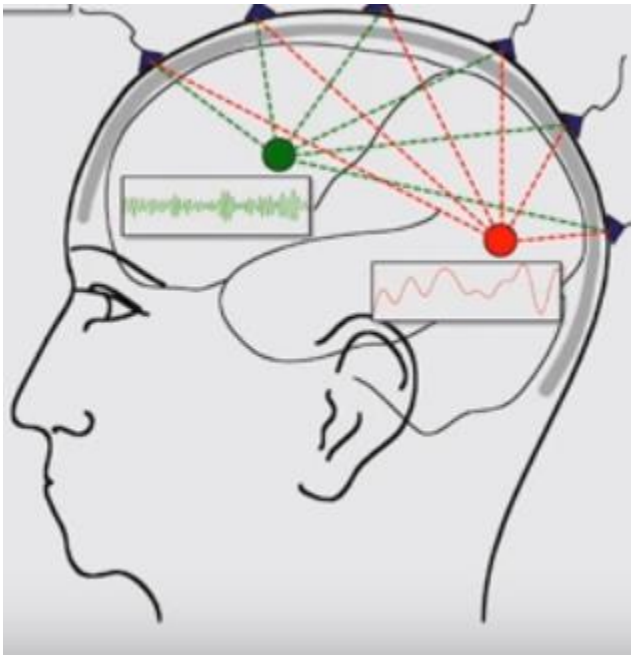

Fig 2.5

Superposition of source activity thus follows the following points:

- Varying visibility of each source to each channel
- Time course of each source contributes to each and every channel
- The contribution of each source depends on its visibility
- Activity of each channel is a superposition of all source activity.

Some of the inverse methods used are:

Single and multiple dipole model: Assume a small number of source and determine where and how many are the strongest sources. A dipole is selected and put into the space that has to be reconstructed. This is tried to fit until we find the correct source representation.

- Distributed dipole models: Here the activity is assumed and the distribution of activity over the brain is determined.

- Spatial Filtering: Here the time course of different sources are uncorrelated and the likelihood of an activity at a given location in the brain is determined. We take one dipole,

but unlike fitting it like is single dipole model, we scan location in the source space and iterate it over again, deeming it a scanning method.

Data model which we obtain can be given by:

$$X = h_1 s_1 + h_2 s_2 \ldots + h_n s_n + Noise \quad (16)$$

Where, h = leadfield

s = sources

X = data

In single or multiple dipole model, the error between the model and the measured potential is minimized in a least squared sense. Thus making it,

$$X - (h_1 s_1 + h_2 s_2 \ldots + h_n s_{n)} = Noise \quad (17)$$

Where n is typically small.

In distributed dipole models, perfect fit of model to the measured field is done with additional constraint on sources that allows us to find a unique solution to the problem. This makes the equation as,

$$H^{-1}(X - Noise) = S \quad (18)$$

Where H = leadfield matrix

S= all sources in the brain

And n is typically large

In spatial filtering, we scan the brain location after location with a single dipole. A major method is used beamforming algorithm. Beamforming is an approach of source localization, in which the contribution of a single brain position with respect to the measured field is estimated.[12] Beamformers are based on the variance of the source, not directly on its strength. The equation becomes,

$$X = h_1 s_1 + N \quad (19)$$

Where N = all the other activity which is not of interest.

We take one source and find out the location with scanning, and the next source is taken and so on.

The toolbox used in the making of the thesis is fieldtrip. It uses beamforming using the spatial filtering method. To execute beamforming, we require:

1. Forward model: Predicting the data from the source at a given location and ensures the specificity in space. To compute this, we determine the data X, given a source s at a location r. Since it projects the activity to all the sensors, based on the linear superposition of the dipole activity, we can form the data model:

$$X(t) = h(r) * s(r,t) \tag{20}$$

Where $X(t)$= data obtained (eg: channel x timepoints)

$s(r,t)$= source time series

$h(r)$= leadfield

While computing the forward model, we make a leadfield. For this, we obtain the sensor positions or head shape positions (eg CTF, polhemus). This allows us to know the locations of the sensors with respect to the brain.

Additionally we make a source model which can be made using the toolbox itself. The source model specifies the sources want to include in our scan. This discretizes a headspace to a grid where each grid voxel is considered to be a source. The voxel size can be as small as possible for better accuracy.

Further, we compute the volume conductor model, which is coregistered with the source model and electrode position to provide us with the leadfield matrix H. This matrix then can be used to obtain the s(r,t) or the source time series as we obtain X(t) through EEG or MEG. [13] It is illustrated below.

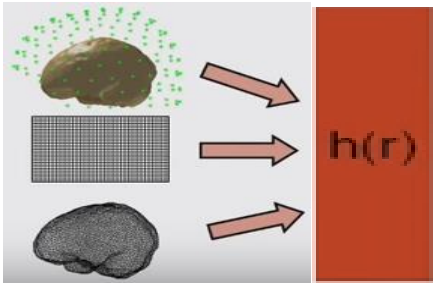

Fig 2.6

Forward model explains how we can get from source to data, but to obtain the source from data we use the following,

2. Spatial Filter (w): The spatial filter determines the sources of maximum power which can be differentiated from the other interferer sources or the sources not making the activity of interest. [12] This is also called a unity passband. It tries to attenuate the interferer and let as much as signal from the desired source as possible.

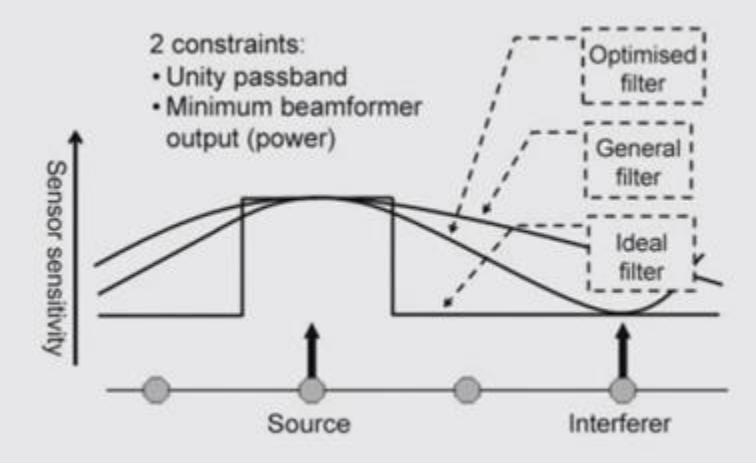

Fig 2.7

3. Experimental data: Ensuring selectivity for effect of interest.

Using the given three ingredients, beamforming algorithm is used by the toolbox to reproduce the sources as per given by the data model.

CHAPTER 3

EXPERIMENT

Healthy volunteers participated in the study. No participant had any neurological or audio related problems. They all had normal or corrected-to-normal vision.

The stimuli consisted of 5 paradigms wherein participants were shown any of them randomly. All paradigms exercised 2 kinds of stimuli, one being the standard stimulus which was shown in the majority of the session and oddball was presented infrequently in between. The 5 paradigms and the two kinds of stimuli used are given as follows:

1. Pure Visual: Only visual perception is required (shown in Fig 3.1)
   Standard: Blue Rectangle
   Oddball: Red Triangle

2. Pure Audio: Only audio perception is required
   Standard: Low tone
   Oddball: High tone

3. Audio-Visual: Congruent audio and visual stimuli were shown
   Standard: Blue Rectangle with low tone
   Oddball: Red Triangle with high tone

4. Cross modal:
   a) Audio Oddball on Visual Standard
      Standard: Blue Rectangle
      Oddball: High tone

   b) Visual Oddball on Audio Standard
      Standard: Low tone
      Oddball: Red Triangle

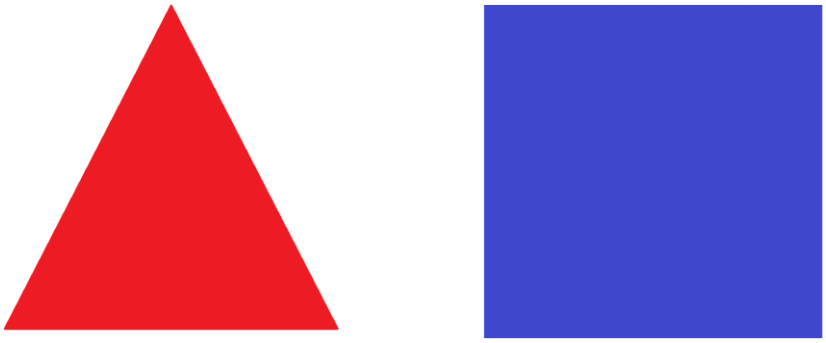

Fig 3.1: Deviant (Triangle) and Standard (Rectangle) Visual Cues

The stimuli were rendered into 800 x 600 pixel movie with a digitization rate of 29.97 frames per second. Stereo soundtracks were digitized at 48 kHz with 32 resolution. The stimuli were presented via Presentation software (Neurobehavioural system Inc.). The video was presented using a LED desktop monitor. Sounds were delivered at an overall medium intensity through sound tubes.

Each of the 5 experimental paradigms were carried out in 5 runs comprising 1 full session. The subject was given a break between every run. Each run consisted of 500 trials which constituted 14% of oddballs and 86% of standard stimuli. Each run was divided into 5 blocks of 100 trials with a 15 second break in between the blocks.

Length of both stimuli was 200 msec with ISI of 400 msec. Length of each block was 60 seconds, thus, rendering the length of each run as 6 minutes. The total session took 30 minutes excluding breaks in between the runs. Experimental parameters such as the height and distance from the screen were standardized, including the dim lighting inside the experiment room.

The subjects were instructed to count the number of oddballs they perceived in each block. They were informed about what the stimuli that can be presented in their runs. The subject were asked to be as attentive as possible while remaining calm.

The following sections elaborate each point in the given flowchart, Fig 3.2. The flowchart represents the whole work provided in this thesis.

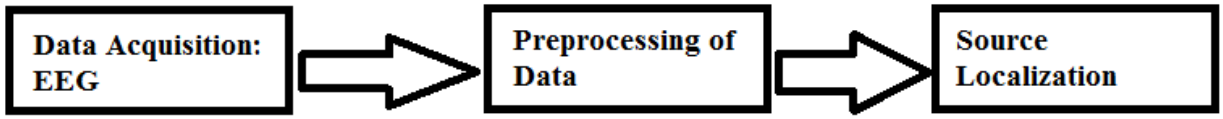

Fig 3.2: Process Flow

CHAPTER 4

ACQUISITION OF EEG

The subject was to wash his/her hair at the start so as to remove and substance that can provide impedance. Additionally, some alcohol may also be applied on the scalp to get rid of dead skin or impurities. A 64 Ag-Cl electrode EEG head cap was put on the scalp of the subject, fitted as per standardized 10-20 electrode placement convention. To attach electrodes, Ag-Cl gel was applied to reduce the impedance further. The subject was made as comfortable and relaxed as possible.

The head cap is attached to a box containing the amplifier and filters for initial hardware preprocessing of the signal. The sampling frequency is 1 KHz acquired continuously in AC mode.

The software used for the acquisition in Neuroscan. The stimulus was given by Neurobehavioral System Inc. (presentation software). The Neuroscan system consists in 2 subsystems.

1. SynAmps RT: Deals with the transduction, amplification, digitization and storage of the EEG signal.

2. The second group allows registering the 3 dimensional locations of the electrodes so that precise maps can be reconstructed during the analysis phase.

The stimulus activation system is also used to show the stimuli. The software used for the purpose is Presentation.

The recording is done as per the experiment guidelines. Channel impedance were kept below 5KΩ. Sometimes the impedance fluctuates which can be compensated by a proper contact of the electrode with the scalp or addition of more gel. Recordings of 5 subjects has been done. The setup is given in Fig 4.1.

4.1 Procedure

4.1.1 Head Digitization

The subject was asked to keep his/her head as still as possible. The Polhemus stylus was used to digitize the participant's head shape. We placed the point in the centre of a coil and pressed the Polhemus button to record the location (informed by a'beep' sound. The order of entry is as follows:

- Left PA
- Right PA

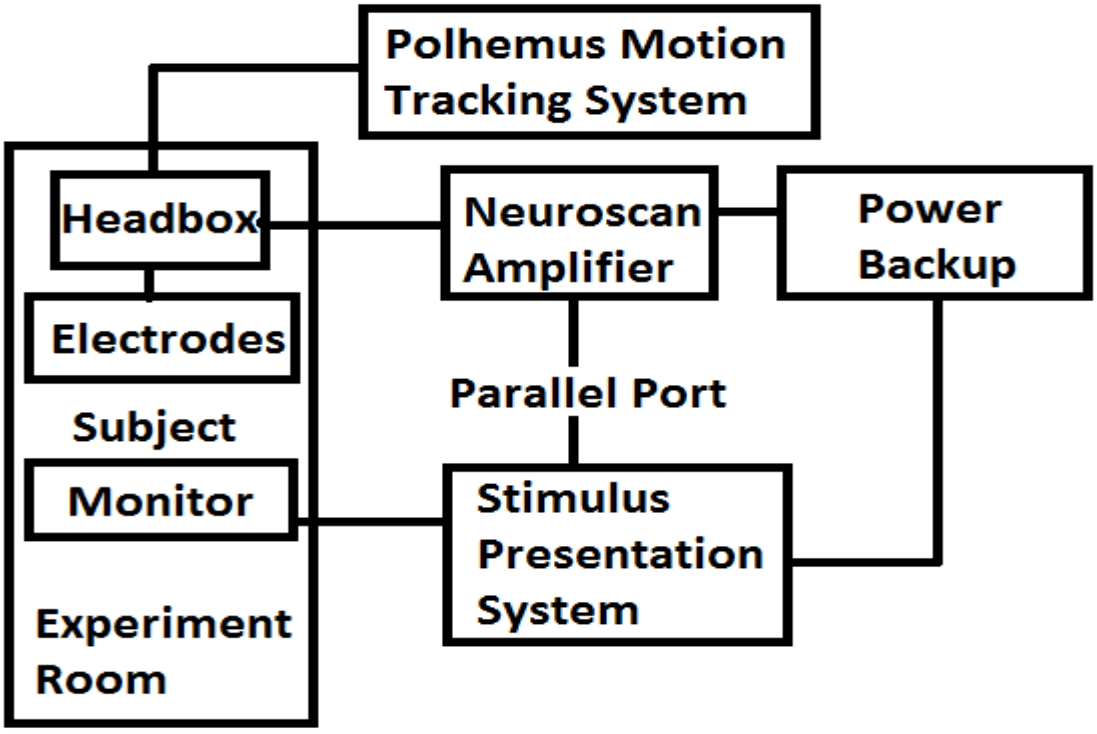

Fig 4.1

- Nasion
- CZ (left-hand side of the head)
- Inion (right-hand of the head)

The button was pressed to accept (2 beep sounds were heard). We repeated the above procedure and pressed the button once to accept and verify discrepancy.

A maximum discrepancy of less than 0.2 cm is ideal. If the discrepancy is greater than 0.3 cm, it is recommended that the procedure be redone.

Alternatively, half distance was measured from the inion to the nasion and from the left PA to the right PA and was correspondingly marked. The point of intersection from these points was marked as Cz.

4.1.2 Preparation:

1. Materials required during the experiment: Electrode Cap, Alcohol spray and sterile gauze, Hair brush, Tape measurer, Adhesive patches/plaster, Scissors, Nuprep Quikgel/EASY gel, Cups, Spoon, Syringes, Canula/needle, Gloves, Cotton swab, Alcohol swab / alcohol & cotton, Shampoo and towel (for subject's hair cleaning).

Fig 4.2

2. Some alcohol was applied on the subject's scalp as alcohol reduces impedances by dissolving the lipid barrier present on the scalp, and allows partially removing the

conditioner or gel if applied. Head of the subject was brushed thoroughly for 5 minute to striate the surface of the scalp, and allow a better current flow.

3. Preparing the abrasive and the conductive gel: EASYCAP gel (ABRALYT AgCl (1000g)), an abrasive electrolyte gel was taken in a container and mixed with alcohol.

4. For mounting the cap, first fiduciary points were marked on the subject's head. These are the landmarks above which the brain is most directly located underneath the scalp. They are:

    a. Nasion: the indentation between the forehead and the nose.

    b. Inion: the bony protuberance that can be felt as you run your finger up the back of the neck to the skull.

    c. Right and left periauricular point (RPA, LPA): the indentations just above the cartilage which covers the external ear opening.

5. In 1958, International Federation in Electroencephalography and Clinical Neurophysiology adopted standardization for electrode placement called 10-20 electrode placement system. This system standardized physical placement and designations of electrodes on the scalp. The head is divided into proportional distances from prominent skull landmarks (nasion, pre-auricular points, and Inion) to provide adequate coverage of all regions of the brain.

6. Nasion-Inion distance was measured with the tape measurer. The vertex was marked by dividing the distance between the two. Location of cap was standardized w.r.t. the fiduciary points. The cap was made symmetrical so that the vertex electrode is midway between LPA and RPA and that the sagittal lines appear properly aligned.

7. Some types of electrodes used are:

    i. Disposable (gel-less, and pre-gelled types)
    ii. Reusable disc electrodes (gold, silver, stainless steel or tin)
    iii. Headbands and electrode caps

8. Electrode cap was used in our experiment. The electrodes consisted of Ag-AgCl disks, 1 to 3 mm in diameter. AgCl electrodes can accurately record also very slow changes in potential. [24] There are various reference electrode placements mentioned in literature. Physical references can be chosen as vertex (Cz), linked-ears, linked-mastoids, ipsilateral-ear, contralateral-ear, C7 reference, bipolar references, and tip of the nose. Our reference electrode was present near the Cz electrode. We used 64 electrodes for recording. Electrodes for artifact removal such as one near mastoid bone and near the eyes were also present.

9. A small amount of gel prepared was taken in the syringe and ample circular movements with the tip of it were made in order to tear the hairs apart and striate the scalp's greasy layer. Each electrode was filled with equal quantities of gel, so that the conductive surfaces are identical, and so that all electrodes dry simultaneously.

10. If the electrical contact between the electrode and the scalp is insufficient, the ionic flow can be intermittent or absent and the recorded signal will be poor. By sending a minuscule current and collecting it back, Neuroscan checks the contact between electrodes and scalp.

11. We measure Electrode impedance via the Impedance command under the Acquisition menu as the electrodes are applied, or between recordings to verify acceptable resistance levels.

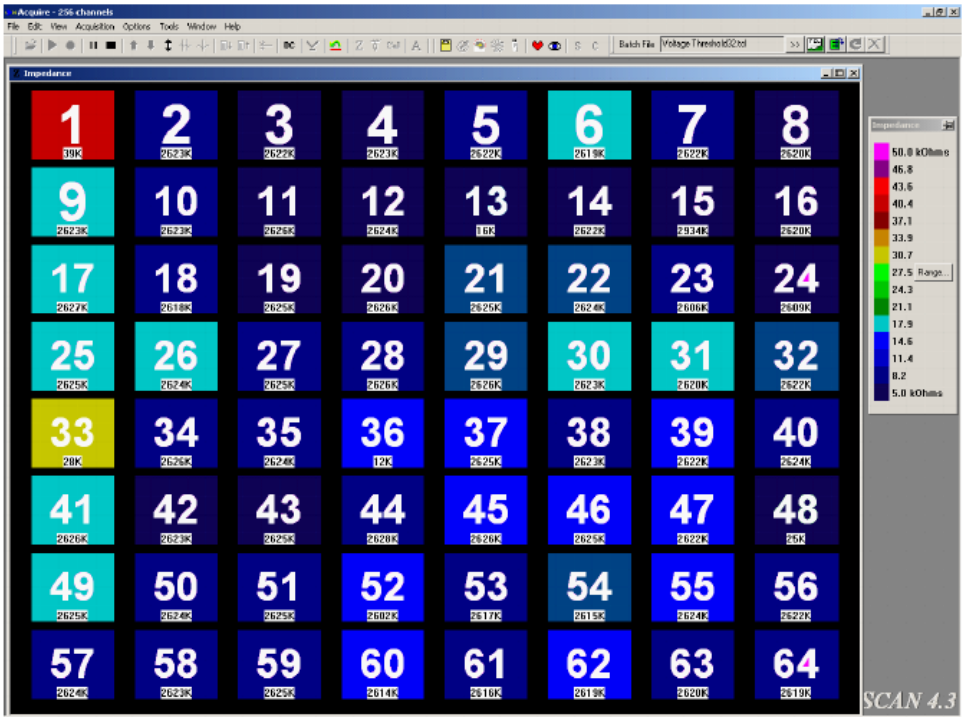

Fig 4.3

12. In order to prevent signal distortions impedances at each electrode contact with the scalp should all be below 5 K Ohms. If a couple of electrodes were shown in pink, circular movements and filling operations were repeated. When all the electrodes were low and matched, we were ready to start the recordings.

13. Some basic parameters are to be set before we start acquiring the signals. They include Amplifier settings, filter settings, Artifact rejection parameters etc.

- Amplifier Settings: Parameters like A/D rate, Acquisition type, Gain should be set. It can be done for individual channels also.

- Filter Settings: One of FIR or IIR filtering is to be selected. We can select the type of filter for individual channels: Low pass, High pass, Band pass or Band stop. We can also apply a 50Hz or 60Hz notch filter during acquisition.

- Artifact Rejection: We select this field to designate scan selected channels for artifact in the automatic artifact rejection of sweeps. The electrodes that monitor eye movement as well as those that pick up other sources of artifact were selected with this option. Also **Deblocking** feature enables reducing stimulus artifact.

CHAPTER 5

PREPROCESSING

Data was recorded as per the experimental guidelines. The obtained files were in *.cnt format. Following process was opted to preprocess raw EEG data and was implemented in MATLAB.

1. **Import** *.cnt file into EEGLAB toolbox using the import function. Update the metadata and file information.

2. **Re-referencing** of the data via toolbox**.** During the experiment, using neuroscan, we get the EEG data referenced to the linked mastoid electrodes M1 and M2. If raw data is not referenced, then we can re-reference the data according to the desired electrode channel(s).

3. Discard the undesired channels such as the EOG, EMG etc.

4. **Epoch** the data to trials, dividing into standard and oddball such that, there are 70 oddballs and 430 standards for each paradigm. We would obtain 500x64x70 and 500x64x430 matrices corresponding to numberoftrials x numberofchannels x numberoftrials.

5. Reject data by eye. The trials which are noisy should not be included for further processing.

6. **Detrending** of epoched data. Also known as baseline correction. In certain cases, the baseline for signals can shift due to artifacts during recording. This parameter is done to obtain all the data at a certain or 0 baseline so all the data can be compared to each other. This is done by subtracting each time point from its mean in each trial.

7. For **Filtering**, We can subject the signal to many kind of filters. The most used is a notch filter. eg: If we are interested only in the alpha component of the EEG signal, then we can adjust the cut off frequency accordingly. [14] Therefore, this step depends on the application as well. We used a low pass filter to remove the gamma component of the EEG, so as to focus more on the alpha component. Filtering is done using a customized bandpass filter. Function filtfilt was used to make the bandpass allowing low frequency from 0.2 Hz to high frequency of 45 Hz. The sampling frequency of the data was 1000 Hz throughout.

8. **Artifact Rejection** is done to remove the trials which are noisy or have huge fluctuations in the amplitude of the EEG signal, even after baseline correction and filtering. For noise such as eye blinks or head movements during recording, artifacts need to be dealt with. Mostly they are visible in the recording as very high or low fluctuations in the recording. The rejection can be a done by a statistical filter, which removes the undesirable peaks to give us noise free EEG data.

9. Averaging of the trials can be done so as to plot the EEG data of different paradigms. ERP analysis is conducted. So as to get a statistically sound EEG signal, we perform averaging which also eliminates the noise.

All the plots which are produced at this stage are given in the Observation section.

CHAPTER 6

SOURCE LOCALIZATION

6.1 Using sLoreta

Source Localization of P300 was initially done using sLoretta. The steps are as follows:

1. Provide the software with electrode configuration list (*.sxyz). It contains all the positions of the electrodes with coordinate positions in reference to the taken reference. The software allows data to be read in *.txt format.

2. Make a transformation matrix so as to map the processed EEG to the coordinates list. This transformation matric is based on the *.sxyz file and has an extension of *.spinv. The matrix helps in computing the amplitude of each EEG channel as per unit time to map it on a template brain.

3. Load EEG data from MATLAB. This needs to be done by converting data into a notepad file. The data is taken as epochs row wise and channels column wise. The software has the capability to recognize this kind of file.

4. Input the sampling rate at which the data can be represented. Also the offset can be provided if data is not processed with null offset or according to the experiment paradigm.

5. Multiple function exist in the software viewer such as scalp electrode monitor which gives a general view of our brain activation regions, slice viewer gives in depth view in different planes, EEG viewer provides a comprehensive view to all channels and their respective channels along with max and min amplitude and log operations. There exists a flexibility to go at any time point and the data on the other viewers get synchronized. For this project, these 3 form the main tools for view to study source localization.

6. To conduct T-test, we use statistic toolbox. The data before this needs to be converted to normalized form and equal number of time points or epochs need to be there for the 2

datasets. The averaged trials of oddball and averaged trials of standard are taken as the 2 datasets. This is done for each paradigm. The T-test confirms if the datasets are different from each other or not.

7. There are majorly 2 ways to localize, firstly the Independent Component Analysis and secondly we use the ERP mode on the software. The ERP mode is selected as it gives a good approximate method for our observations.

8. We specify number of electrodes and transformation matrix by loading the *.spinv and *.sxyz files. Check the box which conducts paired groups t-test A=B.

9. Load the 2 EEG datasets by simple drag and drop.

10. Next, we can choose options for if we require for a specific time frame or the whole interval. As we have localized the epochs, we choose the whole interval. (i.e. 500 msec or 500 time points).

11. Make the variance smoothing parameter to 0 and perform the test. The results are saved in a file. The result file can be opened on the viewer.

12. The EEG viewer shows whether the zero lag Ta Response is different than zero lag Pa Response. We observe a huge deflection which surpasses the 2 t-test threshold in all the paradigms, stating that all paradigms have the P300 present at the corresponding time (within 200 to 400 msec varying depending on paradigm). The error rate is minimal.

13. Since we obtain the answer of when both the datasets are different from each other, source localization is the next step. We figure out what brain regions are responsible for the significant difference found at the particular time point. Tests will be made on estimated standardized current density (i.e. standardized electric neuronal activity) obtained between the intervals specified.

14. Drag and drop the 2 datasets at the utility section of the software. This is done to make the *.sLor files which are used later. Load transformation matrix and convert all time frames. The *.sLor files are then obtained.

15. Use the statistic tool to test the sLor files. The procedure is more or less the same except that we are using sLor mode.

16. We conduct log of ratio of averages and randomized Statistical Non Parametric Mapping (SnPM) to obtain our results. The observations are shown and discussed in the next section.

6.2 Fieldtrip

Fieldtrip is an open source toolbox, which can be used in MATLAB and is developed by Donders Institute for Brain, Cognition and behavior at Nijmegen. The toolbox offers advanced analysis methods of MEG, EEG, and invasive electrophysiological data, such as time-frequency analysis, source reconstruction using dipoles, distributed sources and beamformers and non-parametric statistical testing. It supports the data formats of all major MEG systems (CTF, Elekta/Neuromag, 4D, Yokogawa) and of most popular EEG systems, and new formats can be added easily. FieldTrip contains high-level functions that you can use to construct your own analysis protocols in MATLAB. Furthermore, it easily allows developers to incorporate low-level algorithms for new EEG/MEG analysis methods.

There are variety of functions which are used in fieldtrip, ranging from importing data, preprocessing, spectral and timelock analysis to source localization. Each function have their parameters which can be set by listing the needful in the configuration or the [cfg] data structure. Fieldtrip stores the data and parameters in its own defined data structure. Fieldtrip also extends its flexibility to import or export data from various toolboxes and softwares such as EEGLAB, SPM etc, which is used in this project.

In this project, fieldtrip is used for source analysis. The mechanism of how fieldtrip executes this function is given under literature review. The flow diagram for source analysis can be given as:

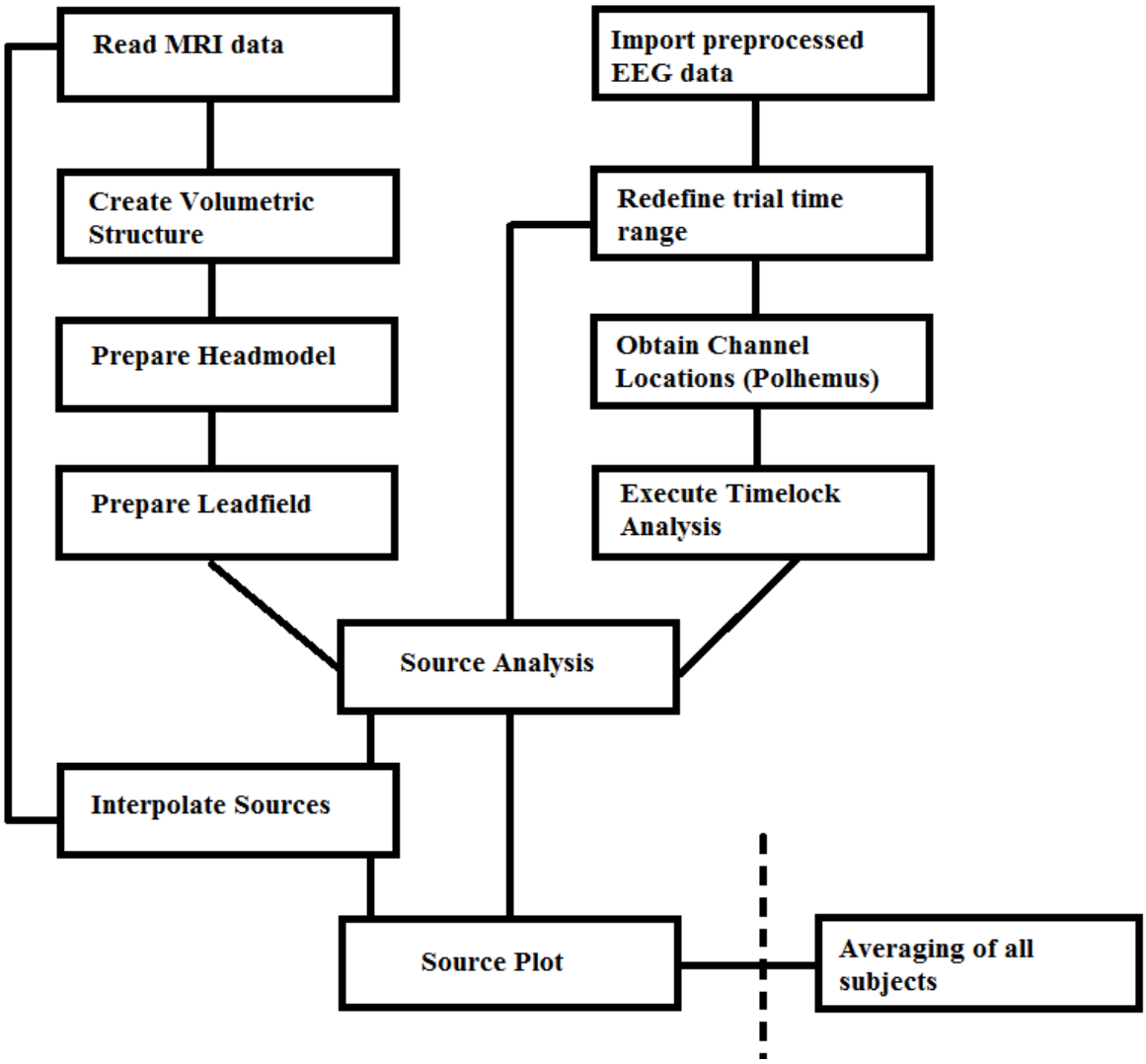

Fig 6.1: Process Flow of Source Localization (Fieldtrip)

6.2.1 Process

1. **Import preprocessed EEG data**: The data is preprocessed as per written in Chapter 5. To import the data into fieldtrip, we first import the data via EEGLAB. After defining the channel locations in EEGLAB using polhemus data, obtained using he 3D polhemus tracking system, the eeglab2fieldtrip function is used. This converts the data and the metadata into the data structure which is rendered usable to fieldtrip toolbox. For channel location in EEGLAB, the Boundary Element Model is selected, as that corresponds with the next analysis in fieldtrip and preparation of the leadfield (the forward process).

2. **Redefine Trial Time:** The trial time is defined to include the specific time points at which source localization needs to be done. The window should be as small as possible, but should include the peak or trough of interest. For P300 localization, a window of 100 msec was taken (mostly from 300 msec to 400 msec post stimuli). Thus, we can adjust the time axis (also changing data from stimulus locked to response locked/ temporal locked). The function used if ft_redefine trial containing the main parameters:

    - cfg.trials: Which trials are need to be selected for trimming
    - cfg.offset: For any offset added
    - cfg.begsample: The starting point of the shortened trial.
    - cfg.endsample: The end sample or point of the shortened trial.

3. **Obtain Channel Locations:** Channel locations can also be imported if not done the same in EEGLAB. The one used for the project is gui format as an input in cfg.method.

4. **Timelock Analysis:** The function used is ft_timelockanalysis(cfg,data) and conducts the timelock average of the ERPs. It also computes the covariance matrix. Parameters used are:

    - cfg.channel: Refers to the channel locations already executed.
    - cfg.trials: selection of all or specific trials
    - cfg.covariance: ‘no’ or ‘yes’ can be specified
    - cfg.vartrllength: if trials of different lengths exist, it needs to mentioned

5. **Obtain MRI:** T1 structural images of the subjects are obtained using fMRI and imported into the toolbox using ft_read_mri. The localization will finally will be interpolated to the T1 image. It is necessary to get individual T1 images because of different head shapes in the subjects. This is done to attain accurate sources, diminishing the error varying across different head shapes. Volumetric slices are taken by the toolbox, which is corregistered with head model prepared in the next step.

6. **Prepare leadfield:** As explained in the literature review, the model is prepared comprising of a head volume, sensor or electrode locations and head grid. Head volume is prepared by function ft_volumesegment(cfg, mri) by segmenting an anatomical MRI. A template can be selected manually or one can use the fieldtrip templates. Various parameters exist based on what part of brain needs to be concentrated upon. Eg: white, gray and csf or anatomy of the brain only etc. Sensor locations are fed into the toolbox using the desired function. Grid of voxels are created in the volumetric head model, dividing into multiple voxels using ft_sourcemodel. Each voxel is a source, thus the size of the voxel can be controlled via parameters, depending upon the need and accuracy required. All three are prepared to make the leadfield, which is compilation of all data under one data structure. This is our final head model with particular volume with respect to sensors.

7. **Source Analysis:** ft_sourceanalysis(cfg, timelockeddata) is used for source localization. It uses beamformer technique by performing dipole analysis on the timelocked EEG data. The parameters used are:

    - cfg.method: lcmv (linear constrained minimum variance beamformer
      dics (dynamic imaging of coherent sources)
      eloreta (exact low resolution electromagnetic tomography, used)
    - cfg.grid= output of ft_sourcemodel or ft_prepare_leadfield
    - cfg.channel= channels
    - cfg.elec= structure with electrode position, this can be in coordinate format pr a structure with gradiometer definition.
    - Many other parameters exist, but mainly the above written are used.

8. **Interpolate sources:** This refers to corregistration of the sources in the leadfield and the sources/ voxels in the MRI image of the subject. Both functional and anatomical data can be described as a volumetric 3D regular grid, a triangulated description of the cortical sheet or it can be a random cloud of points. The anatomical data obtained is interpolated with the functional data as the output data, such that the location correspond to the same section of the brain.

9. **Plot sources:** Sources are plotted as a source reconstruction data on slices or on a surface which can be an overlay of an anatomical MRI data. Functional and structural data are interpolated and can be directly, thus, plotted. Many different plotting option exist, such as slice, orthogonal slices, 3D brain surface (as in sLoreta) etc. This thesis shows only the orthogonal slices.

10. **Averaging by subject (to be carried out):** The whole process, that if from points 1 to 9, is iterated per different subjects. The sources of all subjects are imported to SPM12, another GUI toolbox which averages the sources based on different statistical algorithms.

CHAPTER 7

7.1 ERP Observations

Standard and deviant stimuli were epoched and averaged separately across all the subjects. The plots of the 2 kinds of stimuli were very different from each other. The ERP plots are shown in Fig 7.1. The

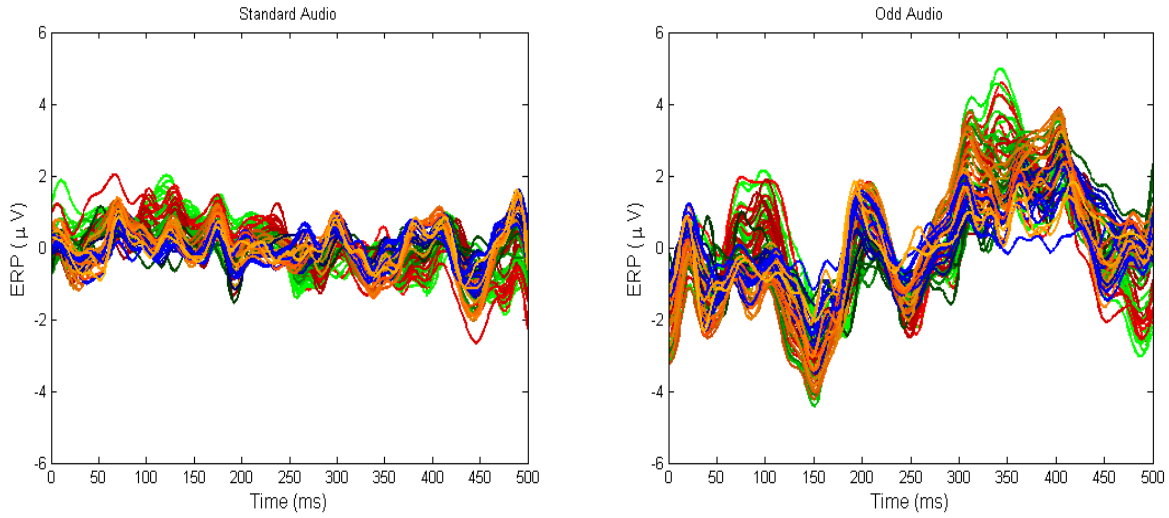

Fig 7.1(a): Audio standard (left) and deviant (right) ERP compared.

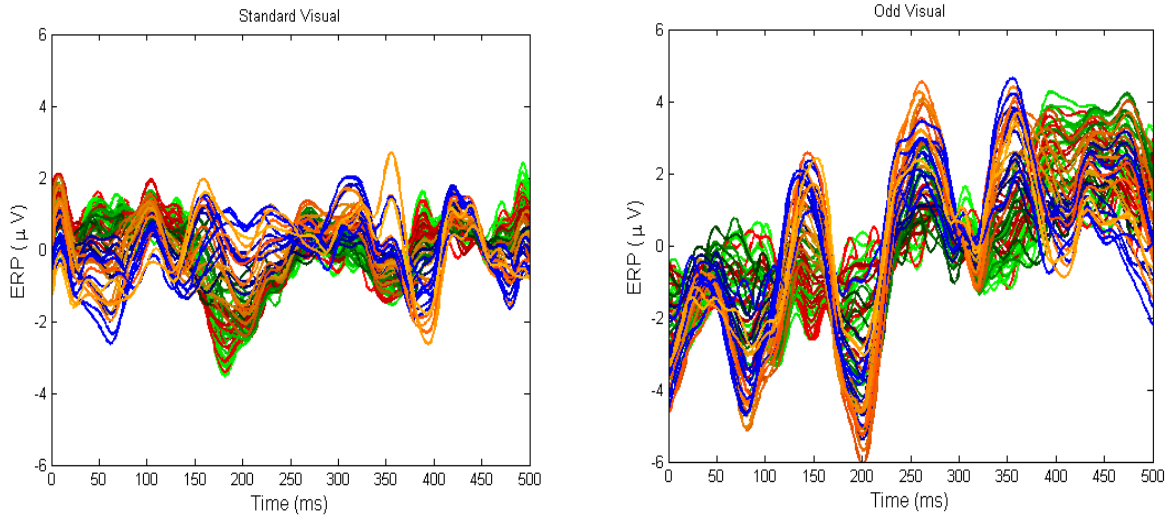

Fig 7.1(b): Visual standard (left) and deviant (right) ERP compared.

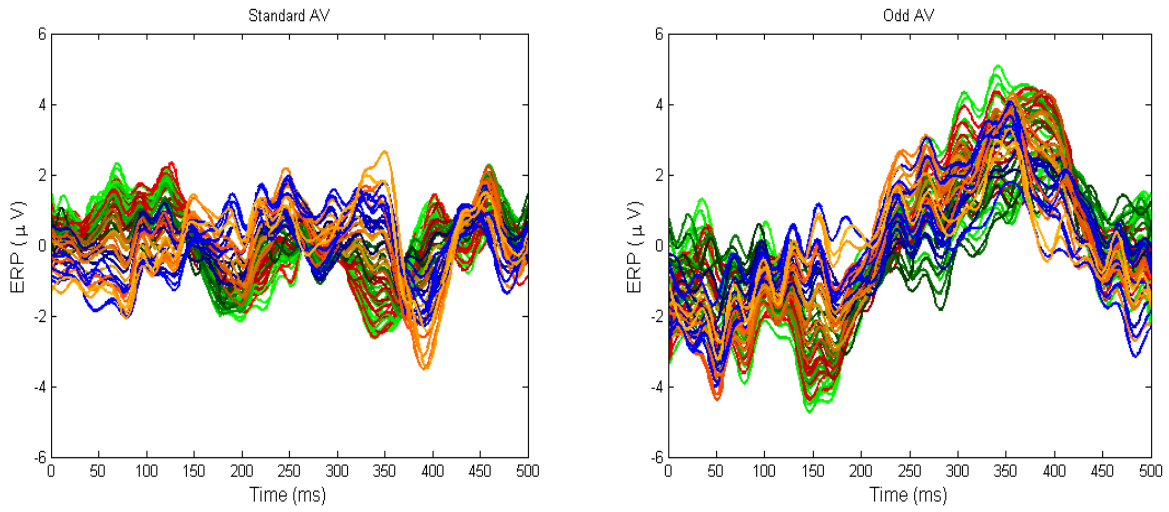

Fig 7.1(c): Audio-Visual standard (left) and deviant (right) ERP compared.

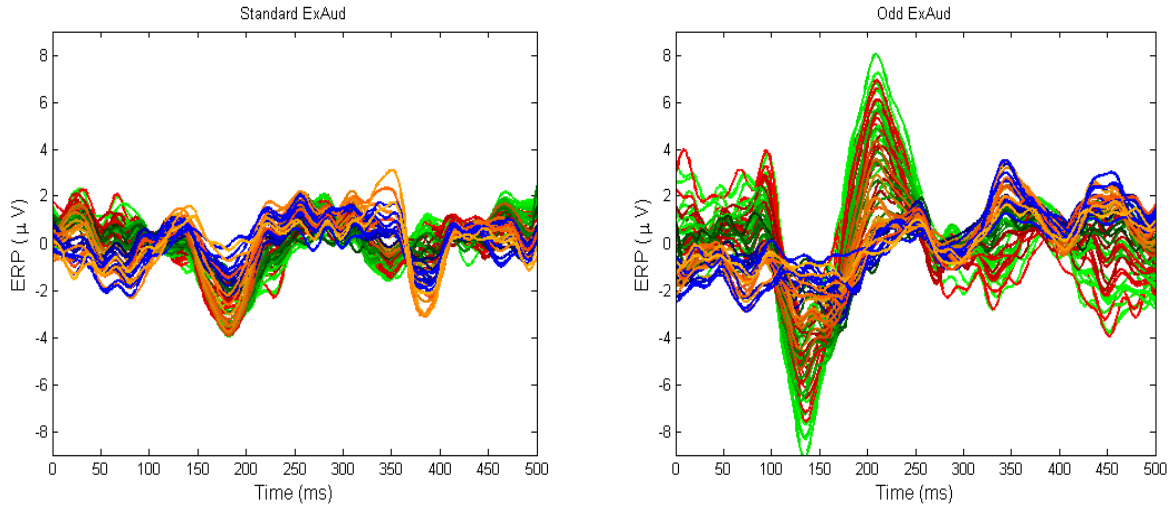

Fig 7.1(d): Audio oddball (left) on Visual standard (right) ERPs compared.

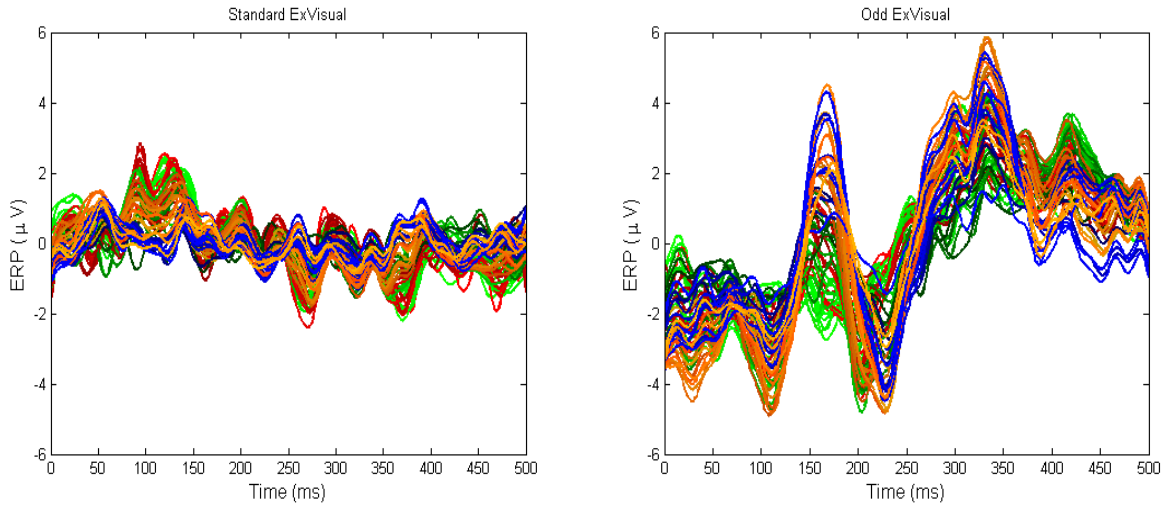

Fig 7.1(e): Visual Oddball (right) on Audio Standard (left) ERPs compared.

All the oddballs signify an N100, visual or auditory depending upon the task and P300 are present in all the paradigms. The properties of each are given in the following table.

P300 Paradigm	**Latency (peak)**	**Amplitude**
Audio	350 msec	5 µV
Visual	270 msec	4.8 µV
Audio-Visual	350 msec	5 µV
Audio oddball on Visual Standard	350 msec	3.8 µV
Visual Standard on Audio oddball	340 msec	6 µV

Table 7.1

N100 Paradigm	Latency (peak)	Amplitude
Audio	150 msec	-4.2 µV
Visual	80 msec	-5 µV
Audio-Visual	150 msec	-5 µV
Audio oddball on Visual Standard	180 msec	-8 µV
Visual Standard on Audio oddball	110 msec	-5 µV

Table 7.2

Comparing the P300 wave in different paradigms, the latency of each is similar in all the cases (approx. 350 msec) except in visual paradigm, where the P300 occurs earlier at 270 msec. This may indicate a different network for the presensory process in different modalities. The latency of audio and audio-visual are very similar and the same of visual and audio-visual are different.
The N100 represents the onset of the the presensory process. That also varies in all, except the audio and audio-visual paradigms. The P300 and N100 amplitudes both lie in the same duration stating that they both might have the same network.

EEGLAB is used to compute the scalp maps which are shown in Fig 7.2. Scalp maps identify the electrodes which scan the greatest amplitude. It doesn't tell about the sources, as any sensor can pick up any activity occurring in the brain. But, it provides an estimate of the source, in layman terms, where to look for the sources.

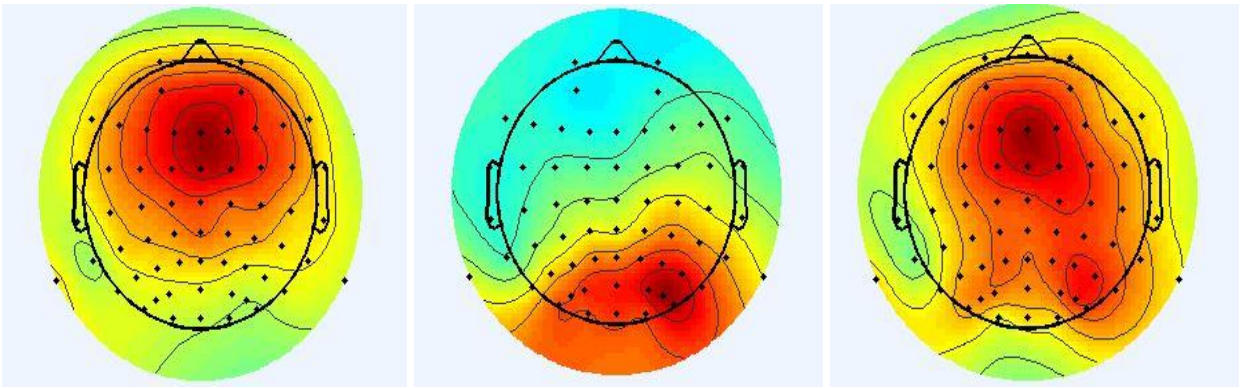

Fig 7.2(a): From left to right: Audio, Visual, Audio-Visual

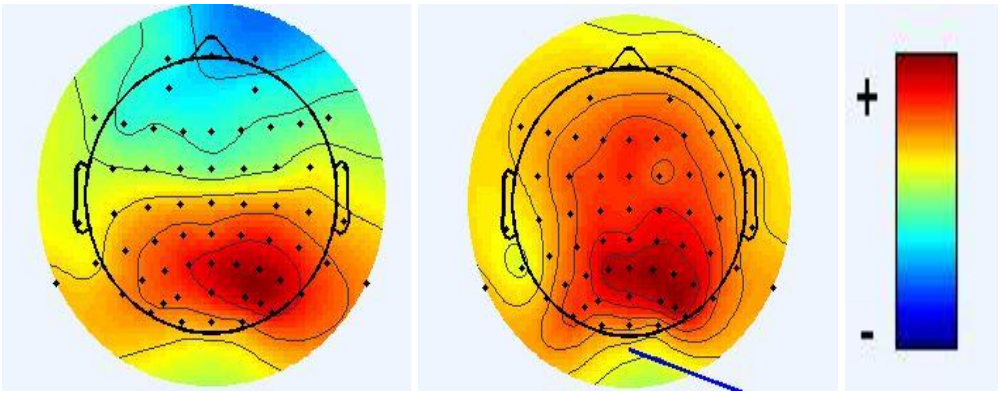

Fig 7.2(b): From left to right: Audio Oddball on Visual Standard, Visual Oddball On Audio Standard, range.

It is very clear that the peaks exhibiting as the P300 are sensed from different sensors in different modalities. Auditory P300 is focused at the frontal and parietal lobe, Visual P300 is focused at the occipital lobe in the right hemisphere and AV is very interestingly, from both the locations.

If we compare both the auditory modalities (one with auditory standard and one with visual standard), the red shade lies in different areas, suggesting that maybe the sources of an auditory P300 might be different varying in different sensory modalities. The Visual modalities show the same region, suggesting the sources might be same or close to each other.

The scalp maps suggest different sources for P300, but it can only be proven by source localization techniques. Apart from the regular plots, topoplots were also studied. It indicated noise in few channels which are removed. By including further more subjects in this research, the noise can be reduced by averaging.

7.2 Source Localization

Source Localization was conducted using the following methods. Explanation of source localization is given in Chapter 2: Literature Review and procedures of each is given in Chapter 6.

7.2.1 sLoreta

The observations as per the experiment are given in Fig 7.3

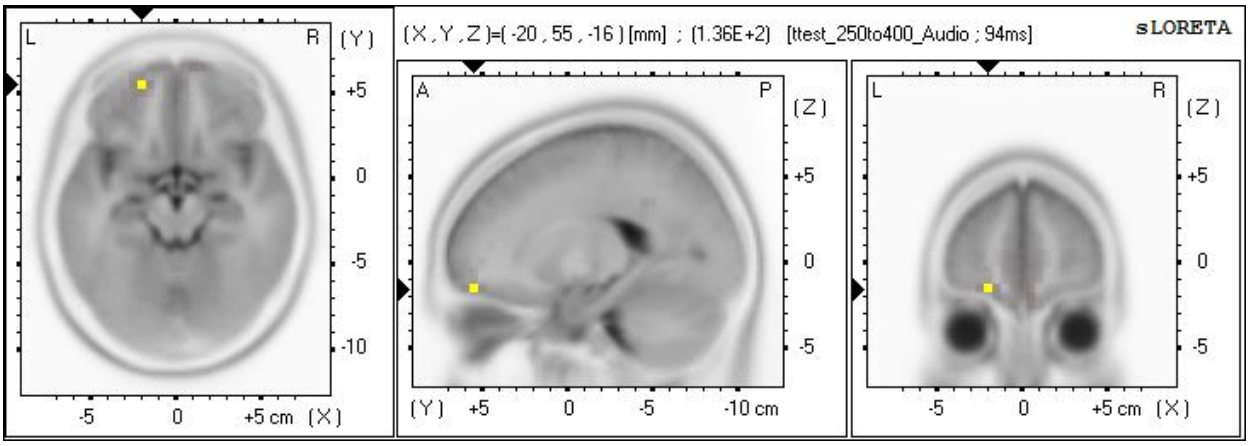

Fig 7.3(a): Auditory P300 Sources

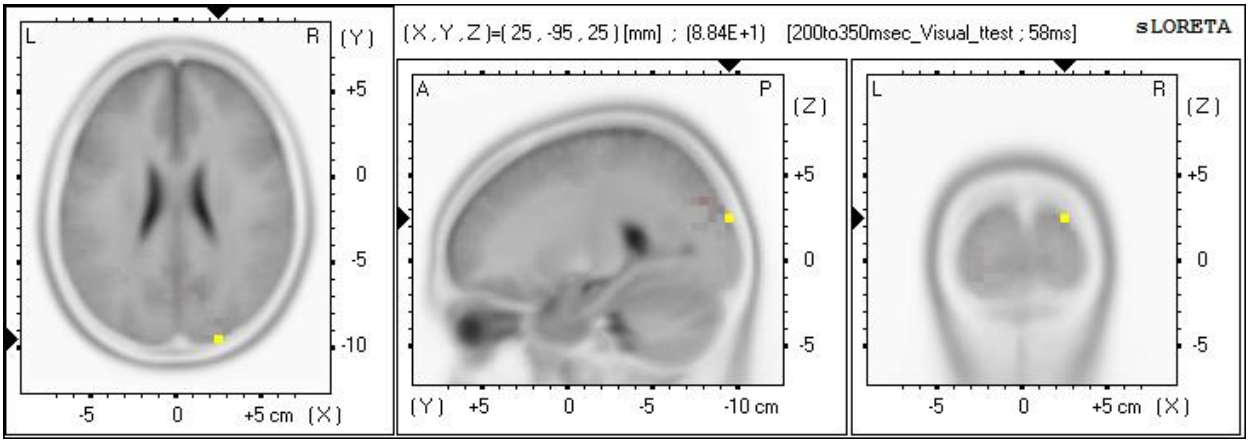

Fig 7.3(b): Visual P300 Sources

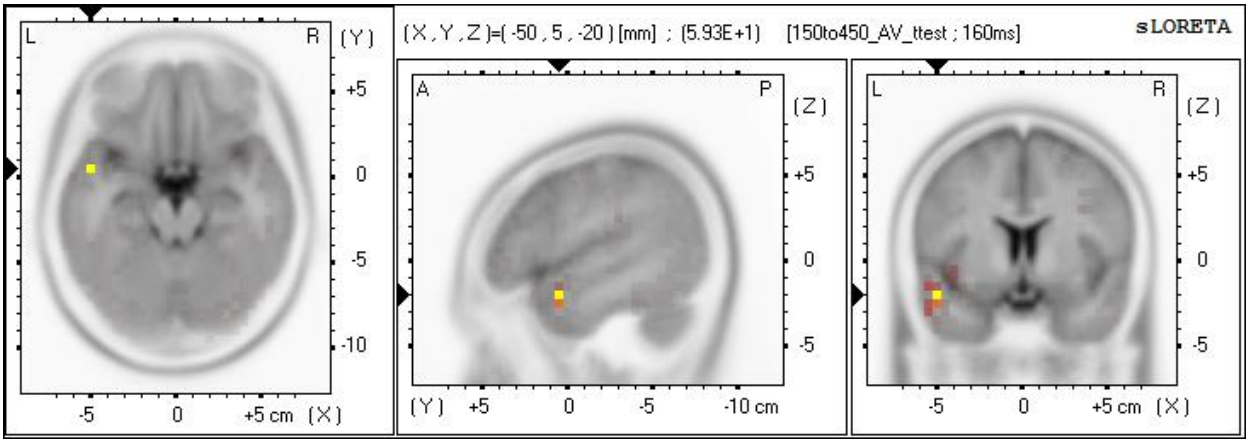

Fig 7.3(c): Audio-Visual P300 Sources

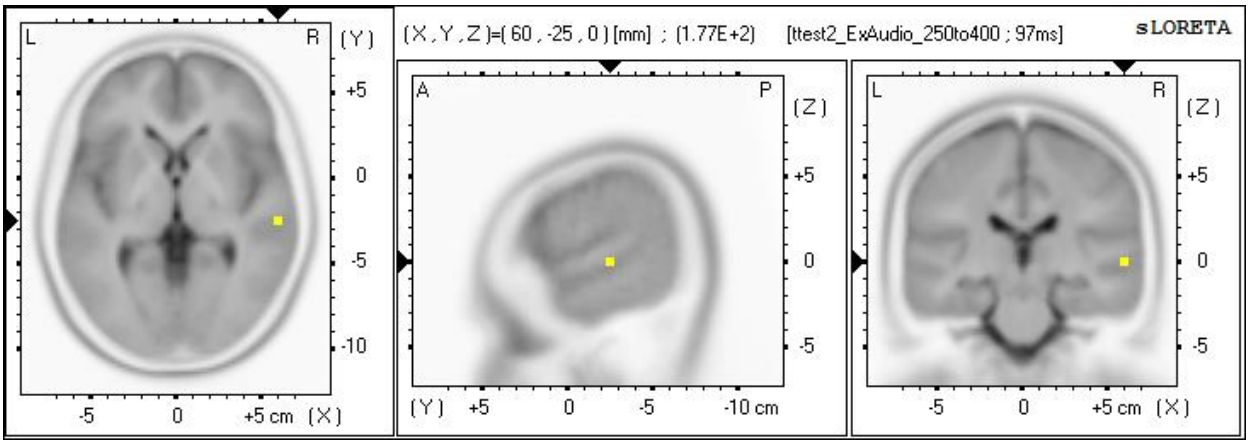

Fig 7.3(d): Auditory P300 Sources with Visual Standard

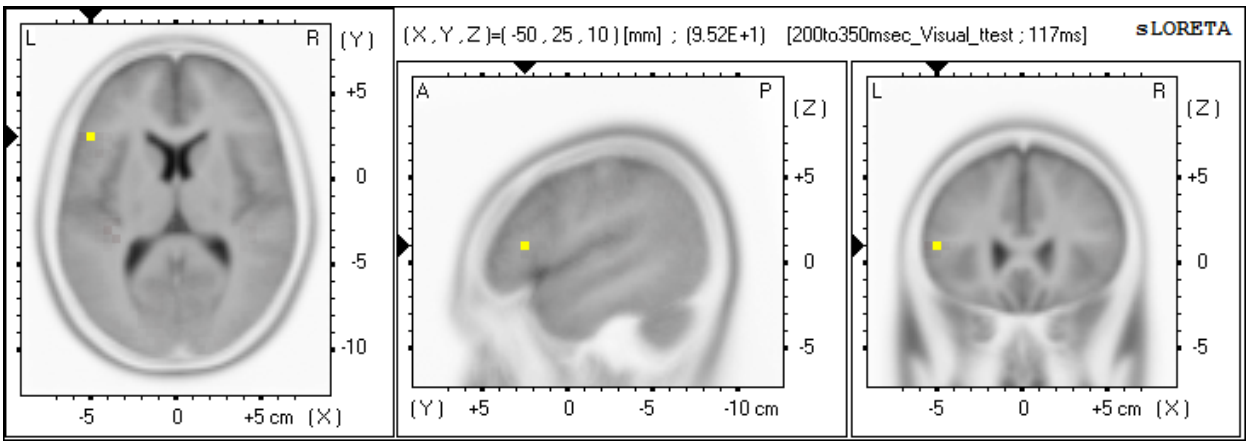

Fig 7.3(e): Visual P300 sources with Auditory Standard

7.2.2 Fieldtrip

The observations using fieldtrip are given as follows:

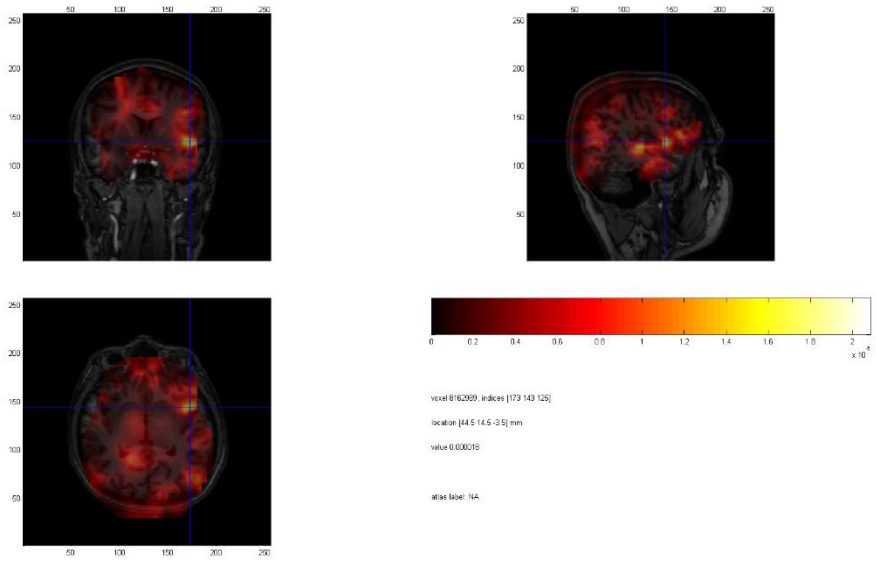

Fig 7.4(a): Auditory P300 sources

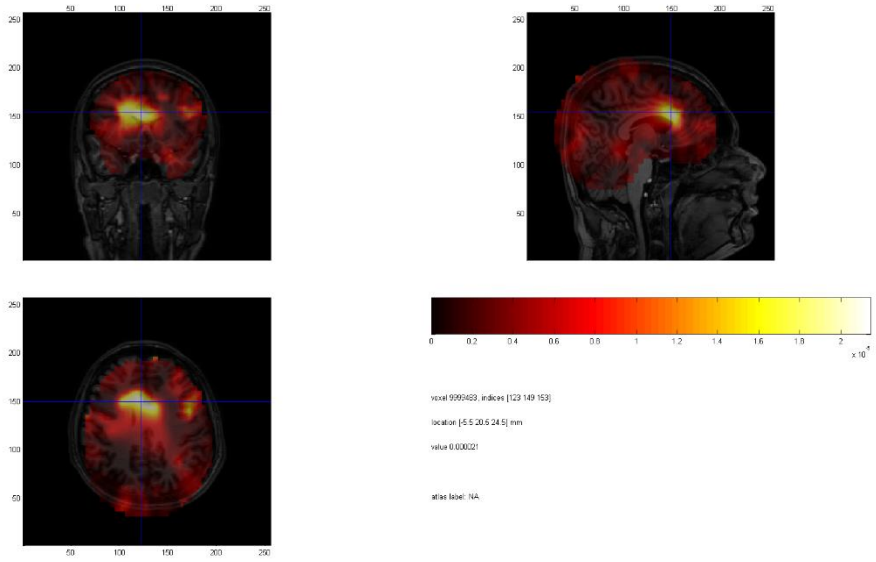

Fig 7.4(b): Visual P300 sources

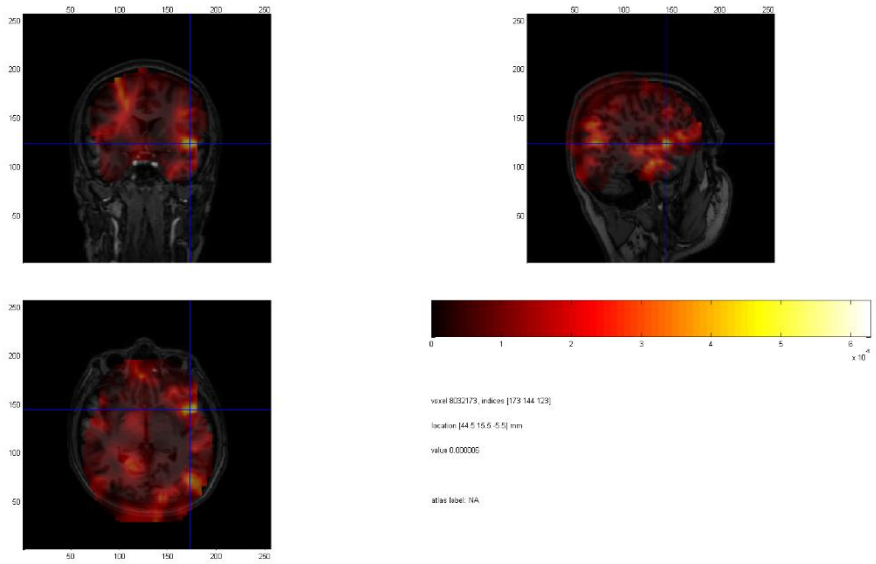

Fig 7.4(c): Audio-Visual P300 sources

The sources are formulated in the table below:

Paradigm	**Loreta**	**Fieldtrip**
Pure Audio	Frontal lobe, LH	Temporal lobe, RH
Pure Visual	Occipital lobe, RH	Frontal Gyrus, LH
Audio-Visual	Temporal lobe, LH	Temporal lobe, LH
Audio oddball on Visual Standard	Temporal lobe, RH	
Visual oddball on Audio Standard	Frontal/Occipital lobe, LH	

Table 7.3: Comparison of Sources

Although more subjects are required to validate the results, these results give us an idea where to locate sources. Loreta and Fieldtrip, both have given different results, but the probability of multiple sources also exist due to dipole factor [19]. With more subjects, the probability of finding similar sources using both techniques will increase. Also, the noise seen as such in visual P300 source of the fieldtrip plot will also reduce with more EEG data.

CHAPTER 8

FUTURE WORK

As per the observations it is clear that more data is required to validate the results. Although, the observations have given a decent picture, it is better to include more subjects in the project. With more subjects, the accuracy will also be bound to increase so we can pin point the regions responsible for elicitation of P300.

Other parameters in fieldtrip are also required to be studied in depth, for obtaining best results. Once the sources are obtained, coherence tests between different regions with the brain responsible for the presensory network can be studied. Sources of N100 can also widen the scope of finding the network.

Other paradigms, such as the McGurks effect being an illusory effect on the subject, is also said to elicit the P300. Comparison of networks in various sensory modalities will also widen the results and give an accurate working of the network.

Sources of P300 can also help in optimizing the number of channels to be used, so as to cover the region of the scalp corresponding to the source well enough to acquire the signal. This can revolutionize the BCI sector as new headsets with better ergonomics and comfort can be made for different applications.

REFERENCES

(As per their appearance in the chapters)

[1] Walsh, P., Kane, N., & Butler. (2005). The clinical role of evoked potentials. Journal of Neurology, Neurosurgery, and Psychiatry, 76 Suppl 2(Suppl II), ii16–22. doi:10.1136/jnnp.2005.068130

[2] Hauk, O. (2014). Introduction to EEG and MEG Basics of EEG and MEG: Physiology and data analysis, 1–11.

[3] H.H. Jasper. 1958. The ten-twenty electrode system of the International Federation; Electroencephalography and Clinical Neurophysiology, 371-375.

[4] Baillet, S., Mosher, J. C., & Leahy, R. M. (2001). Electromagnetic Brain Mapping using MEG & EEG, (November)

[5] Barnett MW, Larkman PM (June 2007). 'The action potential'; Practical Neurology 7 (3): 192–7. PMID 17515599.

[6] ADRIAN,E.D.(1936);J.Pysiol.88,127-161.)

[7] Nunez PL (1981): Electric Fields of the Brain: The Neurophysics of EEG, 484 pp. Oxford University Press, New York.

[8] P. Gloor, Neuronal generators and the problem of localization in electroencephalography: Application of volume conductor theory to electroencephalography; J. Clin. Neurophysiology vol. 2,pp. 327-354, 1985.

[9] Mosher, J. C., Leahy, R. M., & Lewis, P. S. (1999). EEG and MEG: forward solutions for inverse methods. IEEE Transactions on Bio-Medical Engineering, 46(3), 245–259

[10] Whittingstall, K., Stroink, G., Gates, L., Connolly, J. F., & Finley, A. (2003). Effects of dipole position, orientation and noise on the accuracy of EEG source localization. Biomedical Engineering Online, 2, 14.

[11] Matti S. Hamalinen AND Jukka Sarvas: Realistic Conductivity Geometry Model of the Human Head for Interpretation of Neuromagnetic Data: IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING. VOL. 36. NO. 2, FEBRUARY 1989

[12] J. de Munck, The potential distribution in a layered spheroidal volume conductor; J. Appl. Phys., vol. 64, pp. 464-470, 1988

[13] J. Ashburner and K. Friston. Multimodal image coregistration and partitioning- a unified framework.; Neuroimage, 6, pp. 209–217, 1997.

[14] R. B. Dubey and A. Pathak, Digital Analysis of Brain EEG Signals.

[15] Birgitta Berglund Measurement with Persons: Theory, Methods, and Implementation Areas, , Chapter 14, Page no 307.

[16] S. Murakami and Y. Okada. Contributions of principal neocortical neurons tomagnetoencephalography and electroencephalography signals.; The Journal of Physiology, 575(3):925{936, 2006}

[17] Saeid Sanei Adaptive Processing of Brain Signals; Chapter 1, Page 12.

[18] Banerjee et al: Spatiotemporal re-organization of large-scale neural assemblies underlies bimanual coordination. NeuroImage 62 (2012) 1582–1592

[19] YNiC Documentation and Guides, York NeuroImaging Centre, University of York; Chapter 7. Scanning: Experimental Procedures.

[20] J. D. Bronzino. 1995. Principles of Electroencephalography. In: J.D. Bronzino Ed. The Biomedical Engineering Handbook, pp. 201-212, CRC Press, Florida.

[21] M. Teplan FUNDAMENTALS OF EEG MEASUREMENT, MEASUREMENT SCIENCE REVIEW, Volume 2, Section 2, 2002(Teplan, 2002)

[22] Acquire 4.5 Manual by Neuroscan(Online Acquisition of Neurophysiological Data)

[23] EEGLAB Wiki, The EEGLAB Tutorial Outline by Arnaud Delorme, and Scott Makeig

[24] Fieldtrip Wiki Page

Appendix

ERP Plots

1. Plots taken from the ‘z’ line of the headcap showing P300 at a latency of 200 to 400msec latency. Order from top to bottom: FPz, Cz, Pz, POz, Oz.

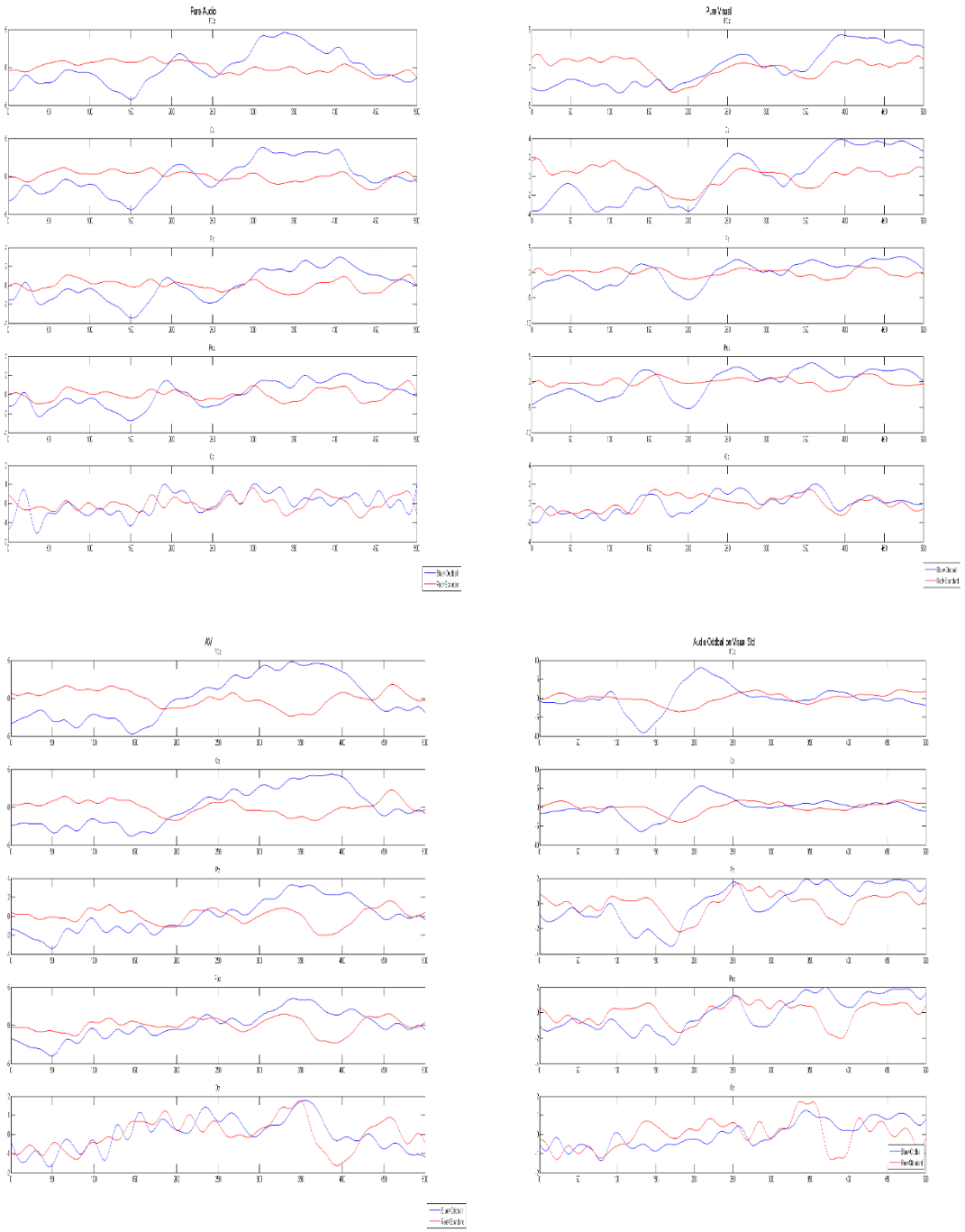

Fig 10.1(a): Left Top: Pure Audio, Right Top: Pure Visual, Left Bottom: AV, Right Bottom: Audio Oddball on Visual Standard

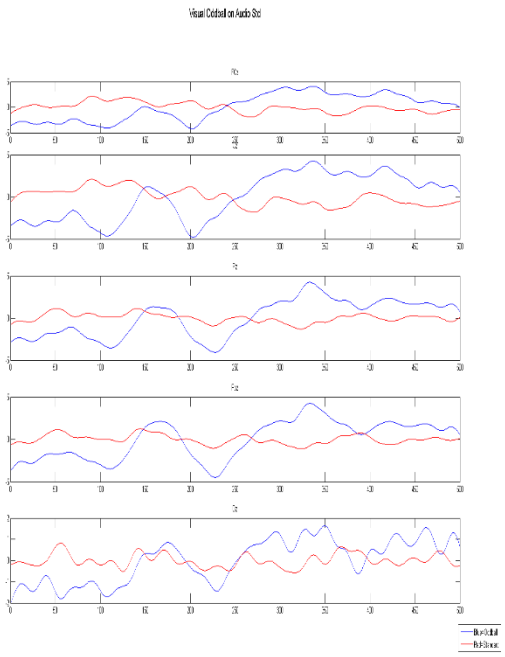

Fig 10.1(b) Visual Oddball on Audio Standard

2. Topoplots:

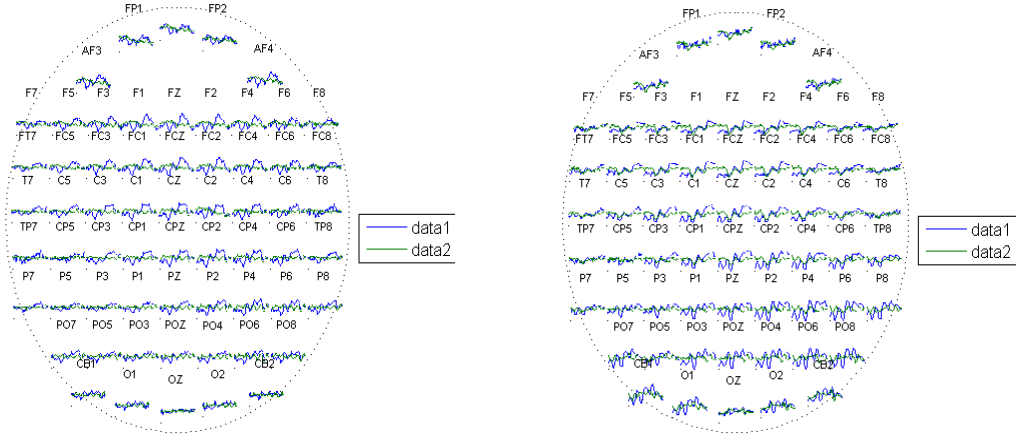

Fig 10.2(a): Pure Audio and Pure Visual Topoplots

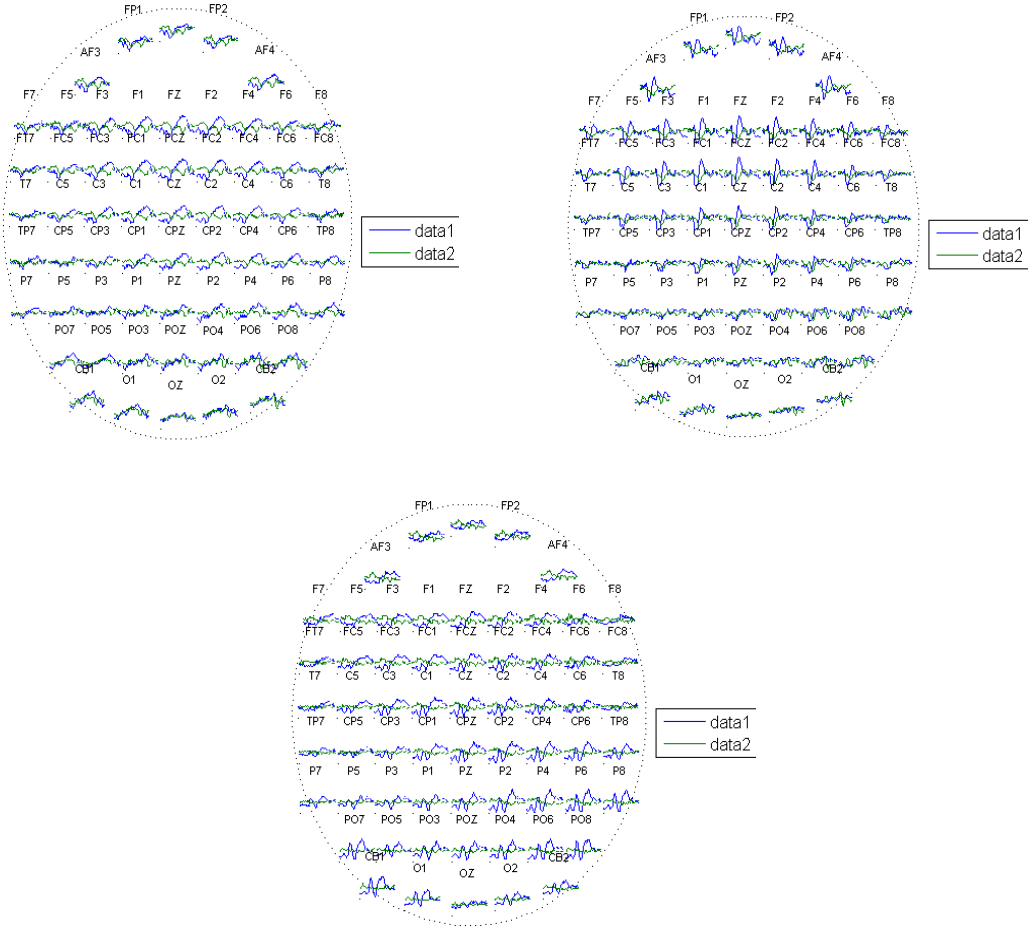

Fig 10.2(b): AV, Audio On Visual Standard, Visual on Audio Standard