EEG-fMRI Combination for Better Understanding of Brain Functions: Pros and Cons

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***Abstract*— Multimodal neuroimaging techniques have shown better understanding of human brain functions and dysfunctions as compared to the standalone modality. EEG and fMRI are widely used in neuroscience community. EEG signals recorded at scalp have high temporal resolution and poor spatial resolution due to limited number of electrodes. Functional Magnetic Resonance Imaging (fMRI) has a very high spatial resolution and low temporal resolution due to slow scanning. The complementary nature of EEG and fMRI can be combined to get high temporal and spatial resolution at the same time. Simultaneous EEG-fMRI imaging can help researchers to develop better understanding of brain mechanism and functionality. Simultaneous EEG-fMRI can be used for assessment of person's cognitive abilities which include working memory, attention and learning process as well as in diseases like schizophrenia, epilepsy, etc. However, simultaneous EEG-fMRI brings many challenges in terms of data acquisition and data quality point of view. In this paper, we have addressed the main issues involved during simultaneous EEG-fMRI data recording. Further, pros and cons of combined EEG-fMRI are discussed.**

***Keywords*—EEG; fMRI; Simultaneous EEG-fMRI; Multimodal neuroimaging**

I. Introduction

Neuroimaging modalities like electroencephalography (EEG), magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), etc. are widely used in many research areas which include engineering sciences, psychology and neuroscience. In cognitive neuroscience, an increase trend has been seen in simultaneous EEG–fMRI studies in order to obtain better insight of brain functionalities, e.g., functional connectivity. The neuronal activity occurring inside the human brain generates the electromagnetic signals and hemodynamic response changes, i.e. blood oxygenation level dependent (BOLD) signal. All the neuroimaging methods are relying on these brain dynamics inside the brain. EEG measures the neural activity from the scalp potentials and MEG is based on magnetic fields recorded through dense arrays of sensors [7]. EEG and MEG produce the high temporal resolution in order of milliseconds. Both are capable of measuring fast changes of neuro-physiologic process. EEG/MEG provides poor spatial resolution. It encouraged the investigators to go towards the multimodal neuroimaging in order to combine the strengths of the other techniques. fMRI and PET are functional neuroimaging techniques. Both measures the secondary effect instead of measuring the neural electric activity directly as EEG/MEG does. EEG-fMRI data for cognitive tasks indicate much more plausible results to achieve spatiotemporal mapping of event related responses in the human brain.

Each Electroencephalogram (EEG) and functional Magnetic Response Imaging (fMRI) has its own advantages and constraints [1]. Both modalities are complementary to each other. Instead of using each modality separately, a combined data analysis can give much better results to address different aspects of human brain structure and functionality [2]. This multimodal combination can give better information which provides new understanding for early detection of brain diseases and also better treatments to the patients. Diseases like brain tumor (BT) which causes major effect on patients with memory deficits [3]. It also has effects on brain structure, its functions and functional connectivity.

EEG has very high temporal resolution, i.e., in milliseconds but having poor spatial resolution because of the volume conductance and ill pose problem. It has very low resolution in order of centimeters [4]. On the other hand functional MRI gives very high spatial resolution but has a poor time resolution. fMRI measures the vascular responses mostly based on blood oxygenation level dependent (BOLD) which depends on the oxygen intake referring to the neuronal activity occurred. This BOLD response has very low temporal resolutions, i.e. in seconds [5]. fMRI covers whole brain and has very high spatial resolution, i.e. in millimeters. The BOLD response is delayed and indirect measure of neuronal activity in human brain. The researchers are working to find better relationship between BOLD response and neural activity. Also to capitalize the complementary characteristics of EEG and fMRI BOLD response in the investigation of brain dynamics. This leads the researchers towards multimodal analysis based upon simultaneous measurement of both modalities.

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In this paper, we have presented the combination of EEG and fMRI data acquisition. It also discusses the artifacts induced during the simultaneous EEG-fMRI recording and methods to rectify it. Section II describes the simultaneous EEG-fMRI setup, experimental paradigm considerations and Pros/Cons of combined EEG-fMRI data. Section III we presented some preliminary results and section IV ends with conclusion.

II. SIMULTANEOUS EEG-FMRI

A. Data Acquisition Setup

Many technical challenges are involved to combine the EEG and fMRI. The major problem is due to the physical phenomenon of electromagnetic induction which states that when any conductor is place inside the changing magnetic field, there is emergence of electromotive force in conductor. This induced electromotive force is directly proportional to the cross section area of the loop wire and rate of change of magnetic field, according to Lenz's law [2]. Based on these physical phenomena, it is not recommendable to place the conducting EEG electrodes inside the MR scanner where the magnetic fields are changing with respect to time [6].

To develop simultaneous EEG-fMRI setup, the first instrument required is to have MR compatible EEG equipment. Normal EEG equipment cannot be used inside the MRI scanner as due to higher magnetic fields i.e., 3T, 7T or even now a days 9.4T scanner available. The normal EEG electrodes cannot use inside the scanner as they are made from ferromagnetic material. Silver or gold is non-magnetic material which can be used inside high magnetic fields and are not attracted by the magnetic fields [7]. Therefore, the cost of these kinds of electrodes and caps would be higher as compared to the normal EEG equipment. Also we cannot put the normal EEG amplifier inside the MRI room as MR compatible amplifier which is normally shielded is required.

Fig. 1. 128 channel EEG and 3.0 Tesla Philips fMRI scanner experimental setup

Fig.1 shows simultaneous EEG-fMRI setup. We developed this setup and utilized 128 Channels EEG equipment (EGI Systems, USA) compatible with 3.0 T Philips fMRI.

B. Paradigm Consideration

Experimental design for simultaneous EEG-fMRI is complex in term of data acquisition perspective and type of experiment which should be presented to the participant to capture the neuronal activity. EEG signal has fast dynamics as compared to the fMRI signal which is the delayed response after neuronal activity inside the human brain. The ability of fMRI signal to capture theses changes in brain induced by a particular task over span of time is very important [8]. The main important concern is the efficiency of post experiment statistical analysis which relies on the experimental paradigm. Hence, it is mandatory to consider all the parameters before designing the experimental paradigm. Currently, two types of experimental paradigms are followed; one is called block designs and second one is the event related designs [9]. In block design, experimental conditions/tasks are separated into repetitive intervals of time or in blocks. Each block consist of two parts; either a task or rest condition. Fig. 2 shows the block design experimental paradigm. The increase of length of each block leads towards the higher evoked response during the specific task. In event related design, the stimulus is presented in term of discrete events. The timing of these events is randomized. Fig.3 shows the event related experimental paradigm. The advantages of the event related design are that they can differentiate the different conditions effects. Also it avoids habituation and boredom for participants which is another advantage.

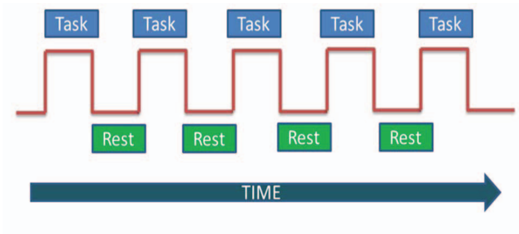

Fig. 2. Block design experiment paradigm

The decision to choose block and event related experimental design depends upon the task and comparison between different conditions of interest. Other parameters are; fMRI signal capability to follow the changes induced during task, shape of BOLD response, noise in the data acquisition setup, etc. [10]. We have designed block design experiment for our simultaneous EEG-fMRI recording. Different pictures like animals, building and human faces are shown to the participant. Each task or stimulus remains for 2 seconds and then 2 seconds fixations. The rest period is 15 seconds in between two tasks.

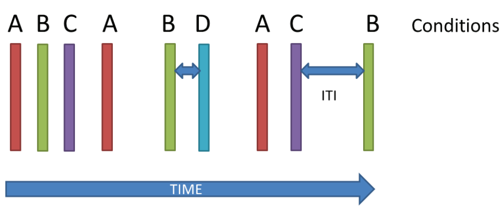

Fig. 3. Event Related Design

EEG data is recorded with 128 Channel with sampling rate of 250 Hz and fMRI data in DICOM format is recorded from 3T Philips fMRI scanner

C. Pros: Common Neuronal Process

The major advantage of acquiring EEG and fMRI data simultaneously is that the two data types i.e., EEG and fMRI reflects the same neuronal processes occurring inside the human brain. Simultaneous data acquisition ensures that human subjects used the same strategy for both kinds of data types. It is important for tasks which involves complex cognitive processing e.g., localization epileptic zone. There are other important clinical applications in which simultaneous EEG-fMRI is critical, particularly those cases in which symptoms can changed over short durations e.g., some patients with schizophrenia have problems to distinguish self-generated from externally generated percept during hallucination which can wax and wane unpredictably [11]. Further, simultaneous EEG-fMRI can be used in resting states as well as brain dynamics underlies intrinsically in EEG rhythms. Recent studies using simultaneous EEG-fMRI are: investigating the functional connectivity, study on different brain rhythms [12] , Evoked Potentials either auditory or visual and epileptic source localization.

D. Cons: Artifacts

During the normal EEG data recording, the standards EEG artifacts like eye blinking, eye movement etc. are present in the EEG but for simultaneous EEG-fMRI data acquisition, EEG signals are contaminated with large repetitive artifacts generated due to switched magnetic field gradients [19, 20]. Normally gradient artifacts and Ballistocardiographic (BCG) artifacts are also present in the recorded raw EEG as shown in Fig.4.

The most challenging artifact to remove is Ballistocardiogram artifacts commonly known called BCG artifacts. The removal is difficult as it is originated from physiological activities occurring inside the human body. BCG artifacts are induced in EEG due to cardiac-related activities. This artifact generally produced due to the electrode movement of pulsatile scalp and blood movement in cardiac cycle. This artifact is induced due to electrode movement and conductive blood (due to ferromagnetic nature) in the magnetic field of fMRI scanner [13, 14]. The magnitude of BCG artifacts is very large as compared to the normal EEG signals. Many methods for BCG artifact removal were developed by the researcher and mostly are based on ICA and PCA. We have removed the BCG artifact using the Optimal Basis Set (OBS) method [14]

III. RESULTS

A. EEG Data Processing

Gradient artifacts is removed by subtracting the mean artifact through all the functional volume acquisition. For standard artifact removal, we used digital filters, e.g., 0.5 Hz high pass filter was used to remove the DC component present in the EEG signals. After that a notch filter of 50 Hz is used to remove electrical noise. At the end a low pass filter of 40 Hz is applied on EEG data to remove the high frequency artifacts which are not associated with the neurophysiological process. All these filters are applied together to avoid the phase and magnitude distortion induced by the phase delay of the filters.

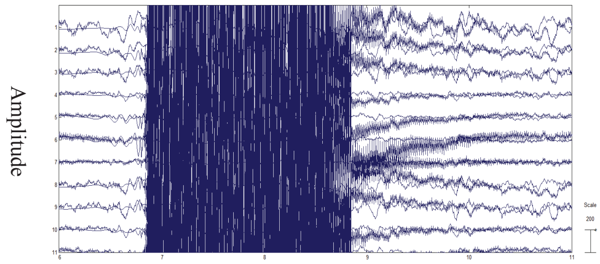

Fig. 4. EEG with Gradient and BCG Artifacts

Fig. 5 shows the raw/contaminated EEG with the clean EEG after removing BCG as well as other artifacts. The clean EEG has less magnitude as compared to the contaminated EEG with artifacts.

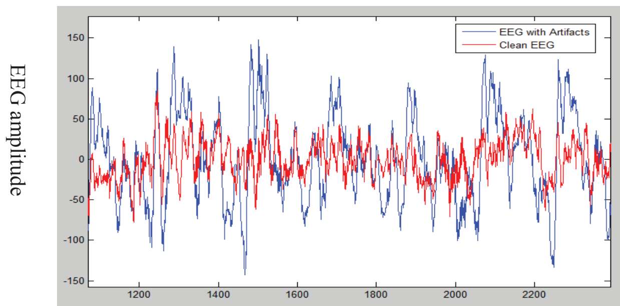

Fig. 5. Clean and Contaminated EEG

B. fMRI Data Processing

Functional MRI data are in the form DICOM format images recorded from 3.0T Philips MRI system. The first step after getting data is to analyze it using preprocessing which consist of slice time correction, Motion correction, Co registration, Normalization and spatial smoothing. The quality of the results depends upon the preprocessing block. To get the good results, preprocessing should be done carefully. The predicted fMRI signal can be calculated by convolving the stimulus onset with the hemodynamic response function (HRF) *h(t)* as given by the following equation.

$$x(t) = stimulus(t) * h(t) \qquad (1)$$

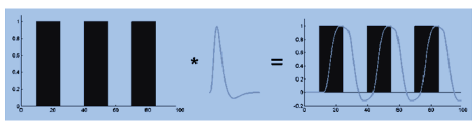

Fig. 6. Convolution of Stimulus function with HRF [8]

Fig. 6 shows how the block design time onset is convolved with the HRF. To further process this data and to get the localization of brain activated area; first the data is preprocess in terms of slice timing correction, after that due to subject head movement , Motion correction is performed. After that, the structural MRI data recorded is co register with the functional MRI data. For group analysis, it is recommended to do normalization. This was done using Montreal neuroimaging (MNI) template. Spatial smoothing improves the quality of voxels in terms of any discrepancy produced after normalization. The functional images are then smoothed with full width half maximum (FWHM) Gaussian kernel of 6mm. Fig. 7 Shows how the data is processed to get the activated brain region.

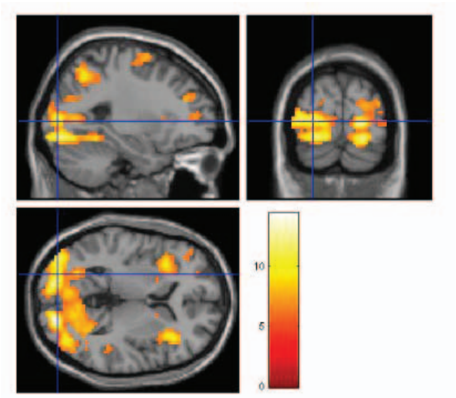

Fig. 7. fMRI data after processing

IV. Conclusion

Simultaneous EEG-fMRI study can provide us better understanding of brain functions/dysfunctions and areas affected in case of any neurological disease due to common neuronal source activities captured by the both modalities at the same time. However, this combination brings challenges in terms of data quality specifically in the case of EEG data. Gradient and BCG artifacts are induced in EEG data. These can be removed by using specialized methods and using optimized filtering. Data fusion can also be performed on EEG-fMRI data to get better information and insights of the human brain.

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