**Pakistan Journal of Engineering and Technology, PakJET**
Multidisciplinary | Peer Reviewed | Open Access
Volume: 03, Number: 03, Pages: 8-13, Year: 2020

# Functional MRI Based Brain Mapping in Occipital Gyrus using Face Stimuli

Anwar Ali Gaho[1], Ahmed Muddassir Khan[2], Muhammad Abul Hasan[3]

[1,2]Department of Electrical Engineering, Indus University, Karachi - 75300, Sindh, Pakistan
[3]Department of Biomedical Engineering, NED University of Engineering & Technology, Karachi - 75270, Sindh, Pakistan

Corresponding author: Anwar Ali Gaho (Email: anwar.a.gaho@gmail.com)

***Abstract*- Functional magnetic resonance imaging (fMRI) is one of the most powerful neuroimaging modalities due to its high spatio-temporal resolution characteristics. This known modality is applied on mapping the temporal, occipital, frontal cortices of the brain for localizing the neural activities generated due to any visual, physical or mental task or brain diseases or brain disorders. The occipital cortex is composed of middle, left, right, interior and exterior occipital gyrus and is responsible for visional function of human brain. The occipital gyrus reflects the neural image generated in the brain due to any visual activity. In this research paper, four different visual stimuli images of faces, scrambled, scenes and objects along with gap of blank space, forming a long sequence of stimuli observed by two female subjects, are experimented to examine and localize the most contrasting neural image generated in occipital gyrus of the brain. The visual fMRI brain data received from the two subjects is processed through fMRI-SPM12 toolbox based on Matlab software. In order to demonstrate the results statistically, two regressions such as T-contrast and F-contrast vectors are applied on fMRI images to highlight, and to localize the most active neural stimuli activities generated in the occipital gyrus of brain. In the results, it is demonstrated that maximum neural response can be mapped only for face stimulus in the bilateral occipital gyrus of the brain by applying T-contrast vectors regressions as when compared to other stimuli conditions and F-contrast vectors regressions. Further, it is also investigated that, the response of the face stimulus in F-contrast regressions achieved is somehow dispersed and unclear due to the large variances and interlinked communication of other stimuli or induced neural noises generated in entire volume of the brain. Further from the given images, it is also investigated that the most reflecting and contrast area for any visual stimuli (such as face stimulus in this case) is either the middle or bilateral part of occipital gyrus of the human brain as identified through application of T-contrast vectors regressions.**

***Index Terms*-- Neuroimaging, fMRI, Visual stimuli, Occipital gyrus, Brain mapping, T- and F-contrast vectors regressions.**

## I. INTRODUCTION

The human brain is most complex organ with $10^{12}$ neurons which are interconnected via axons and dendrites and $10^{15}$ synaptic connections. The development of brain usually starts from an age of 17-18 week of parental development and thus, electromagnetic activity is produced due to various mental and physical tasks. The research work in brain science aims to comprehend the neural activation leading to cognitive processes. The process to learn the brain dynamics involves deep understanding of various domains such as the combination of neuroscience (intense study of brain anatomy revealing connections and dynamic interactions between synaptic micro sources); deep applied mathematical skills for brain signaling and imaging understanding approach specialized for neuroimaging [1]. In this regard, various techniques are devised for brain activity analysis. These techniques are called functional neuroimaging techniques. Furthermore, these techniques are classified with respect to various parameters such as resolution (temporal and spatial), availability, computational complexity etc. The popular neuroimaging approaches used for clinical and research purposes are: magnetoencephalography (MEG), electroencephalography (EEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI) and near-infrared spectroscopy (nIRS) [2]. Functional magnetic resonance imaging (fMRI) is one of the brain imaging modalities in the field of neuroscience [3]. This imaging modality visualizes the brain topology by detecting variations of the oxygen quantity in the blood flow so-called blood oxygenation [4]. fMRI is the most powerful functional neuroimaging modality as the MRI scanner used for it, can provide both anatomical and functional features with high spatial resolution but at high instrumentation cost. The variation of the oxygen in the blood flow is due to brain neural activity by some stimuli actions. The stimuli actions enhance the intake of oxygen [5]. The water is main contributor of producing the oxygen and hydrogen items in the blood thereby giving the phenomenon called blood oxygen level dependent (BOLD) [6]. Hydrogen atoms absorb energy at some radio frequency and then subsequently release the energy at the same radio frequency until they gradually return to their equilibrium state. The MRI scanner measures the sum of the total of the emitted radio-frequency energy [7]. This mechanism is termed as functional MRI. Anatomically, the brain is divided into various lobes. Each lobe has its own functionalities for example; human memory, language perception and listening are associated with temporal lobe [8]. However, language interpretation, sensory intelligence and signals interpretation from different stimuli lie in parietal lobe. The brain areas such as amygdala, superior temporal sulcus, fusiform gyrus and lateral occipital cortex are investigated with the data of fMRI scanner images with visual and other stimuli [9]. This research work deals with visual stimuli of the images observed by two female subjects so, the neural activation in occipital lobe or cortex is focused [10]. The visual primary cortex is a part of an occipital lobe within brain which is reserved for visualization of the objects and their memory in the brain [11, 12]. This lobe consists of the hippocampal region and the adjacent perirhinal, entorhinal, and para-hippocampal cortices [13, 14].

In this paper, the brain activity of two healthy female subjects for visualizing the four stimuli such as faces, scrambled, scenes and objects with the application of different sequences and time will be investigated. This paper is divided into four sections: Section I as mentioned above is about the introduction. Section II gives detailed discussion for the methodology adopted for organizing and processing the fMRI data, Section III is composed of the results and discussions and Section IV describes conclusion and remarks.

## II. METHODOLOGY

fMRI data was collected from the two healthy female subjects having the age of 18 and 36 years respectively. In the designed experiment, health conditions for two female subjects were good such as they were free from depression, blindness, accident, surgery, brain disorders or any abnormal situations. During the experiment, body and head movement of subjects were kept as static and fixed. The room temperature and other conditions were maintained as normal and same for both subjects [15, 16, 17]. In this experiment as shown in Table 1, each individual female subject was asked to look at respective stimuli images for 16s and sequence of faces, scrambled, scenes and objects, separated by blank space for a total duration of 320s to complete the entire experiment.

TABLE I

STIMULI TIMELINE

| Stimuli | Blank | Faces | Scrambled | Places | Objects | Blank | Places |
|---|---|---|---|---|---|---|---|
| Counter | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Time[s] | 0 | 16 | 32 | 48 | 64 | 80 | 96 |

…

| Faces | Scrambled | Objects | Blank | Scrambled | Objects | Faces |
|---|---|---|---|---|---|---|
| 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 112 | 128 | 144 | 160 | 176 | 192 | 208 |

…

| Places | Blank | Objects | Places | Scrambled | Faces | Blank |
|---|---|---|---|---|---|---|
| 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 224 | 240 | 256 | 272 | 288 | 304 | 320 |

### A. DATA COLLECTION

For each subject, 113x images were stored in Neuroimaging Informatics Technology Initiative (NIFTI) format for further processing. There were also 3x orthogonal structural images stored in the data giving full volumetric anatomical T-image and high-resolution image showing a good contrast of gray and white matter [18]. The distortion, rotational and translational errors were removed during the process of normalization, warping and smoothing of the structural images by running SPM12-fMRI toolbox software [19]. Though these processes were performed but are not discussed in this paper.

### B. fMRI DATA ACQUISITION

In this paper, SPM12-fMRI toolbox in brain mapping is used to localize and analyze the most active and effective areas of the brain by showing a particular contrast while observing various stimuli. images This toolbox acquisition includes several steps of the execution steps such as spatial pre-processing, model specification, estimation, inference, analysis etc. for producing the results. These steps through were processed but are not discussed here. The fMRI data obtained from two female subjects is good enough for getting the complete neural activity mapping of the brain while visualizing the different stimuli images in different sequences [20].

### C. NORMALIZING AND WARPING STRUCTURES

Initially during pre-processing step, brain structures of different sizes and orientations were normalized, warped, smoothed and averaged for optimized stimuli brain mapping solution [21]. The normalization is one of important steps in pre-processing where brain structures are warped and smoothed to a standard template to match the true shape of the human head in brain mapping. These can be compared directly preferably voxel by voxel [22]. Images of the given subjects are matched to the standard template and make the new images [23].

### D. CONTRAST REGRESSIONS

The main objective of using T-contrast regressions in functional imaging experiment is to find the paraphernalia of several contrast regressions and their interaction with other visual and induced conditions. For testing this hypothesis and exploring the effect of individual stimuli in brain mapping, several generalized linear models (GLMs) can be fitted into data for estimating the required parameters [24, 25]. Since the fMRI data is too large to be explored and analyzed, therefore, T-contrast and F-contrast regression techniques are expedient in fMRI for estimating neural activities in visualizing different stimuli in visual cortex of brain.

### E. MATHEMATICAL MODEL FOR REGRESSIONS

The mathematical model [26, 27] for T-contrast and F-contrast regressions can be represented by:

$$Y = X\beta + \varepsilon \quad (1)$$

where $Y \in \Re^{nxt}$, $X \in \Re^{nxp}$ and $\varepsilon$ = additive noise with normal distribution with a zero mean and covariance of $\sigma^2\Sigma_i a$, $\beta$ = true parameters which are estimated by:

$$\hat{\beta} = \left(X^T X\right)^{-} X^T Y \quad (2)$$

where $X^{-}$ = Moore-Penrose pseudo inverse of X, $\hat{\beta}$ = estimated parameters

The fitted data is expressed by:

$$\hat{Y} = X\hat{B} \quad (3)$$

where estimated noise is defined as: $Y - \hat{Y} = RY$, $RY = \tau$, $R = I_n - XX^{-}$, $R$ = residual matrix.

Noise variance is estimated by:

$$\hat{\sigma}^2 = Y^T RY / tr\left[R\Sigma_i\right] \quad (4)$$

The linear function for estimation of parameters is defined by:

$$\lambda_1\hat{\beta}_1 + \lambda_1\hat{\beta}_1 + \ldots = \lambda^T\hat{\beta} \quad (5)$$

where $\lambda_i$ = coefficient that 'contrasts' parameter estimates. where contrast vector can be calculated as:

$$\lambda^T = \left[\lambda\lambda\ldots\lambda_P\right] \quad (6)$$

where $p$ = number of parameters in $X$, whereas contrast vectors with the noise is defined as:

$$\lambda^T\hat{B} \quad (7)$$

It is assumed that a contrast is a random variable which can be estimated from noisy available data.

## F. DESIGNING MATRIX CONDITIONS

Figure 1 as mentioned below can be reviewed and examined for four stimuli conditions in terms of order, timing and placement for each individual female subject.

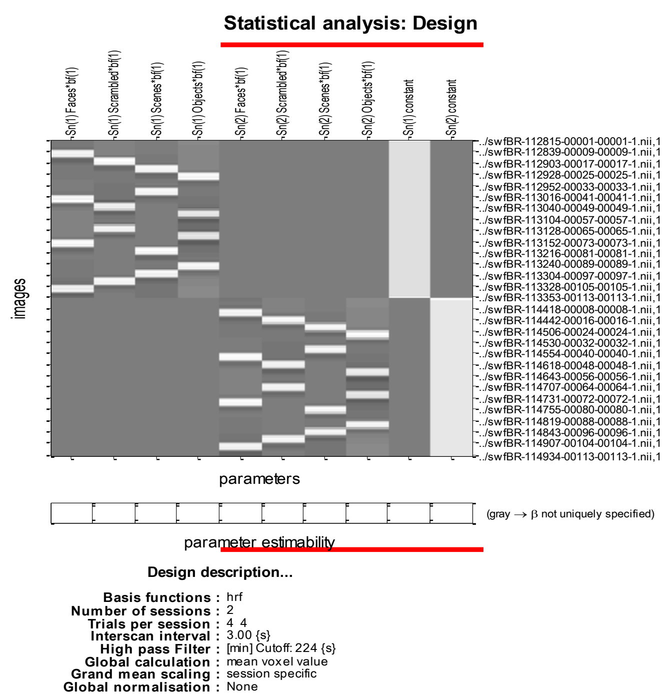


FIGURE 1. Designing matrix structure

In this figure, on the y-axis, there are two subjects mentioned and for each subject there are four stimuli image conditions. On the x-axis, there is an order of the stimuli images shown to each subject. In this way, a matrix is designed for statistical analysis which further leads to develop the contrast stimuli conditions such as T-contrast and F-contrast vectors regressions for distinguishing the other neural activities in the brain mapping. Thus, fitting of the images and their masking in the cortex can be estimated by designing the matrix and its contrast vectors [4]. The results are analyzed on the basis of applying different types of contrasts so-called regressions. Thus, in this paper, the neural activities in brain mapping for each individual stimulus can be observed by applying either T-contrast or F- contrast vectors regressions.

Table 2 is designed from the figure 1. On the y-axis as shown in figure 1, faces stimulus is placed above the scrambled one, therefore it is assumed that faces stimulus neural activity is greater than scrambled one and it is subsequently subtracted from scrambled one and suppressing all other stimuli conditions to zero in the T-contrasts. Hence contrast vector for faces stimulus is designed as [1 -1 0 0]. Here 1 represents the faces and -1 represents the scrambled one. Similarly, other conditions of the T-contrast vectors for scenes and objects stimuli are designed with the reference to scrambled one and thereby subsequently suppressing all other stimuli conditions to zero. In other words, only two conditions are highlighted in T-contrast vectors to highlight the neural activities. Generally, in designing T-contrast vectors, given stimuli neural conditions either are either subtracted or compared for providing relative responses of the neural activities in the brain mapping.

Table 2 and Table 3 give the pattern of assigning T-contrasts and F- contrast vectors for each individual subject. The order of the stimulus in sequence shown to each subject is faces, scrambled, scenes and objects. This stimulus order in sequence may vary for showing the high contrasts in the neural images. T-contrast vectors give the individual stimuli mapping in the brain whereas the F-contrast vectors provide the blended or mixed variance of the neural activities occurring in the entire brain volume. T-contrast vectors for both forward and reverse orders are designed from figure 1 and are shown in Table 2,

TABLE 2
T - CONTRAST REGRESSIONS

| S. No. | 4x conditions for each individual subject | |
|---|---|---|
| Forward Order | | |
| 1. | Faces > Scrambled | [1 -1 0 0] |
| 2. | Scenes >Scrambled | [0 -1 1 0] |
| 3. | Objects > Scrambled | [0 -1 0 1] |
| Reverse Order | | |
| 1. | Scrambled > Faces | [-1 1 0 0] |
| 2. | Scrambled > Places | [-1 0 1 0] |
| 3. | Scrambled > Objects | [-1 0 0 -1] |

Table 3 is designed from F-contrast vectors regressions. In this table, four stimuli conditions are demonstrated for the given two female subjects thereby giving entire total eight conditions in F-contrast vectors. Therefore, eight vectors are designed in such a way that at a time only one condition of one stimulus is selected so called a ‘ON-status’ while the rest conditions of other stimuli are suppressed to zero so called ‘OFF-status’ in a sequence.

TABLE 3
F-CONTRAST REGRESSIONS

| 4x conditions for each individual subject | |
|---|---|
| Contrast vectors sequence | 1<br>0 1<br>0 0 1<br>0 0 0 1<br>0 0 0 0 1<br>0 0 0 0 0 1<br>0 0 0 0 0 0 1<br>0 0 0 0 0 0 0 1 |

### G. T-CONTRAST REGRESSIONS

In the reverse order results, it was investigated that the response of the neural activities obtained was insufficient and very poor, Hence, reverse order and its image results are not discussed here. However, in the forward order, the brain glass view yields a good picture of the neural activities occurring in the visual cortex [28, 29-31]. In forward order results, it is investigated that maximum neural response is achieved only from the faces stimulus and not from other stimuli conditions such as scenes and objects. Thus, it can be said that in forward order the utilization plan of the T-contrast vectors is very beneficial for showing the specific neural activity occurring in the brain for a particular stimulus and can easily be mapped for individual stimulus.

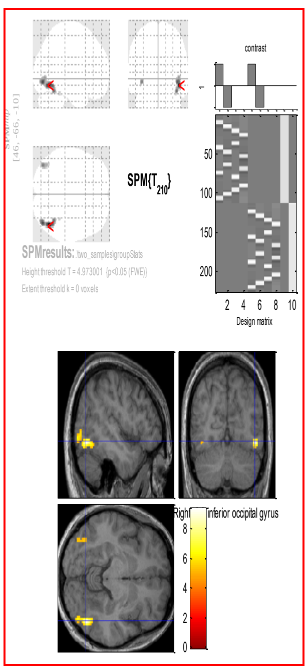

FIGURE 2. Face stimulus

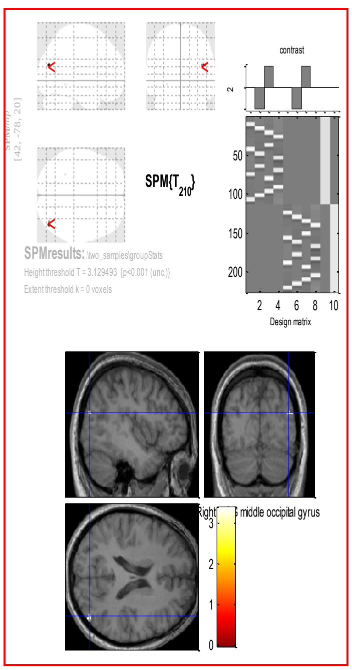

FIGURE 3. Scene stimulus

Figure 2 gives the maximum neural response for the face stimulus particularly in the right inferior occipital gyrus while considering the high threshold i.e. $T = 4.97$ and family wise error (FWE) i.e. $P < 0.05$ [28, 29]. However, extent threshold was also applied for availing the chances of the availability of the neural activities in the whole brain volume. Figure 3 gives the poor neural response for the scenes stimulus when referenced with the scrambled. Here maximum threshold i.e. $T = 3.129493$ and family wise error (FWE) i.e. $P < 0.001$ are obtained. This FWE is even less than standard value of FWE i.e. 0.05. It is set to that value in order to get a chance of availing the neural activities occurring even in the whole brain. However, extent threshold (k) is assumed as zero for considering the whole brain. Similarly, figure 4 gives the poor one-sided neural response for the objects stimulus when referenced to scramble. Here height threshold i.e. $T=4.973001$ and family wise error (FWE) i.e. $P <0.05$ are obtained. However, extent threshold (k) is assumed same as zero voxels for considering the whole brain.

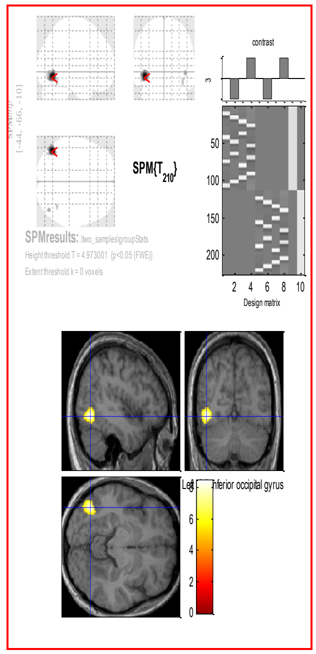

FIGURE 4. Object stimulus

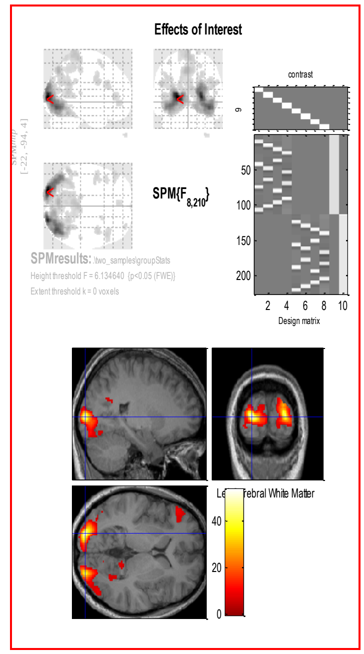

FIGURE 5. F-Contrast regressions

### H. F-CONTRAST REGRESSIONS

F-contrast mechanism provides poor response for the blended and overlapped active regions of the brain, so it is difficult to infer or to find any clue of the localization of neural activities genrated for any particular stimulus image. The maximum response of the brain mapping is found at cerebral white matter. So, it is difficult to infer the exact localization of the particular stimulus in the brain mapping other than visual cortex [29]. It is also examined that there are also chances of losing data from the brain regions particularly assigned for the visualizing the data. Figure 5 shows the blended and dispersed neural response for the object stimulus when referenced with respect to scrambled one. Here maximum threshold $T=6.134$ and family wise error (FWE) so called $P < 0.05$ are assigned. However, extent threshold (k) is assumed as zero voxels while considering the whole brain volume [30].

### I. 3D VIEW AND AXIAL VIEW OF THE BRAIN

Figure 6 as mentioned below, shows that neural response for the two-stimuli conditions taking place in the 3D rendered view of neural activities in occipital cortex. Here the major stimulus neural response for face stimulus is represented by red spots whereas the lower object stimulus neural response is represented by green spots. Figure 7 below gives the sliced axial view of the images of the neural activities occurring in the brain. Axial image view of the brain is sliced or montaged into 11 x parts showing the piecewise existence of the neural activities in the occipital region.

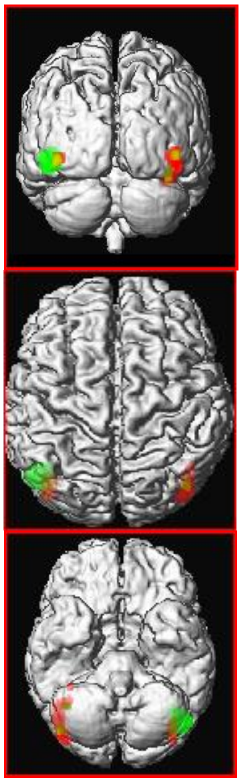

FIGURE 6. 3D rendered view

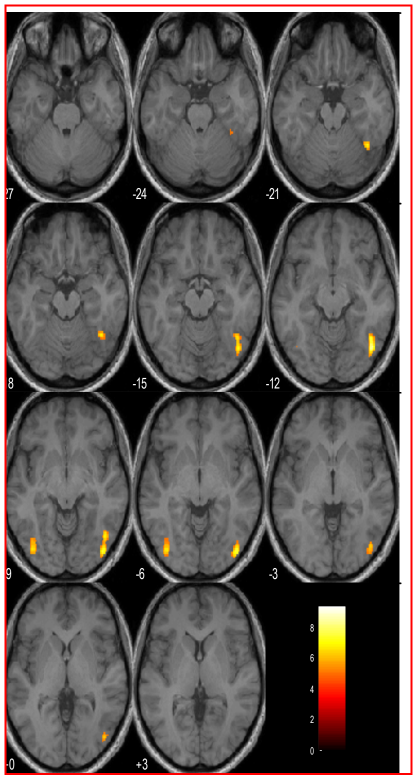


FIGURE 7. Axial montage view

## III. RESULTS AND DISCUSSION

As a general phenomenon of the functioning of eyes, brain and memory, the visual information of the stimuli images observed by subjects, passes through the lateral geniculate thalamus part of the brain and subsequently reaches to the visual cortex. It is mandatory to mention here that pre-processing step is most important part of the data acquisition. Before performing any statistical analysis, sliced images acquired from the fMRI scanner are initially calibrated, reoriented, realigned and smoothed to get the required accurate results. SPM12-fMRI toolbox, being a powerful robust analysis tool has been used for pre-processing and executing the fMRI images achieved from two female subjects. In this paper, fMRI images were obtained from two female subjects. These subjects were asked to watch four stimuli conditions in a compact environment. T-contrasts and F-contrasts are two vectors regressions which were developed theoretically and were implemented during the designing matrix for neural activities generated in the brain. The results, as demonstrated from figure 2 to figure 5, the maximum neural responses were achieved from the face stimulus as compared to other stimuli conditions such as scramble, scenes and objects. This maximum neural activity response for the face stimuli was demonstrated by applying T-contrast vectors in both lateral parts such as left and right occipital gyrus of the brain. On the other side, the F-contrast vectors provided the poor blended and overlapped neural responses with the large variances of the data, dispersed across the entire brain which subsequently yields nothing to get any neural clue. It rather reflects unnecessary and noisy neural responses in the brain as shown in figure 5. So, it is not beneficial to highlight the visual stimuli neural responses in the brain by applying F-contrast vectors. Rather, it can be said that there are more chances of losing the data in application of F-contrast vectors as compared to application of T-contrast vectors particular for faces stimuli. Therefore, it can be concluded that T- contrast vectors conditions give an optimum result for reflecting the face stimuli responses in bilateral occipital gyrus in processing the fMRI data with a high spatio-temporal resolution.

## IV. CONCLUSION AND REMARKS

In this research paper, the objective was to demonstrate the maximum neural responses or activities generated in the human brain by applying either T-contrast or F-contrast vectors conditions respectively to each individual female subject. SPM12-fMRI Matlab based toolbox; a powerful analysis tool of the brain was applied for processing and demonstrating neural responses. The fMRI brain images data was obtained from two healthy female subjects by showing them the different sequences of different orders of stimuli images such as faces, objects, scenes and scrambled for a 16s and thereby making a total of 320s duration for the whole experiment. In the results, it is demonstrated that bilateral occipital gyrus of the brain is the most reflecting and active areas of the brain of the two female subjects for observing face stimulus condition. In this paper, it is also investigated that T-contrast and F-contrast vector conditions are good enough for demonstrating and distinguishing the different stimuli neural responses or activities occurring in occipital gyrus of the brain.

It is concluded that F-contrast vectors yield the poor, blended and noisy data with the large variances even for the face stimuli images, therefore no any targeted neural clue can be inferred for treatment or localization. On the contrary, T-contrasts vectors for a face stimulus provide maximum neural response at a unique location so a proper treatment for any brain disorder or diseases can be recommended by a neurologist.

**Future Work:** Future work will be based on the detailed analysis of the blended contrasts of the overlapping regions in the visual cortex and its neighboring regions for different stimuli image conditions.

**Acknowledgements:** The authors are very thankful to Dr. Justin O'Brien, Division of Psychology, Department of Life Sciences, Brunel University for providing the data for this paper.

## REFERENCES


[1] M. A. Jatoi, N. Kamel, A. S. Malik, I. Faye, and T. Begum, "A survey of methods used for source localization using EEG signals," Biomedical Signal Processing and Control, vol. 11, pp. 42-52, 2014.

[2] M. A. Jatoi, N. Kamel, A. S. Malik, I. Faye, and T. Begum, "Representing EEG source localization using finite element method," in Control System, Computing and Engineering (ICCSCE), 2013 IEEE International Conference on, 2013, pp. 168-172: IEEE.

[3] Chaturvedi, "Analysing the Use of EEG, fMRI, PET and Behavioural Studies of Brain Lesioned Patients Associated with Non-Literal Language eg Metaphors, Sarcasm, Some Types of Humour Etc," 2017.

[4] T. J. Van Grootel et al., "Development of visual cortical function in infant macaques: A BOLD fMRI study," PloS one, vol. 12, no. 11, p. e0187942, 2017.

[5] Mo, D. He, and F. Fang, "Attention priority map of face images in human early visual cortex," Journal of Neuroscience, vol. 38, no. 1, pp. 149-157, 2018.

[6] T. Swetha, B. Swedha, G. Vaishali, and A. Rohini, "FMRI ANALYSIS AND IDENTIFICATION OF AAP BRAIN REGIONS."

[7] H. Ffytche and S. Zeki, "The primary visual cortex, and feedback to it, are not necessary for conscious vision," Brain, vol. 134, no. 1, pp. 247-257, 2010.

[8] P. Hermann, M. Grotheer, G. Kovács, and Z. Vidnyánszky, "The relationship between repetition suppression and face perception," Brain imaging and behavior, vol. 11, no. 4, pp. 1018-1028, 2017.

[9] M. Müller-Bardorff et al., "Early brain responses to affective faces: A simultaneous EEG-fMRI study," NeuroImage, 2018.

[10] H. Han and A. L. Glenn, "Evaluating methods of correcting for multiple comparisons implemented in SPM12 in social neuroscience fMRI studies: an example from moral psychology," Social neuroscience, vol. 13, no. 3, pp. 257-267, 2018.

[11] A. Leopold, "Primary visual cortex: awareness and blindsight," Annual review of neuroscience, vol. 35, pp. 91-109, 2012.

[12] R. Kato, K. Takaura, T. Ikeda, M. Yoshida, and T. Isa, "Contribution of the retino-tectal pathway to visually guided saccades after lesion of the primary visual cortex in monkeys," European Journal of Neuroscience, vol. 33, no. 11, pp. 1952-1960, 2011.

[13] P. Golland et al., "Discriminative analysis for image-based studies," in International Conference on Medical Image Computing and Computer-Assisted Intervention, 2002, pp. 508-515: Springer.

[14] B. A. Wandell and J. Winawer, "Computational neuroimaging and population receptive fields," Trends in cognitive sciences, vol. 19, no. 6, pp. 349-357, 2015.

[15] M. A. Jatoi, N. Kamel, A. S. Malik, I. Faye, J. M. Bornot, and T. Begum, "EEG-based brain source localization using visual stimuli," International Journal of Imaging Systems and Technology, vol. 26, no. 1, pp. 55-64, 2016.

[16] S. J. Kiebel, S. Klöppel, N. Weiskopf, and K. J. Friston, "Dynamic causal modeling: a generative model of slice timing in fMRI," Neuroimage, vol. 34, no. 4, pp. 1487-1496, 2007.

[17] N. Kanwisher, J. McDermott, and M. M. Chun, "The fusiform face area: a module in human extrastriate cortex specialized for face perception," Journal of neuroscience, vol. 17, no. 11, pp. 4302-4311, 1997.

[18] P. W. Nicholson, "Specific impedance of cerebral white matter," Experimental neurology, vol. 13, no. 4, pp. 386-401, 1965.

[19] J. Ashburner et al., "SPM12 manual," Wellcome Trust Centre for Neuroimaging, London, UK, 2014.

[20] M. Dale et al., "Dynamic statistical parametric mapping: combining fMRI and MEG for high-resolution imaging of cortical activity," Neuron, vol. 26, no. 1, pp. 55-67, 2000.

[21] J. C. Rajapakse and A. Cichocki, "Independent component analysis and beyond in brain imaging: EEG, MEG, fMRI, and PET," in Neural Information Processing, 2002. ICONIP'02. Proceedings of the 9th International Conference on, 2002, vol. 1, pp. 404-412: IEEE.

[22] M. Fuchs, M. Wagner, and J. Kastner, "Development of volume conductor and source models to localize epileptic foci," Journal of Clinical Neurophysiology, vol. 24, no. 2, pp. 101-119, 2007.

[23] E. Aasebø et al., "Temporal Processing in the Visual Cortex of the Awake and Anesthetized Rat," eNeuro, vol. 4, no. 4, pp. ENEURO. 0059-17.2017, 2017.

[24] Costa, H. Batatia, T. Oberlin, and J.-Y. Tourneret, "Skull Conductivity Estimation for EEG Source Localization," IEEE Signal Processing Letters, vol. 24, no. 4, pp. 422-426, 2017.

[25] Majkowski, Ł. Oskwarek, M. Kołodziej, and R. J. Rak, "An attempt to localize brain electrical activity sources using EEG with limited number of electrodes," Biocybernetics and Biomedical Engineering, vol. 36, no. 4, pp. 686-696, 2016.

[26] Friston, J. Mattout, N. Trujillo-Barreto, J. Ashburner, and W. Penny, "Variational free energy and the Laplace approximation," Neuroimage, vol. 34, no. 1, pp. 220-234, 2007.

[27] Y. Bekhti, F. Lucka, J. Salmon, and A. Gramfort, "A hierarchical Bayesian perspective on majorization-minimization for non-convex sparse regression: application to M/EEG source imaging," Inverse Problems, 2018.

[28] Flandin and K. J. Friston, "Analysis of family-wise error rates in statistical parametric mapping using random field theory," Human brain mapping, 2016.

[29] P. Rodriguez et al., "Multimodal randomized functional MR imaging of the effects of methylene blue in the human brain," Radiology, vol. 281, no. 2, pp. 516-526, 2016.

[30] W. Neuroimaging, "SPM12-Statistical Parametric Mapping," The FIL Methods group. Recuperado a partir de http://www. fil. ion. ucl. ac. uk/spm/software/spm12, 2016.

[31] M. Ashraf, S. Raza, and U. Saleem, “A Comparative Analysis on Wind Speed Forecast using Optimized Neural Networks”, *Pakistan J Engg & Tech*, vol. 3, no. 2, pp. 23-28, Sep. 2020.