ORIGINAL ARTICLE

Functional Connectivity Analysis in EEG Source Space during Deception

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Abstract

Purpose: Deception is described as a deliberate endeavor to deceive others. In this research, the main purpose is to survey the brain network between deception and telling the truth.

Materials and Methods: Electroencephalography (EEG) data were collected from 17 subjects during a deception task in which the subjects had to classify the target stimuli deceptively while responding truthfully to other stimuli (non-targets). Functional Connectivity (FC) analysis was carried out in source space in order to attenuate the volume conduction effect. The coherence criterion was applied for calculating FC.

Results: The results revealed that deception is associated with significantly greater connectivity between distant regions, including frontal-occipital and frontal-parietal connectivity. In addition, Anterior Cingulate Cortex (ACC) demonstrated significantly greater connectivity with regions of the frontal and occipital lobes. Besides, deception was accompanied by high number of strong connectivity between the left parietal and frontal lobes.

Conclusions: The findings demonstrated that the FC studies in source space can strikingly assist in the investigation of deception.

Keywords: Deception; Electroencephalography; Source Localization; Low-Resolution Electromagnetic Tomography; Functional Connectivity.

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1. Introduction

Deception is coupled with more cognitive demands than telling the truth. In fact, liars have to prepare a credible response. To this end, they need to inhibit the truth while keeping the truth active in working memory [1].

Due to the physiological reactions of the body during deception, the study of physiological signs of the body has always been one of the methods of studying deception. In fact, a number of the body's physiological activities are affected simultaneously with deception [2]. However, it is worth noting that the physiological activities of the body can be affected by other factors such as stress; so the results obtained from examining the physiological activities of the body for identifying deception cannot be conclusively trusted. On the other hand, since deception is associated with increased neural activity for executive control using central nervous system resources, methods such as functional Magnetic Resonance Imaging (fMRI) and Electroencephalography (EEG), which provide more accurate information about the central nervous system, can assist in more precisely detecting deception [3].

So far, various neuroimaging studies have been accomplished to identify active areas of the brain during deception. Some meta-analysis researches on deception revealed that deception is accompanied by the prominent activation of the Dorsolateral Prefrontal Cortex (DLPFC) and Anterior Cingulate Cortex (ACC) areas which are associated with executive function [4,5].

The comprehension of the brain function during deception, in addition to identifying active areas of the brain, needs the study of Functional Connectivity (FC) between different areas of the brain. In fact, finding potential interaction between the active regions of the brain in deceptive responses can play a substantial role in better understanding the brain function during deception and differentiating it from telling the truth. FC analysis is one of the appealing methods for investigating cognitive processes like deception in EEG researches since it gives instructional information about the connectivity between the brain areas [6]. The previous meta-analysis on deception studies illustrated that deception involves multiple brain networks, including the Prefrontal Cortex (PFC), middle frontal gyrus, ACC, temporal gyrus, and posterior cortical regions which interact with one another in order to form deception [7]. In an fMRI study [8], a color-reporting game was used as a task in which participants lie about the color of stimuli according to the instruction during fMRI recording. In particular, for each stimulus, they were shown one circle (yellow or blue, randomly). After a few seconds, they were shown four circles with different colors. After that, they were asked to report the color of the circle which matches the previous one. According to the instruction, they could misreport the color of some circles. The results of the brain activity demonstrated that deception is accompanied by the activation in PFC, right Inferior Frontal Gyrus (IFG), and left DLPFC.

The purpose of the current research is to examine the brain FC during deception and to compare the brain network between deception and telling the truth. The separation of independent sources that are mixed with an unknown mixing matrix is referred to as Independent Component Analysis (ICA) [9]. In FC studies using EEG, most connectivity criteria, including coherence are sensitive to the volume conduction effect. Therefore, in order to alleviate this effect, ICA was used to estimate brain sources during deception and thus investigate the FC in source space. One issue with deception-designed tasks is that the emotional state of a person who enters a criminology situation voluntarily differs from that of an offender, which influences the EEG signal. For this purpose, a task with a low emotional load that does not activate the sources of emotions in the brain has been used. As a result, the difference between volunteer participants (who are sometimes motivated by a reward at the end of the recording session) and the offender (who would face punishment if proven guilty) would be greatly decreased.

In summary, this research follows three important points.

1- Using a deception task that involves as few brain sources related to emotions as possible.

2- Estimating the activity of active brain sources while executing this task.

3- Investigating FC among estimated sources.

2. Materials and Methods

2.1. Subjects

Seventeen right-handed students (graduate and undergraduate) participated in this study. The age range was 22 to 31 years old (M= 25,04). The individuals did not have a history of psychotic disorders and all had normal vision. This study is based on the ethical standards of Iran University of Medical Science.

2.2. Stimuli

Stimuli included pictures of five plants and five animals. The following plants were depicted: cactus, sunflower, tulip, dandelion and rose. Animals' pictures included: monkey, fox, horse, mouse, and frog (Figure 1). Pictures were presented in the center of the monitor against a black background. Subjects sat 60 cm away from the monitor.

Figure 1. Pictures used throughout the test as stimuli

2.3. Experimental Design

Subjects were instructed to misclassify two stimuli (targets) which they had seen prior to the task while responding honestly to other stimuli (non-targets). For all subjects, the two target pictures were identical. In other words, inside the two boxes, one for plant stimuli and the other for animal stimuli were five envelopes, all of which possessed analogous plant and animal pictures.

This experiment was carried out in a dim room. The task contained three main blocks, and each block consisted of 12 target and 48 non-target pictures (60 trials overall) which were presented randomly. Each picture emerged 6 times per block. Each trial initiated with the white fixation cross, and it was replaced by the picture. Figure 2 shows the exact timing information for displaying stimulus pictures and rest durations between blocks.

2.4. EEG Recording and Preprocessing

EEG was collected using 32 electrodes based on the international 10/20 electrode placement system. The sampling frequency was 512 Hz. The mastoids were physically linked as the reference point. Prior to performing any processing on the raw signals, preprocessing steps such as baseline rejection, low-pass (80 HZ), high-pass (1 HZ), and notch (50 HZ) filtering, and automatic Electrooculography (EOG) removing using ICA were undertaken. The EEG signals were then segmented from 400 milliseconds before each stimulus to 1600 milliseconds after that. Following that, all bad and false (error response) epochs were identified and eliminated.

2.5. Brain FC and Statistical Analysis

The volume conduction effect is one of the serious challenges in FC research. In fact, due to the distance between the sources of the brain activity and the place of recording brain signals (electrodes on the scalp), instead of one electrode, multiple electrodes record the activity of a brain source. Therefore, the study of FC in the channel space using criteria sensitive to the volume conduction effect, such as coherence can lead to fake connectivity. In this regard, FC was computed in source space. Given that for different individuals, different brain resources are obtained that are not necessarily the same, group ICA [10] was utilized to study the FC among brain sources during deception and telling the truth. The Group ICA enables the identification of identical sources from both states (deception and telling the truth).

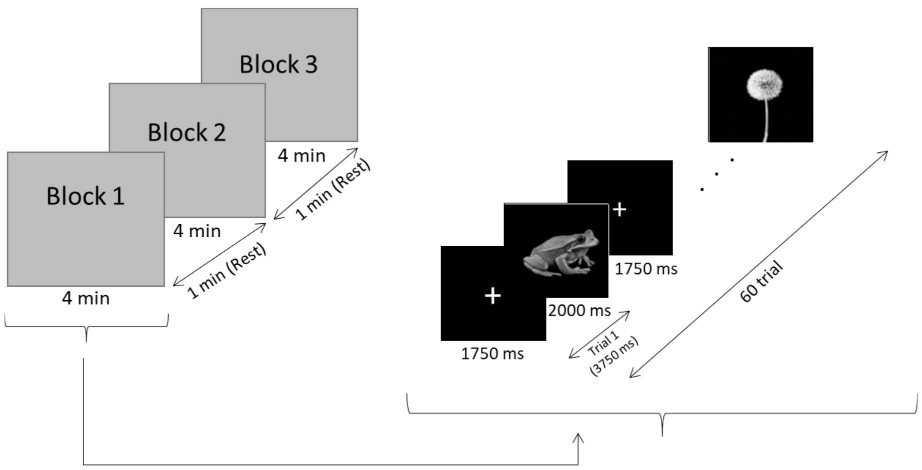

Figure 2. The configuration of the task containing blocks, trials, and rests

Corrmap algorithm [11] was used to identify clusters containing representatives of both groups, and Low-Resolution Electromagnetic Tomography (LORETA) [12] was utilized for source reconstruction.

Before ICA, all subjects' trials were normalized and then placed side by side. The Group ICA was implemented in three groups, including targets, non-targets and all (target and non-target). The results of group ICA in each of these three groups was provided in Figure 3 (A: target, B: non-target and C: all (target and non-target) groups). ICA was implemented using Multicombi algorithm.

Clustering using Corrmap revealed eight clusters with common brain sources from both groups, which were reconstructed using LORETA (by taking each source

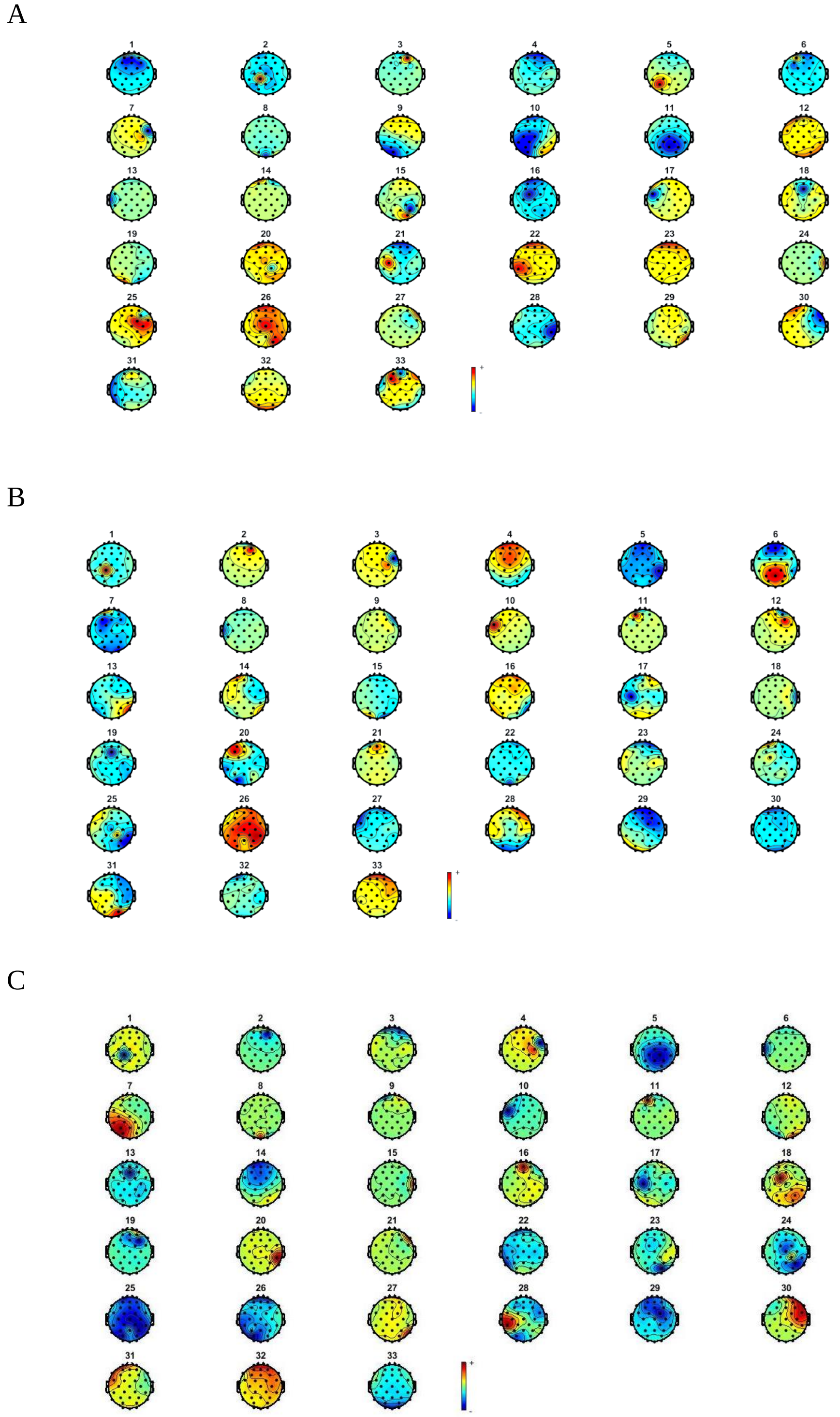

Figure 3. The results of group - Independent Component Analysis (ICA) (using Multicombi algorithm) in A) target, B) non-target and C) all (target and non-target) groups

acquired from the group ICA on all as the center of each cluster). The results of Corrmap were provided in Figure 4. It is noteworthy that Corrmap algorithm of the EEGLAB toolbox was used for this aim. In addition, the results of LORETA were provided in Figure 5 (A: Middle Occipital Gyrus, B: Medial Frontal Gyrus, C: ACC, D: Medial Frontal Gyrus, E: Superior Frontal Gyrus, F: Cuneus, G: Middle Temporal Gyrus and H: Postcentral.).

FC was calculated using the coherence criterion as Equation 1 [13]:

$$C_{xy}(f) = \frac{|p_{xy}(f)|^2}{p_{xx}(f)p_{yy}(f)} \qquad (1)$$

Where $p_{xx}(f)$, $p_{yy}(f)$, and $p_{xy}(f)$ refer to the spectral density of x and y and the cross-spectral density between x and y, respectively. In this equation, the $C_{xy}(f)$ is coherence value between x and y, where f is frequency.

Statistical analysis was performed using a non-parametric test called Wilcoxon signed-rank, due to the abnormal data distribution. This test was used for comparing the FC between the two modes (deception and telling the truth) for each pair of sources [14]. In order to characterize significant differences between the two modes (deception and telling the truth), each value of the FC matrix was checked. If pFDR−corrected < 0.05, the value is equal to 1, and if pFDR−corrected≥ 0.05, the value is equal to 0.

A diagram of the study, which indicates the synopsis of EEG data analysis steps, is shown in Figure 6.

3. Result

The results of source localization showed eight Brodmann areas, including superior frontal gyrus (BA10), medial frontal gyrus (BA8,11), ACC (BA32), postcentral gyrus (BA2), middle temporal gyrus (BA21), cuneus (BA17), and middle occipital gyrus (BA18). For each subject, the FC matrices (8×8) were calculated for each target and non-target epoch, and then the FC matrices were averaged separately in each group. Finally, the two FC matrices (target and non-target) were obtained for each subject. For each pair of sources, statistical analysis was performed between the values of connectivity. Figure 7 demonstrates the source connectivity which shows a significant difference ($p < 0.05$) between the two groups (target and non-target). Results demonstrate that all significant connectivity were stronger during deception than that of telling the truth (targets > non-targets).

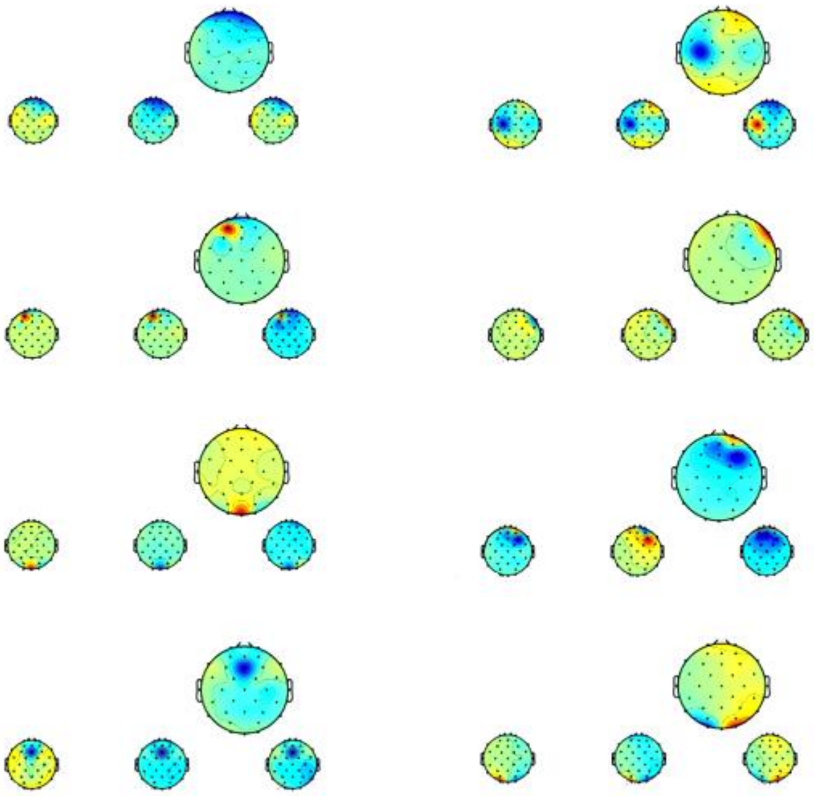

Figure 4. The results of Corrmap including 8 clusters with brain sources which have representatives of both groups

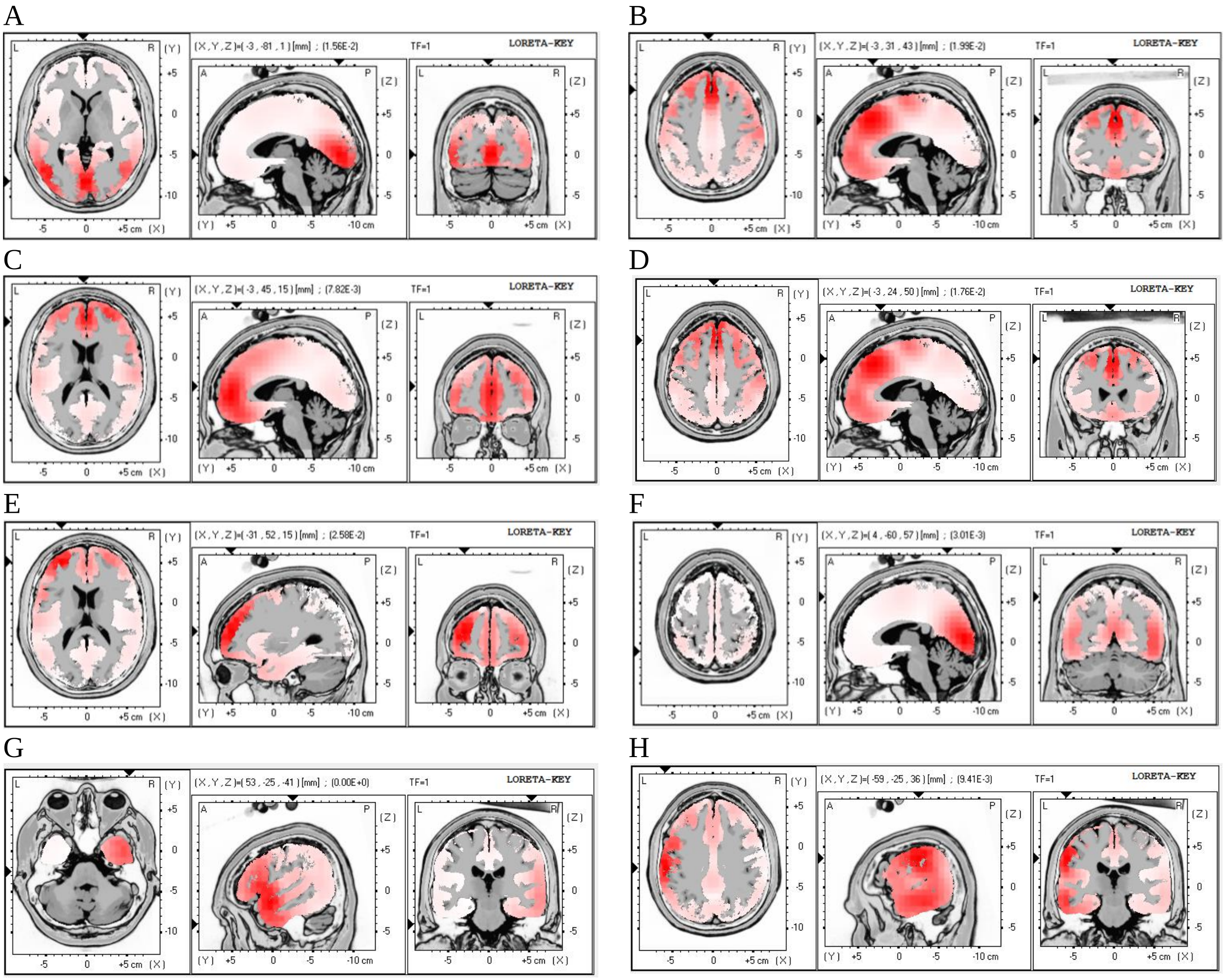

Figure 5. The results of Low-Resolution Electromagnetic Tomography (LORETA) including the brain region which is related to each source. A) Middle Occipital Gyrus, B) Medial Frontal Gyrus, C) Anterior Cingulate Cortex (ACC), D) Medial Frontal Gyrus, E) Superior Frontal Gyrus, F) Cuneus, G) Middle Temporal Gyrus and H) Postcentral

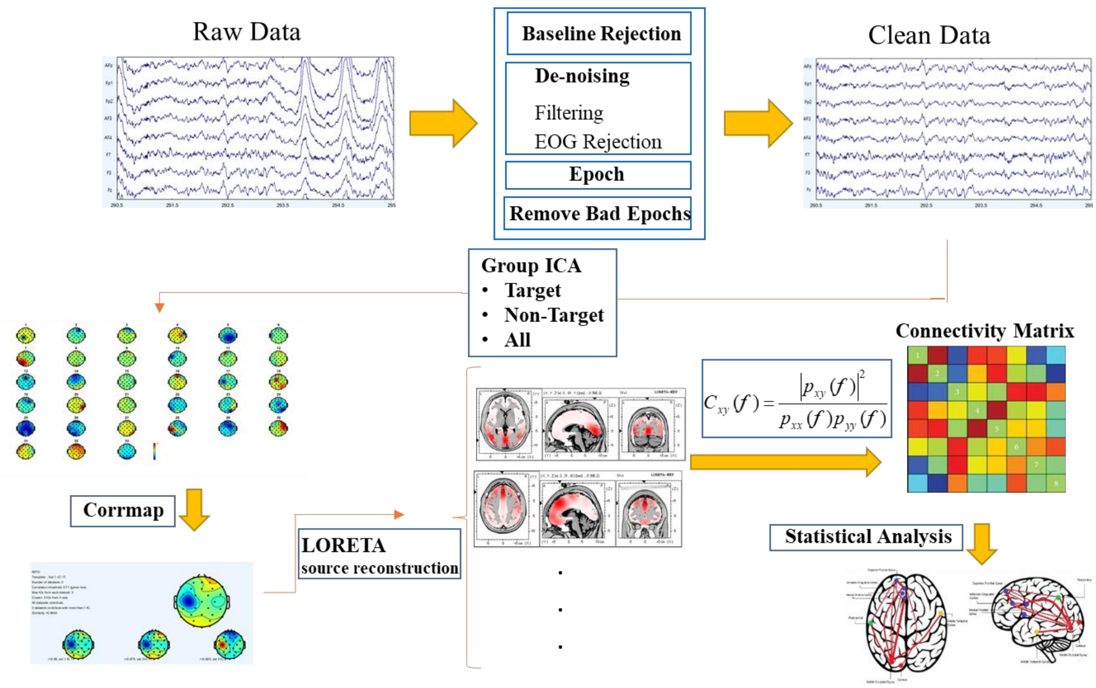

Figure 6. A diagram of the study which indicates all steps of Electroencephalography (EEG) data analysis

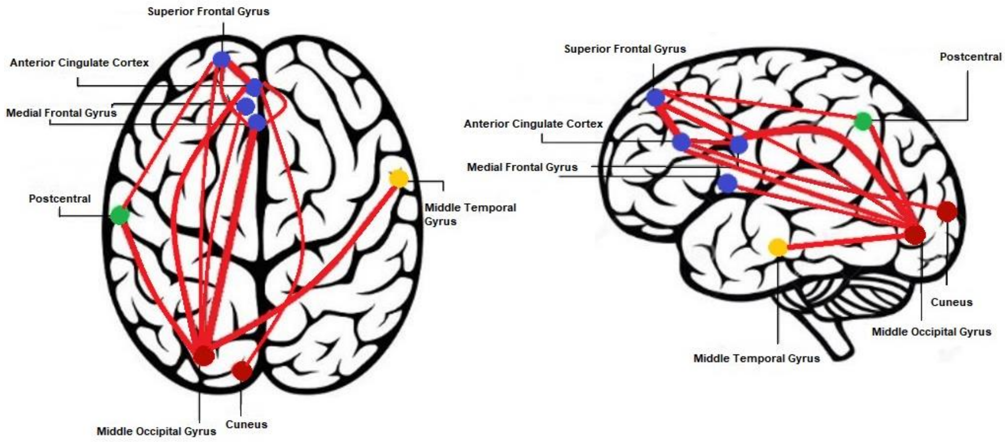

Figure 7. Significant connectivity (P<0.05) between the target and non-target groups. The thickness of the lines expresses the p-values (narrow lines: p<0.05, medium lines: p<0.005, wide lines: p<0.0005)

In order to examine the strongest connectivity between the brain sources in each of the target and non-target groups, after identifying all brain sources of each group, FC between each pair of sources using coherence criterion was calculated. Then, the top 15 percent of the connectivity in each group were identified. For each brain source, LORETA was used to determine the active brain region which was related to that brain source. Figure 8 shows the top 15 percent of the connectivity between the sources in each group from the top and sagittal views. The location of each source is specified using the corresponding color and name in the figure guidance. It is noteworthy that in the top 15 percent of the target group, considerable number of connectivity are observed between the left parietal and frontal, left temporal and frontal and between ACC and frontal, temporal and parietal lobes.

4. Discussion

The purpose of the current research was to identify the brain network during deception and telling the truth. To this end, a test was designed in which the two specific stimuli were purposely misclassified and the rest of the stimuli were correctly classified by the subjects. In this study, a significant number of long-range connectivity

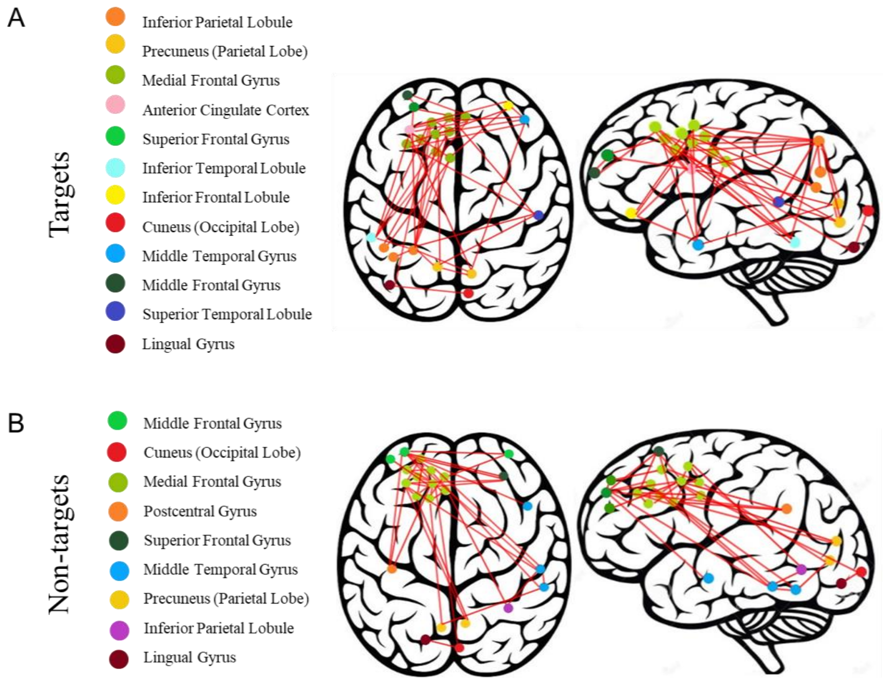

Figure 8. The top 15 percent of the functional connectivity (FC) between the sources in A) target and B) non-target groups

was observed during deception. In [15], stronger connectivity was observed between distant regions which could be attributed to increased cognition. Strong connectivity was also observed between ACC and areas of the frontal and occipital lobes, which is in line with [15] indicating that greater connectivity between ACC and occipital lobe might be related to the functions that are most important in performing deception.

The results of the strongest connectivity between the brain sources in the target group showed that deception is associated with high number of strong connectivity between the left parietal and the frontal lobe, which is in line with [16], demonstrating that the left parietal has a key role in the scheming of skillful behaviors. Therefore, the result of this research showed that the study of the brain connectivity can provide useful information about the difference of the brain networks between deception and telling the truth.

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References

1- Kristina Suchotzki, Geert Crombez, Fren TY Smulders, Ewout Meijer, and Bruno Verschuere, "The cognitive mechanisms underlying deception: An event-related potential study." *International Journal of Psychophysiology,* Vol. 95 (No. 3), pp. 395-405, (2015).

2- Elizabeth B Ford, "Lie detection: Historical, neuropsychiatric and legal dimensions." *International Journal of Law and Psychiatry,* Vol. 29 (No. 3), pp. 159-77, (2006).

3- Wang Yue, Ng Wu Chun, Ng Khoon Siong, Wu Tiecheng, and Li Xiaoping, "An EEG source localization and connectivity study on deception of autobiography memories." in *2013 6th International IEEE/EMBS Conference on Neural Engineering (NER),* (2013): *IEEE,* pp. 468-71.

4- Junhong Yu, Qian Tao, Ruibin Zhang, Chetwyn CH Chan, and Tatia MC Lee, "Can fMRI discriminate between deception and false memory? A meta-analytic comparison between deception and false memory studies." *Neuroscience & Biobehavioral Reviews,* Vol. 104pp. 43-55, (2019).

5- Francesca Mameli et al., "The guilty brain: the utility of neuroimaging and neurostimulation studies in forensic field." *Reviews in the Neurosciences,* Vol. 28 (No. 2), pp. 161-72, (2017).

6- Spiro P Pantazatos, Ardesheer Talati, Paul Pavlidis, and Joy Hirsch, "Cortical functional connectivity decodes subconscious, task-irrelevant threat-related emotion processing." *Neuroimage,* Vol. 61 (No. 4), pp. 1355-63, (2012).

7- Nina Lisofsky, Philipp Kazzer, Hauke R Heekeren, and Kristin Prehn, "Investigating socio-cognitive processes in deception: a quantitative meta-analysis of neuroimaging studies." *Neuropsychologia,* Vol. 61pp. 113-22, (2014).

8- Lijun Yin and Bernd Weber, "I lie, why don't you: Neural mechanisms of individual differences in self-serving lying." *Human brain mapping,* Vol. 40 (No. 4), pp. 1101-13, (2019).

9- Farnaz Ghassemi, Mohammad Hasan Moradi, Mahdi Tehrani Doust, and Vahid Abootalebi, "Combination of independent component analysis and feature extraction of ERP for level classification of sustained attention." in *2009 4th International IEEE/EMBS Conference on Neural Engineering,* (2009): *IEEE,* pp. 136-39.

10- Pierre Comon, "Independent component analysis, a new concept?" *Signal processing,* Vol. 36 (No. 3), pp. 287-314, (1994).

11- Filipa Campos Viola, Jeremy Thorne, Barrie Edmonds, Till Schneider, Tom Eichele, and Stefan Debener, "Semi-automatic identification of independent components representing EEG artifact." *Clinical Neurophysiology,* Vol. 120 (No. 5), pp. 868-77, (2009).

12- RD Pascual-Marqui. (2007). LORETA: Low resolution brain electromagnetic tomography." Zurich, Switzerland: The KEY Institute for Brain-Mind Research.

13- Rosaleena Mohanty, William A Sethares, Veena A Nair, and Vivek Prabhakaran, "Rethinking measures of functional connectivity via feature extraction." *Scientific reports,* Vol. 10 (No. 1), pp. 1-17, (2020).

14- Bernard Rosner, Robert J Glynn, and Mei-Ling T Lee, "The Wilcoxon signed rank test for paired comparisons of clustered data." *Biometrics,* Vol. 62 (No. 1), pp. 185-92, (2006).

15- Weixiong Jiang et al., "Decoding the processing of lying using functional connectivity MRI." *Behavioral and Brain Functions,* Vol. 11 (No. 1), pp. 1-11, (2015).

16- Scott H Johnson-Frey, Roger Newman-Norlund, and Scott T Grafton, "A distributed left hemisphere network active during planning of everyday tool use skills." *Cerebral cortex,* Vol. 15 (No. 6), pp. 681-95, (2005).