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The Comparison of Cortical Neural Activity Between Spatial and Non-spatial Attention in ECoG Study

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Abstract

In this study, we investigated the spatiotemporal dynamics during spatial and non-spatial attention tasks employing human electrocorticographic (ECoG) signals. Ten epileptic patients who underwent subdural electrodes insertion for epileptic surgery performed spatial and non-spatial attention tasks. Time-frequency and statistical analysis for ECoG signals resulted that both spatial and non-spatial attention commonly had event related desynchronization (ERD) over the low frequency (theta, alpha, beta) and event related synchronization (ERS) over the high frequency (gamma band). The difference between two paradigms have been found in the right parietal area showing ERD in superior parietal area during spatial task and ERD in inferior parietal area during non-spatial task.

1 Introduction

The posterior parietal cortex (PPC) has known to be a main part for cognitive processes including attention, spatial representation, working memory, and visuomotor control [1]. However, details about the neural mechanism underlying spatial and non-spatial attention are unclear because of the limitations of poor spatial and temporal resolution of the method used in previous studies [2]. The electrocorticographic (ECoG) recording may be the one of solutions because of its high temporal and spatial resolution and high signal fidelity.

The aim of this study was to investigate the neural mechanisms associated with two types of attention processing using ECoG signals from epileptic patients.

2 Materials and Methods

2.1 Participants

Thirteen epileptic patients (6 females, mean age 32.6 ± 10.1 years) who had underwent an invasive study with intracranial electrodes for epileptic surgery participated in this experiment (Figure 1). After finishing a video-monitoring study to localize seizure foci with intracranial electrodes, the patients' seizures were controlled by anticonvulsant medications. The studies were conducted approximately 5-7 days after the electrode implantation therefore all patients were healthy and able to perform this

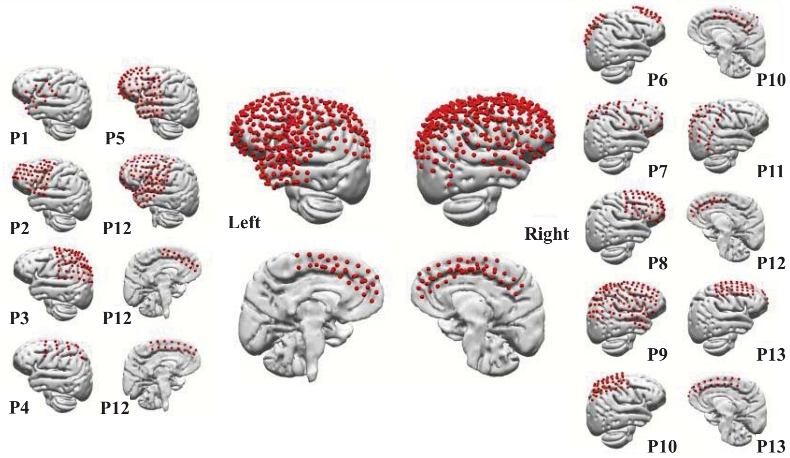

Figure 1: Location of electrodes. Left two columns and right two columns illustrate the location of electrodes for each participants. Four figures in the center show the electrode maps of whole participants overlaid on the standard brain surface.

experiment. This study was approved by Asan Medical Center, Seoul, Korea. Informed consent was obtained in accordance with the regulations of the Research Ethics Board of our institution.

2.2 Experimental Task

The tasks were developed using VIZARD software (World Viz Inc.) and adopted from a Malhotra's paradigm [3] which combined spatial (location-based) and non-spatial (feature-based) visual attention. The patients were asked to respond as quickly as possible by pressing the space bar on the keyboard with their right hand when they saw predefined target stimuli according to attention type (spatial: two locations are target stimuli, non-spatial: two patterns are target stumuli). The visual stimuli consist of five different patterns that were presented sequentially in a random order at one of five positions along the vertical midline of the screen. Each stimulus was presented every 2 seconds, and remaining on the screen for 1 second. 500 stimuli were presented in total over a period of ~15min, with 200 target stimuli and 300 non-target stimuli shown during that time period.

2.3 ECoG Recordings and Processing

During the Experiment, ECoG signals were recorded continuously at a sampling frequency of 1000Hz and referenced by the Pz on the scalp with a Stellate Harmonie System (Stellate, Montreal, Canada) for 7 participants and with a Nihon Koden EEG system 1200K (Nihon Koden, Tokyo, Japan) for 3 participants. The electrodes were identified by co-registered image between pre-operative T1-MRI data and post-operative CT data using the FMRIB software library (Oxford, UK). The locations of each electrode were transformed into the Talairach coordinate system using Curry software (Compumedics, Charlotte, NC, USA).

The Matlab (MathWorks, Natick, MA, USA) and EEGLAB toolbox (Swartz Center, CA, USA) were used for processing ECoG data. ECoG signals were processed with a band-pass filter from 1 to 200Hz and were re-referenced with a common average reference [4]. An independent component analysis (ICA) was performed to remove artifact components such as eye movement and muscle movements. ECoG signals were then segmented into 2000msec epochs from 500msec before stimulus to 1500msec after stimulus. Noisy epochs were then removed.

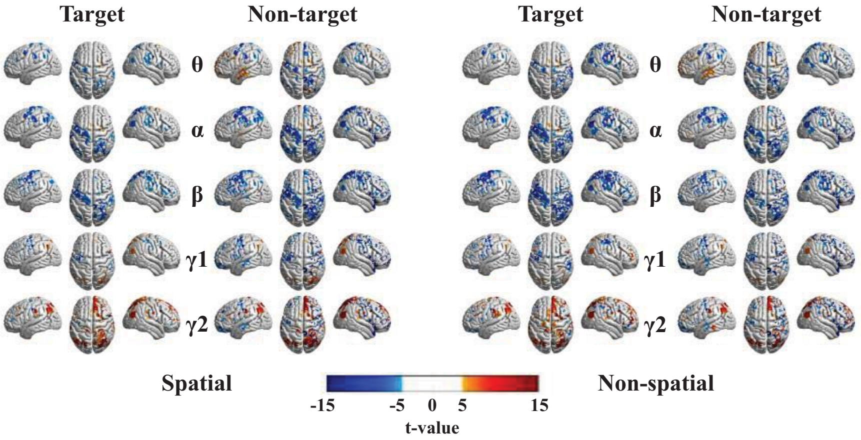

Figure 2: *T*-values calculated from the paired t-test during 400-600ms period after cue onset are mapped on the MNI brain surface. If the power of an electrode is significantly decreased, the *t*-value becomes negative and the region is colored blue. If the power of an electrode is significantly increased, the *t*-value becomes positive and the region is colored red.

Spectral analysis was performed using the short-time Fourier transform (STFT), which is one of the most widely used signal analyzing methods. Briefly, STFT divides the ECoG signal into small overlapping time segments, analyzes each time segment and provides a time-frequency distribution. In each 2000msec epoch, we used a 500msec sliding Hanning window with overlapping 7.5msec and obtained 200 time bins. After that the time-frequency features are reduced into 10 time bins (200ms window with 100ms overlap) and 5 frequency bands (theta: 4-7 Hz, alpha: 8-13 Hz, beta: 13-30 Hz, low-gamma: 30-50 Hz, high-gamma: 50-150Hz).

To evaluate the spatiotemporal change during spatial and non-spatial attention tasks, we computed paired t-test using the features of trials for each channel. *P*-values of less than 0.01% were considered statistically significant and the color plot (Figure 2) shows that the *p*-values following the t-values are much smaller than this criterion. We compared the spatiotemporal course during each spatial and non-spatial attention task with respect to the baseline interval (from 500ms before the cue to cue onset). In this analysis, the *p*-values were used for defining the significance of the feature and *t*-values were for identifying whether the power of the feature was increasing or decreasing in comparison with the baseline.

Electrodes of all participants were projected on the template brain provided by the Montreal Neurological Institute (MNI). The fractional changes in 5 frequency oscillatory powers were assigned to each electrode and the signal power was displayed with color. A nearest-neighbor method was used where a cortical triangular mesh was colored strongest when the closest electrode and a linear faded to zero as the distance increased [5].

3 Results

Significant activations are displayed over cortices following the presentation of the cue onset during both spatial and non-spatial attention tasks (Figure 2). Event related desynchronization (ERD) is common across low frequency bands (theta, alpha, beta), and in gamma bands show event related synchronization (ERS). Oscillatory power changes were salient at 400 ~ 600msec post stimulus onset and maintained to 600 ~ 800msec. Especially spatial attention shows focused ERD in right superior parietal lobe, whereas non-spatial attention shows stronger ERD in inferior parietal lobe in low frequency bands. Also, in high gamma band, the stronger ERS pattern is observed at the parietal area from the spatial attention and at the anterior frontal lobe from the non-spatial attention. According to the result from the non-target stimulus which the participants don't respond, these activation after 400 ~ 600msec post stimulus onset may not be affected by the button press or motor preparation.

4 Discussion

In this study, we analyzed ECoG signals to investigate oscillatory power changes in the processing of spatial and non-spatial attention in the bilateral cortex. The results demonstrated that both spatial and non-spatial attention seem like sharing common areas over the cortices for all frequency bands. In the right parietal area, we found some difference including spatial attention shows decreasing low frequency power in the superior parietal lobe while non-spatial attention appears to be desynchronized in the inferior parietal lobe. Although many studies about attention paradigm shows BOLD change using fMRI and most of them demonstrated that the BOLD signal has increased in the parietal region during the attention period [1], they were not able to show how the neural activity had been changed. To the best of our knowledge, this is the first study demonstrating the neural variation with spatiotemporal oscillatory power changes during spatial and non-spatial attention.

The current study drives a novel result that how the neural activity changes and which areas within cortices are the main role in both spatial and non-spatial attention tasks. A further study will let us know much more about the neural mechanisms of attention and it would be applicable to the passive mapping technique.

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