# SPECTRAL ANALYSIS OF THE CEREBRAL ACTIVITY DURING VOLUNTARY MODULATION OF MENTAL STATES

## *A High Resolution EEG Study*

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Abstract: In the neuroscience field, the use of advanced techniques of EEG recording and analysis, led to look for adequate methodology to prevent type I errors, which occur in computing thousands of univariate tests in order to highlight the brain areas in which significant activity arises. In this paper we illustrate the capability of tracking the brain activity during tasks consisting in tennis playing imagery and spatial navigation imagery, by using advanced high resolution EEG methodology accompanied by the use of appropriate statistical techniques that takes into account the risk of the Type I errors. Results showed that in the Spatial Navigation condition the power spectra activity is significantly different from the rest in the bilateral parietal areas and left motor area, while in the Tennis condition the cortical activity differs from the rest in bilateral parietal areas and in the left sensory-motor cortex. These preliminary findings are in partial accordance with previous hemodynamic studies.

## 1 INTRODUCTION

The rationale beyond this study relies on some considerations about the use of adequate statistical techniques in the framework of the neuroelectromagnetic brain mapping.

With the use of advanced EEG/MEG recording setup, involving a high number of sensors and thousands of sources, the issue of the protection against the Type I errors that could occur during the execution of a high number of univariate statistical tests has become of relevance.

Considering that in neuroscience, thousands of univariate tests are performed to highlight the brain areas in which significant activity arises, to seek for adequate methodology to prevent this type I errors has remarkable importance.

In this paper we illustrate the capability of tracking the brain activity during some mental imagery tasks (Owen et al., 2006), by using advanced high resolution EEG methodology in the time and frequency domains, accompanied by the use of appropriate statistical techniques that takes into account the risk of the Type I errors.

## 2 METHODS

### 2.1 Experimental Design

Five healthy volunteers took part in the experiment. All the subjects were informed about the aim of the EEG recording and signed an informed consent. Subjects seated in front of a monitor. They executed one of the three fixed imagery task (Play Tennis, Relax or Imagine to visit the rooms of your house) according to the position of a red target on the screen (Figure 1).

The experiment was divided into 6 sessions of 18 trials each (6 for each task), with events randomly ordered within each session. We set a task length of 15s and an inter-trial interval of 2s.

A 61-channel system was used to record EEG potentials by means of an electrode cap. Sampling rate was 200 Hz. EEG signals were then band pass

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filtered (1-45 Hz) and eye movements were removed from recordings utilizing Independent Component Analysis (ICA). For the EEG analysis we considered the interval [5:10] seconds in the middle of task execution.

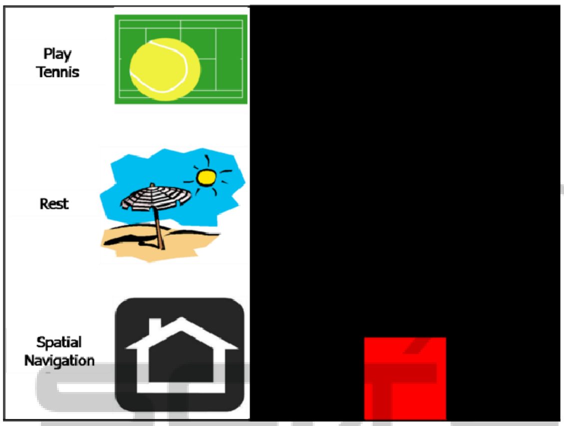

Figure 1: Stimulation window used for the experiment. Subjects were asked to execute a particular task of mental imagery according to the position of a red target on the screen.

## 2.2 High Resolution EEG

High-resolution EEG technologies have been developed to enhance the spatial information content of EEG activity.

Accurate estimates of the cortical current density could be obtained by using adequately detailed geometrical reconstruction of the main compartments lying between the cortical generator sources and the EEG sensors. These estimates can be obtained by solving a linear problem (Babiloni et al., 2005), by means of a transfer matrix (lead field matrix) that mimics the effects of the volume conductor. In mathematical terms the relationship between the modeled sources x, the lead field matrix A, the EEG measurements b and the noise n can be written as

$$Ax = b + n \qquad (1)$$

The solution of this linear system provides an estimation of the dipole source configuration **x** that generates the measured EEG potential distribution **b**.

The system includes also the measurement noise **n**, assumed to be normally distributed. **A** is the lead field or the forward transmission matrix, whose j-th column describes the potential distribution generated on the scalp electrodes by the j-th unitary dipole.

The current density solution vector $\xi$ was obtained as:

$$\xi = \arg\min_{x} \left( \|\mathbf{A}x - b\|_{\mathbf{M}}^{2} + \lambda^{2} \|x\|_{\mathbf{N}}^{2} \right) \qquad (2)$$

where M, N are the matrices associated to the metrics of the data and of the source space, respectively, $\lambda$ is the regularization parameter and $\|x\|_M$ represents the M norm of the vector x. The solution of Eq. (2) is given by the inverse operator G:

$$\xi = \mathbf{G}\mathbf{b} \qquad (3)$$

$$\mathbf{G} = \mathbf{N}^{-1}\mathbf{A}'\left(\mathbf{A}\mathbf{N}^{-1}\mathbf{A}' + \lambda\mathbf{M}^{-1}\right)^{-1} \qquad (4)$$

An optimal regularization of this linear system was obtained by the L-curve approach.

Using the relations described above, an estimate of the signed magnitude of the dipolar moment for each one of the 5,000 cortical dipoles was obtained for each time point.

## 2.3 Spectral Cortical Activity

From the cortical waveforms, we estimated the spectral activity, during the considered task time interval, for each one of the 5 thousands dipoles of the cortical model used.

T-test values obtained from comparisons between Tennis-Rest and Navigation-Rest were then mapped on the cortical model in different frequency bands, defined according to Individual Alpha Frequency (IAF) to take into account inter-individual differences in localization of alpha band. The IAF, defined as the individual frequency peak within the alpha band, was determined from the Fast Fourier Transform spectra over posterior leads (parietal, parieto-occipital, and occipital).

Individually defined bands considered were: Theta (IAF-6 / IAF-2), Alpha (IAF-2 / IAF+2), Beta (IAF+2 / IAF+14) and Gamma (IAF+15 / IAF+30). The uncorrected Student's test and the appropriate techniques of the False Discovery Rate (FDR) (Yoav and Yekutieli, 2001) and the Bonferroni correction for multiple comparisons were applied to the evaluation of the power spectral maps estimated from the data.

# 3 RESULTS

By following the procedure and the methods illustrated above, we obtained statistical scalp and cortical maps for each frequency band of interest and experimental condition.

In the following figures, T-test values,

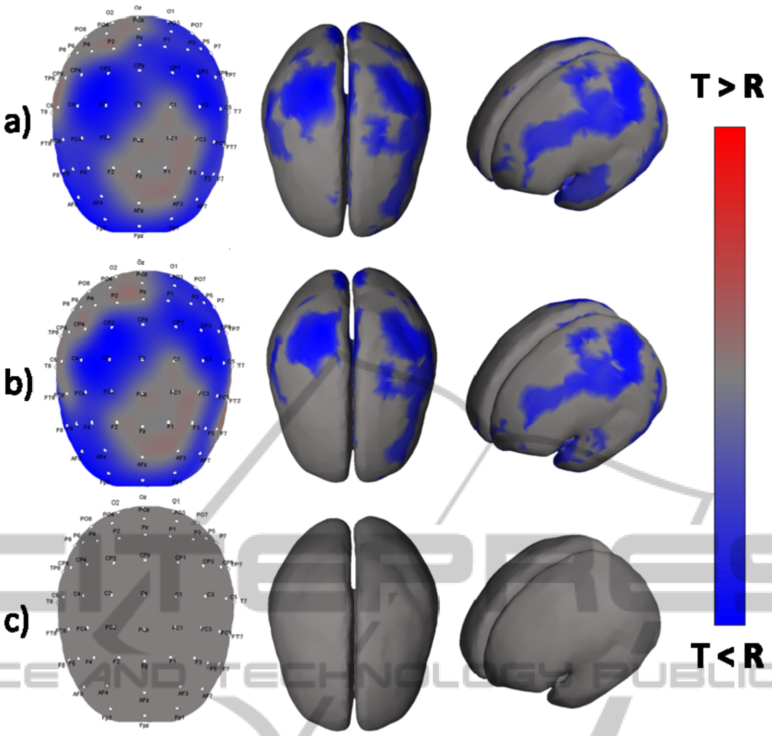

Figure 2: Statistically significant spectral maps in the Alpha band, depicted on the average brain model used in the analysis. The color scale codes for the value of the t-test in that pixel for the comparison Tennis versus Rest, in three different cases: a) no correction; b) False Discovery Rate; c) Bonferroni.

corresponding to a statistical significance of 0.05, were mapped on scalp and cortical average model in three different cases: no correction for multiple comparisons (panel a), FDR correction (panel b) and Bonferroni correction (panel c). The head is seen from above, with the nose pointing down. For each comparison, only frequency bands with significant statistical activations are presented.

In Fig. 2 we show results in a representative subject, describing the statistically significant spectral maps in the Alpha band for the contrast Tennis task (T) versus Rest condition (R).

Scalp maps, obtained without applying any corrections for multiple comparisons (Figure 2a) reveal a decrease of EEG activity in Tennis task on electrodes located in the posterior areas, in the central part of right side of the head and in the frontal region. Cortical maps lead to a better localization of deactivated areas, in particular in the bilateral parietal lobes and left motor cortex.

In both scalp and cortical maps the corrections for multiple comparisons, needed to prevent Type I errors, brings to a decrease of the number of activated pixels on the cortex model. In particular, low reduction in the size of activated areas is shown for FDR correction (Figure 2b), while no significant activations survive using Bonferroni methods (Figure 2c).

In Fig. 3 we show results in a representative subject, describing the statistically significant spectral maps in the Alpha band for the contrast Navigation task (N) versus Rest condition (R). Significant activations on scalp model, not corrected for multiple comparisons, result in left parietal and central areas (Figure 3a). Cortical maps lead to a better localization of deactivated area, in particular in the bilateral parietal and left motor area. Low reduction in the size of activated areas both on scalp and cortical model, is shown for FDR correction (Figure 3b). No significant activations were found using Bonferroni correction for multiple comparisons (Figure 3c).

## 4 CONCLUSIONS

Thanks to the high resolution EEG techniques and the appropriate use of statistical methods, we tracked the subject's brain activity during different imagination tasks. Analyzing the effect of the two methods of correction for multiple comparisons on

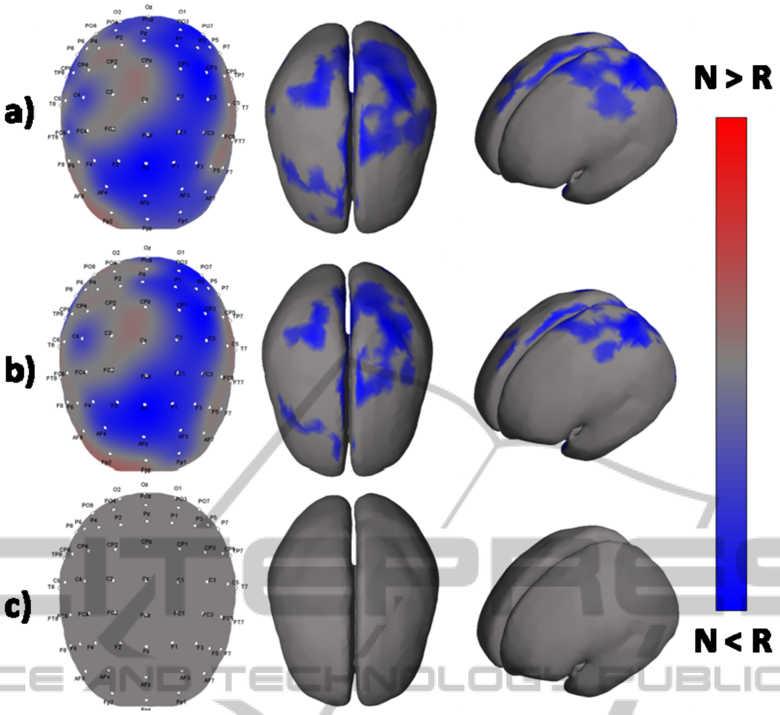

Figure 3: Statistically significant spectral maps in the Alpha band, depicted on the average brain model used in the analysis. The color scale codes for the value of the t-test in that pixel for the comparison Navigation versus Rest, in three different cases: a) no correction; b) False Discovery Rate; c) Bonferroni.

the estimated areas, the technique of False Discovery Rate results as a good compromise to prevent both type I and type II errors. In fact in the Bonferroni method, the increased incidence of false negative led to non-physiological results.

As a whole, these results suggest that the high resolution EEG spectral mapping opens a way to address the analysis of brain imaginative functions, allowing to discriminate between different mental states without the limitations of the use of an fMRI scanner.

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