INDICATORS IN BRAIN REGIONS: THE ENERGY SPATIAL PATTERNS

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Abstract: In this work, a methodology to investigate Energy Spatial Distribution (ESD) has been set up focusing on the analysis of the generic spatio-temporal patterns from different brain regions. An energy indicator has been defined and evaluated on signals filtered in the well-known *neural activity bands.* The identification of energy distribution on brain areas gives a further contribution to understand spatio-temporal neural dynamics in these bands of interest.

Introduction

In the past literature many topics on correlation between neural activity and frequency ranges in particular brain states are continuously investigated [1-2]. Looking at the frequency distribution of neural signals the investigated range is consolidated to be up to one hundred hert z. In particular, it is generally accepted that low frequency components give the higher contribution to the whole energy exhibited by the active cortex. Starting from these remarks a further characteristic of brain dynamics must be faced: the time and spatial distribution on brain regions. Several techniques have been developed to acquire brain signals originated in time and space by active cortex. The most common are Electroencephalography (EEG) and Magnetoencephalography (MEG), both without any invasive recording of deep brain layers.

Thus, the complexity of the recorded signals requires the definition of appropriate indicators characterizing spatio-temporal patterns [3]. These spatio-temporal data and the related brain activity can be analyzed through their fundamental features such us the energy exihibited in various brain states.

In this work, the active cortex energy has been investigated in the main *neural activity bands* [4-5]. The main goal is to distinguish the spatial relationship between frequency bands and energy patterns. The case study is based on recordings of the cortex magnetic field during well established breathing protocols. The measures have been performed using a 148-channel whole-head Magnes 2500 Biomagnetometer (4-D Neuroimaging, San Diego, California) located at The Scripps Research Institute (La Jolla, CA). The analysis has been performed by adopting an energy indicator that reported on the scalp gives information on the Energy Spatial Distribution. This methodology allows the characterization of brain regions mainly involved in opportune frequency intervals and related to particular states of the subject.

In the first section the measurement system and the protocols are described focusing on the exercise timing. Moreover, the methodology adopted to study the Energy Spatial Distribution (ESD) is illustrated and the indicator is defined. The second section illustrates the results obtained by analyzing the available datasets during the whole protocol timing. In particular, the brain region indicator has been reported on the scalp to focus on the spatial proprieties of the ESD. In the Discussion section some remarks have been reported about the effects of the protocol timing on the ESD. Moreover, it has to be underlined that the brain energy indicator changes, probably as a result of the iteration of the breathing protocol on the subsequent experiments.

Materials and Methods

Case Study: The present study has been performed on Magnetoencephalographic data recorded using a 148-channel whole-head Magnes 2500 Biomagnetometer. The magnitude of the magnetic field associated with the active cortex is extremely low; it is estimated that the magnetic field of the alpha wave is approximately 0.1 pT at a 5 cm distance from the scalp surface.

In this application a Superconducting Quantum Interference Device (SQUID) magnetometer uses 148 channels. Each of the 148 pick up coils produces a voltage proportional to the magnetic field radial to the head, resulting in preferential sensitivity to neural electrical sources tangential to the surface of the scalp, sources emanating from cortical sulci. Only one subject was employed during the considered protocol that is highly trained with yogic breathing meditation techniques and as a subject with MEG experimentation. Head shape was digitized, based on known locations on the subject's head (tragus of left and right ears and nose). Head shape data is for later coregistration between measurement coil locations, electrode locations, and scalp landmarks. Eye movements were recorded with electrodes placed above and below the right eye.

Six datasets have been recorded from a subject performing two well-practiced breathing protocols [6] used for treatment of obsessive compulsive disorder as reported in Table 1. Both protocols have the same timing and the patient performs selective breathing

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through either the left nostril (using a plug for the right nostril) or the right nostril (using a plug for the left nostril). In particular, the timing is constituted by three phases: 10 min of resting; 31 min of breathing at a respiratory rate of one breath per minute; 10 min of resting.

Table 1: Datasets of recorded MEG activity.

Left Nostril Exercise	Right Nostril Exercise
2075.5 (13th June 2000)	2075.6 (14th June 2000)
2075.7 (18th July 2000)	2075.8 (19th July 2000)
2075.9 (8th August 2000)	2075.10 (9th August 2000)

Energy Spatial Distribution: The adopted methodology consists of two steps. First of all the recorded signals have been filtered by using a band pass filter and then their energy has been evaluated by using an appropriate indicator [2]. The index of equation (1) is calculated by considering the autocorrelation at lag zero of a generic signal $x_i(n)$, constituted by N samples, where $i=1,\dots,148$ is the recording channel.

$$C_i = \frac{1}{N}\sum_{n=0}^{N-1} |x_i(n)|^2 \tag{1}$$

The MEG signals have been filtered according to the well-known frequency ranges reported in Table 2 and then the energy has been calculated in all phases of the protocols.

Table 2: *Neural Activity Bands.*

Band	Range (Hz)	Activity
Delta	0.1-4	Deep-Sleep
Theta	4-8	Towards Deep-Sleep
Alpha	8-12	Awake - Resting
Beta	12-20	Emotional Processing
Gamma	30-54	Conscious Processing

Results

The datasets have been split in two-minute subset and the ESD has been performed on each subset in all *neural activity bands*. The five panels of Fig. 1 summarize the results obtained on the 2075.5 dataset. The index C has been reported by using 64-color maps coding the intensity: the red color identifies the highest energy level; while the blue color is adopted for the lowest energy level.

The first map shows the intensity of the magnetic field energy in the delta band. Its maximum value is double compared to the other bands. This result confirms the higher contribution of the low frequency components to the whole energy exhibited by the active cortex. Fig. 1 shows that some ESD strip structure can be identified, thus revealing subsets of channels which can be related to regions of high energy in each *neural activity band* as reported in Table 3.

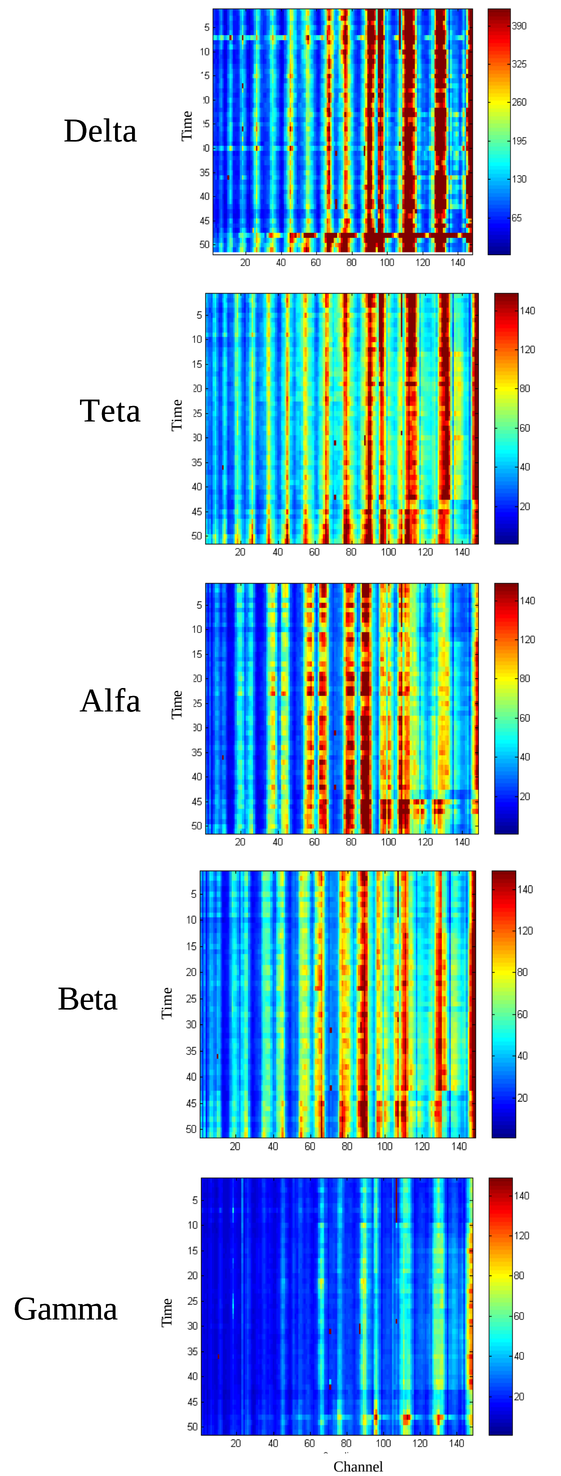

Figure 1: Energy Spatial Distribution in the *neural activity bands* during all phases of the left nostril protocol (2075.5).

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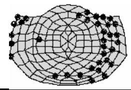
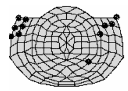
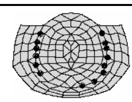
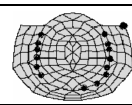
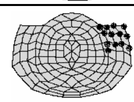
Table 3: Active channel distribution vs. *neural activity bands*.

Delta	**25, 35, 62-78, 82-95, 105-115, 125-135**	
Theta	**115, 130, 80, 85, 90, 148**	
Alpha	**75-80, 85-90**	
Beta	**75-80, 85-90, 148**	
Gamma	**90, 110, 130, 148**	

Thus, the energy spatial distribution on the scalp has been studied in details by considering opportune subset of two minutes each, as indicated in Table 4.

Table 4: Selected minutes of the three protocol phases.

Rest Phase I	5-6
Exercise Phase	25-27
Rest Phase II	46-48

Figs. 2-4 report the distribution of the index *C* considering both the frequency bands and the protocol phases in all datasets. The ESD shows maxima and minima in specific regions of the scalp and underlines the difference between the exercise and rest phase. Moreover, the two protocols are clearly characterized: the neural activity shows an antisymmetric behavior during the exercise phase in all the bands.

The Energy Spatial Distribution on scalp identifies brain regions that are mainly involved in the spatio-temporal neural activities:

- temporal-parietal region for the delta and the gamma band;
- temporal-parietal and occipital region for the theta and the beta band;
- occipital region for the alfa band.

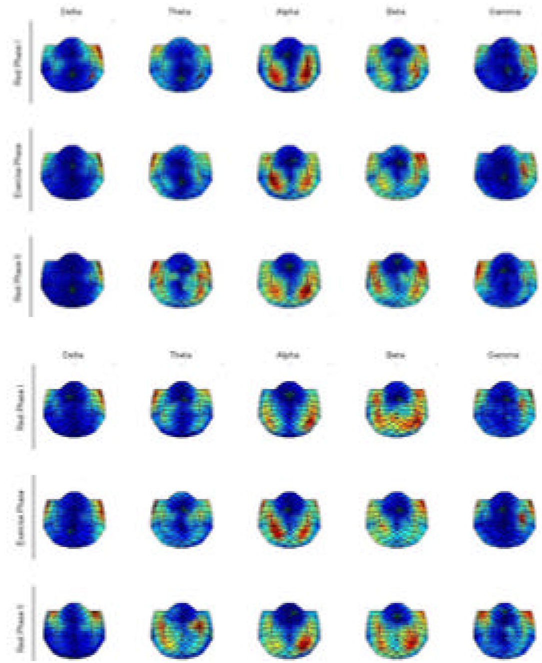


Figure 2: Energy Spatial Distribution during 2075.5 left nostril (above) and 2075.6 right nostril (bottom) protocols.

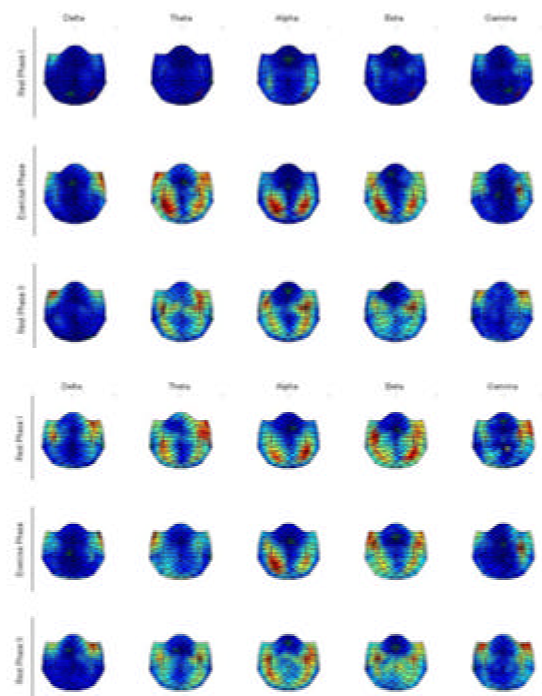


Figure 3: Energy Spatial Distribution during 2075.7 left nostril (above) and 2075.8 right nostril (bottom) protocols.

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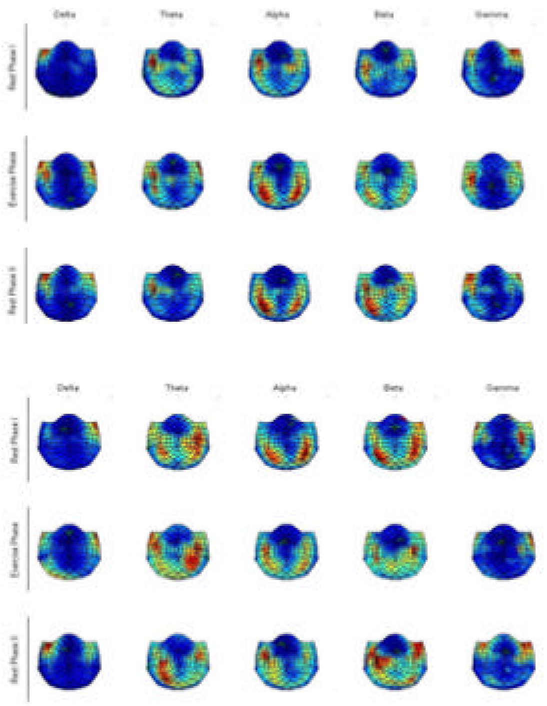

Figure 4: Spatial Energy Distribution during 2075.9 left nostril (above) and 2075.10 right nostril (bottom) protocols.

Discussion

In all the datasets, the ESD has the highest intensity during the exercise phases only in the gamma band: the left nostril protocol shows a higher gamma activity in the right hemisphere while the right nostril one shows the active zone in the left side of the scalp. This means that conscious activity is involved in the exercise phase. Moreover, Energy Spatial Distribution changes its strip structure according to the sequence of the experiments from June (2075.5) to August (2075.9). It can be underlined in Fig. 5 that the ESD in the gamma band decreases its amplitude in the exercise phase. This withnesses the effect of the training in performing the exercise.

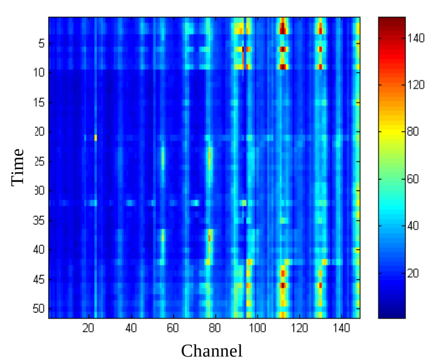

Figure 5: Energy Spatial Distribution during 2075.9 left nostril in gamma band.

The ESD in the low frequency *neural activity bands* does the opposite, it intensifyies the contribution of these components to the whole energy exhibited by the active cortex. These results are clear by comparing the map on the bottom of Fig.1 and the Fig.5 both related to gamma band.

Conclusions

In this work, a spatial approach is adopted to investigate signals generated by active cortex. The defined indicator has been calculated and reported to the scalp to identify the brain regions that mainly contribute to energy distribution. The proposed approach has been applied to MEG datasets recorded during a well-established breathing protocol. The results show a strict relation between brain zones and the spatio-temporal neural activities. The temporal-parietal region is mainly activated by the delta and the gamma band components. The temporal-parietal and occipital region are related to the theta and the beta band. The occipital region shows the higher energy levels in the alfa band.

The systematic analysis of several datasets obtained in subsequent recording periods allowed us to draw important conclusions of the protocol itself. For instance, after the exercise and the recording protocol have been performed several times, the energy in the gamma band during the exercise phase decreases.

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