

## PSYCHOPHYSIOLOGY

Yavna D.V., Ermakov P.N., Babenko V.V.

### Use of Independent Component Analysis for localization of evoked activity sources in distinguishing texture modulations Localization of evoked activity sources in distinguishing texture modulations using Independent Component Analysis

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*Contrast, orientation and spatial-frequency texture modulations are detected by second-order visual mechanisms. Psychophysical data gives the evidence of the second-order mechanisms selectivity (specificity) to the listed types of modulations. This selectivity can have different cerebral localization of second-order mechanisms in it's basis. The aim of current research was to check this assumption using psychophysiological methods. It was shown that evoked activity sources recorded in solving the task of distinguishing types of modulation are located in different cortex areas. This fact is psychophysiological evidence for second-order mechanisms specificity.*

**Key words:** texture, modulation, evoked potentials, Independent Component Analysis, dipole source.

#### Introduction

Second-order visual mechanisms perform preattentive spatial grouping of local information at the early stages of visual processing. Studying second-order mechanisms is needed to understand how local features, processed at the primary visual cortex stage are combined into cognitive blocks.

Classical models of second-order visual mechanisms, known as "second-order models" [5], "non-Fourier" [7, 12], "functional funnel" [1], "back-pocket" [6] or "complex channels" [8], all were non-specific to the modulating parameter of texture image (contrast, orientation or spatial frequency (SF)). Thus, second-order filter response increases when contrast of texture elements that land in second-order receptive field periphery decreases. But we see the same result changing orientation or SF of these elements. In other words, second-order filters pass any modulation. First time such second-order non-specificity was questioned by Kingdom F. et al. [9] in a study that was carried out using the psychophysical paradigm of spatial summation. And a number of more recent studies using masking [4] and adaptation paradigm suggested the



existence of independent channels in a structure of second-order mechanisms, that are selective (*specific*) to the type of second-order modulation.

Second-order mechanisms specificity previously was shown only by psychophysical methods. The aim of current research was to check this assumption using objective parameters. This parameter was evoked brain activity recorded in a response to modulated and non-modulated texture presentations.

Analysis of dipole sources of independent EEG components relative to evoked brain activity, allows to determine general features of the EP generators spatial distribution in identifying different types of stimuli. Data on their various cerebral localization could be an additional argument on the issue of the second-order mechanisms specificity.

### **Methods**

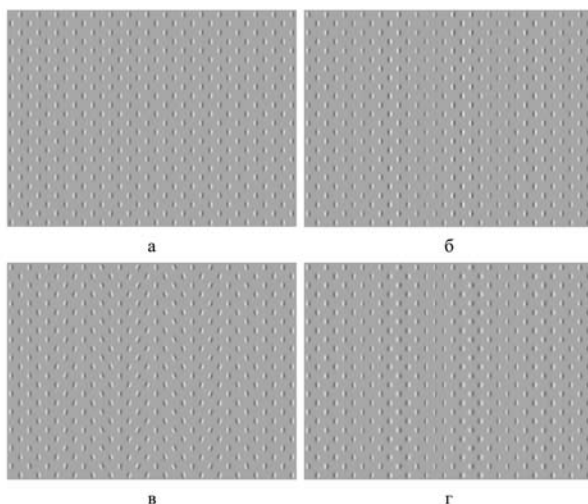
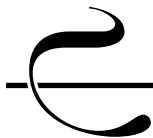
Stimuli were textures composed of staggered Gabor micropatches and presented in 256 shades of gray. Chess field cell size was 0.44 x 0.44 deg. We used four types of textures: non-modulated (NM) and modulated by contrast (MC), orientation (MO), spatial frequency (MF). Spatial frequency of non-modulated texture was 3.5 cycles per degree, the orientation of Gabor elements was vertical, the contrast of elements equaled 0.5. Stimuli average luminance was constant and equaled 135 cd/m<sup>2</sup>.

Modulation was performed by multiplying carrier by envelope (two-dimensional sinusoidal modulation function, the modulation axis is perpendicular to the orientation of micropatterns). Envelope amplitude declined gradually to the screen edges via multiplying it by two-dimensional half-wave cosine. Spatial frequency of the envelope was 0.3 cycles / deg. Envelope didn't produce any significant changes in the spectrum of the stimulus. Modulation amplitude (variation range of a local texture feature from the original to the maximum / minimum value) was 1.5 dB for contrast, 20 deg. for orientation and 3 dB for the spatial frequency (see Fig. 1).

Stimuli were presented on the LG Flatron 775FT monitor (grain size 0.24 mm), calibrated with luxmeter. During the experiments the screen resolution was set to 1024 x 768 pixels, vertical frequency – 85 Hz. The subjects were located at a distance of 130 cm from the monitor, so it's size was equal to 14 x 10.5 deg.

Four types of stimuli (NM, MC, MO and MF), randomly following each other, were presented on the display 120 times each. The task was to determine the type of the presented texture by pressing a certain key on the remote keypad. The exposure time of the stimulus was 500 ms, the interval between the response of the subject and the next presentation of stimulus randomly varied in the range of 1 to 3 seconds.

Monopolar EEG was recorded during the whole experiment. We used 10–20 system without Fpz, instead of it zero-electrode was set. We used the «linked-ears» references. At the same time we recorded trigger labels containing information about the type of stimulus and the time of its presentation. EEG signal sampling rate was 1 kHz. The recording was performed using digital amplifier «Neurovizor-BMM40» (LLC «Neurorobotiks»).



**Fig. 1.** Textures used in our experiment:

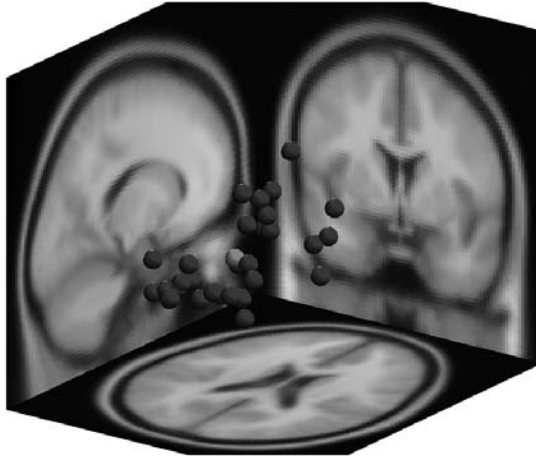
a) non-modulated, b) modulated by contrast (amplitude 1.5 dB), c) modulated by orientation (amplitude 20 deg.), d) modulated by spatial-frequency (amplitude 3 dB)

24 subjects with normal vision aged 20 to 34 years took part in the experiment. All subjects were informed about the procedure of experiments, verified in the health-safety and agreed to participate in research.

## Results

EEG-recording as a set of post-stimulation 500 ms epochs was ICA-decomposed using infomax procedure. Decomposition was carried out individually for each subject and the type of texture stimulus. After that the degree of contribution of each of the independent components in the evoked brain activity was assessed, using indicator based on the Pearson correlation coefficient and corresponding to *nominal accumulation coefficient*. Nominal accumulation coefficient can be calculated, for example, as the correlation between the epochs that follow the presentation of even and odd stimuli [3]. Low values of this parameter indicates that the signal does not contain synchronous with presentation of the stimulus (phase-locked) components, i.e. is formed by a source unrelated to the generation of evoked potentials [3].

In our case, average value of Pearson correlation between all after-stimulation epochs of independent component was used as a nominal accumulation coefficient. Practically, it means assessing the extent of signal waveform frequency from presentation to presentation. To decide if the component makes a significant contribution to the evoked activity, cut-off criterion is used. Threshold value of accumulation coefficient is critical Pearson correlation coefficient with  $p < 0,05$ .



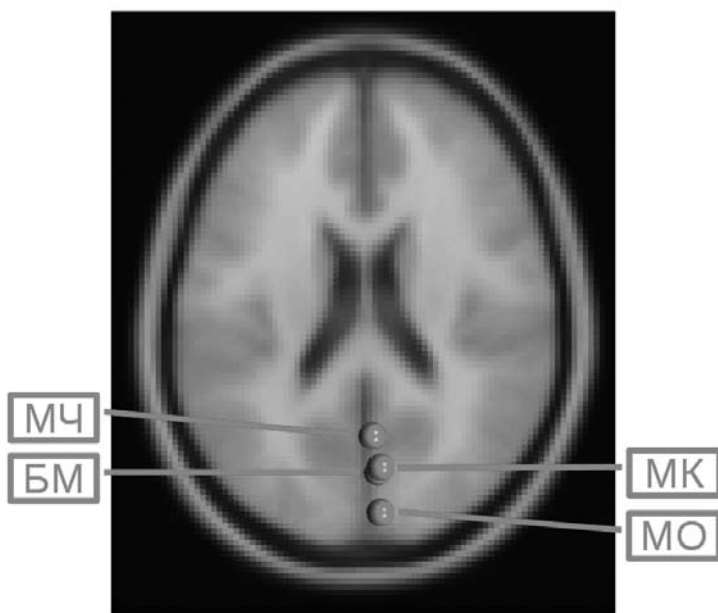
**Fig.2.** The spread of the components dipole sources (blue spheres) and the centroid (red sphere) with a significant contribution to evoked activity upon presentation of MO

Dipole sources characteristics of selected components were calculated using single-dipole model. For further analysis, only components with sources located within brain, or close to it (including information about errors described in [2]) were selected. It turned out that “clouds” of selected independent component sources had large dispersion for all types of experimental conditions. The same time sources in the occipital region were substantially more dense, forming «clots» (Fig. 2). In order to extract additional information from the distribution of dipole sources, their coordinates were subjected to automatic classification using k-means algorithm in EEGLAB system. Sources localizations were divided into 2 clusters for each type of experimental conditions.

Cluster analysis allowed to combine occipital “clots” of dipole sources into separate classes. Model residual dispersion for the centroid (average dispersion of the cluster) was low: 9% for MC, 8% for MO, 8% for MF, 11% for NM. Central clusters joined a relatively small number of sources with a bit larger spread.

The obtained result is illustrated by Fig. 3, where the localization of occipital clusters centroids for each of the used textures is shown. The figure shows that the occipital clusters of independent components, providing a high contribution to the evoked activity under different experimental conditions, have slightly different location. Occipital clusters centroids are located in the following points of atlas J.Talairach [11] space (X; Y; Z): 6, -70, 9 (MC), 6, -86, 8 (MO), 3, -59, 5 (MF) and 5-71, 21 (NM). MF centroid is at a distance of 20.1 mm from the NM centroid, MO centroid at 19.87 mm, MC centroid at 12.08 mm. The distance between MO and MF centroids is 27.33 mm. Thus, the centroid of the MF occipital cluster is significantly more frontal than others.

Statistical significance of variance differences of EP dipole sources occipital clouds was estimated by results of discriminant analysis. For a pair of clouds MC:NM Wilks' lambda statistic ( $\lambda_w$ ) was equal 0.9, approximate  $F=1.0016$ , from which  $p<0.4$ , what may indicate the randomness of variance. In contrast, for pairs MO:NM and MF:NM results were, respectively,  $\lambda_w=0.58977$ ,  $F=6.0283$ ,  $p<0,01$  and  $\lambda_w=0.82883$ ,  $F=2.5816$ ,  $p<0.1$ , which suggests non-randomness of differences in the sources distribution.



**Fig.3.** Dipole sources occipital clusters centroids for MC, MO, MF, NM.

Lets look at the possible version of reference between found sources and anatomical cerebral structures. We used Talairach electronic atlas [10] allowing to perform several types of searches using anatomical coordinates. For occipital clusters centroids we used search within cube with sides of 11 mm, and center located at the point described by specified coordinates. Tables 1, 2, 3, and 4 show search results for MC, MO, MF, and NM respectively. The column «Weight» represents the number of points («voxels») within a cube having the same anatomical label.

In our case, the values from «weight» column can be considered as estimates of the degree of structure involvement in the generation of evoked activity. On the other hand, they also can be used to estimate the *probability* of structure involvement in the process.



Table 1

**Anatomical labels within a cube with sides of 11 mm around occipital cluster centroid for MC (6, -70, 9) by Talairach electronic atlas [10] (gray matter)**

Weight	Hemisphere	Lobe	Gyrus	Brodmann area
140	Right	Occipital	Cuneus	23
116	Right	Limbic	Gyrus Cinguli Posterior	30
100	Right	Occipital	Cuneus	30
64	Right	Occipital	Gyrus Lingualis	18
58	Right	Occipital	Cuneus	18
31	Right	Limbic	Gyrus Cinguli Posterior	31

Occipital cluster centroid of dipole sources components involved in the generation of EP to MC, is located laterally-right (6 mm shift to the right) in 1 mm from the gray matter of the 30th Brodmann area, in cuneus gyrus of occipital cortex. As it appears from Table 1, gray matter from 23, 18 and 31 areas is in the close proximity to the centroid.

Occipital cluster centroid of dipole sources components involved in the generation of EP to MO, is located laterally-right in the gray matter of the 17th Brodmann area, in cuneus gyrus, not far from the 18<sup>th</sup> area boarder (Table 2).

Table 2

**Anatomical labels within a cube with sides of 11 mm around occipital cluster centroid for MO (6, -86, 8) by Talairach electronic atlas [10] (gray matter)**

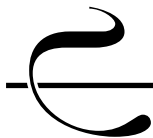
Weight	Hemisphere	Lobe	Gyrus	Broadmann area
298	Right	Occipital	Cuneus	17
140	Right	Occipital	Cuneus	18
102	Right	Occipital	Gyrus Lingualis	17
27	Right	Occipital	Gyrus Lingualis	18

Occipital cluster centroid of dipole sources components involved in the generation of EP to MF, is located medially (with 3 mm shift) in 1 mm from the 30th Brodmann area's gray matter, in the posterior cingulate gyrus, close to 30, 18, 19 and 29 fields (Table 3).

Table 3

**Anatomical labels within a cube with sides of 11 mm around occipital cluster centroid for MF (3, -59, 5) by Talairach electronic atlas [10] (gray matter)**

Weight	Hemisphere	Lobe	Gyrus	Brodmann area
111	Right	Limbic	Gyrus Cinguli Posterior	30
44	Right	Occipital	Cuneus	30
36	Right	Occipital	Gyrus Lingualis	18



21	Right	Occipital	Gyrus Lingualis	19
12	Right	Occipital	*	19
9	Right	Limbic	Gyrus Cinguli Posterior	29
7	Left	Limbic	Gyrus Cinguli Posterior	30
4	Left	Limbic	Gyrus Cinguli Posterior	29

Occipital cluster centroid of dipole sources components involved in the generation of EP to NM, is located laterally-right (with 5 mm shift) in the gray matter of the 18<sup>th</sup> Brodmann area, in cuneus gyrus, close to the border of the 31<sup>th</sup> area (Table 4).

Table 4

**Anatomical labels within a cube with sides of 11 mm around occipital cluster centroid for NM (5, -71, 21) by Talairach electronic atlas [10] (gray matter)**

Weight	Hemisphere	Lobe	Gyrus	Brodmann area
274	Right	Occipital	Cuneus	18
149	Right	Occipital	Precuneus	31
136	Right	Parietal	Precuneus	31
42	Right	Limbic	Gyrus Cinguli Posterior	31
2	Right	Occipital	Cuneus	*

### Conclusion

Occipital clusters centroids for MC and NM are relatively close to each other, located in the border area of primary and secondary visual cortex; whereas the occipital cluster centroid for MF is shifted to the limbic cortex, the retrosplenial area and the posterior cingulate gyrus. In contrast, the centroid for MO is shifted to the primary visual cortex. The differences in the dipole source localization of independent components in different experimental conditions may indicate that there is different localization of the second-order filters in the human cortex, what is compatible with the concept of specificity of second-order visual mechanisms.

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