Location of Biomagnetic Activity Sources in the Brain during Acoustic Stimulation

S. A. Makhortih and R. A. Semechkin

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It is shown that spectral correlation analysis of magnetic field of human brain can be used to solve the problems of functional neurophysiology: mapping of the brain areas involved in the solution of certain higher nervous activity tasks (perception, processing of external stimuli, *etc.*). Location of sources of biomagnetic activity in human brain was carried out during acoustic stimulation. The resultant iterative location procedure converges to the true coordinates and amplitudes of sources and provides location at accuracy of 2-5 mm.

Key Words: *spectral correlation analysis; magnetic encephalography; iterative method for location of magnetic activity sources*

Magnetic encephalography (MEG) is a method for measurement and visualization of magnetic fields emerging as a result of electric activity of the brain. If the model of the studied field generation is known, it is possible in principle to detect its sources (locate them in the brain and evaluate their electrical parameters). In medicine, MEG is used primarily for studies of cerebral diseases manifesting by disorders in the CNS electric activity. We previously described the location of pathologic activity zones in Parkinson's disease, which is very important for planning surgery in these patients [4]. This approach can also be used in functional neurophysiology: mapping of brain areas involved in the solution of certain higher nervous activity tasks (perception, processing of external stimuli, *etc.*). The main advantage of MEG over classical EEG is far higher homogeneity of the magnetic field models (relationship between the parameters and the time and spatial coordinates can be neglected), while in EEG the intracranial heterogeneity of electroconducting environment can essentially modify the structure of the generated electric field [2,5]. Since detailed information on the brain structure of a patient cannot be obtained by noninvasive methods, the use of available models for solution of inverse problems of location leads to great errors in evaluation of the system parameters. Practice shows that errors in location of MEG sources are by about one order of magnitude lower in comparison with EEG errors [9].

We attempted to solve the problem of location of sources of biomagnetic activity in the brain cortex during exposure of the examined subject to external acoustic stimulation. The pair of sources emerging in this case is rather difficult to be located because of absence of sufficiently precise initial approximation. The iterative approach to determination of the coordinates of the pair of sources and a complex of spectral methods for murmur elimination from experimental data and for identification of the emerging sources type are suggested. Analysis of correlation of stochastic activity of the biomagnetic response during external stimulation and without it has been carried out.

Measurements of biomagnetic fields of the brain in normal subjects were carried out at New York Medical School on a Magnes 2500 WH magnetic encephalometer. The measured signal represented

Institute of Mathematical Problems of Biology, the Russian Academy of Sciences, Pushchino, Russia. ***Address for correspondence:*** ras@impb.ru. R. A. Semechkin

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a spatial and time structure: a 148-dimensional vector of measurements in 148 points on the head surface, unfolded in a time series with 500 Hz frequency of pickup scanning. An acoustic signal at pulse frequency of 7 Hz was presented into one ear of the volunteer. General biomagnetic activity of the brain was recorded during experiment. After preliminary processing of MEG data by means of software attached to the magnetic encephalometer, a useful (or close to it) signal was recorded. Measurements detected the periods of high activity, for which the problem of spatial location of the sources was solved. The presence of several excitation zones in the cerebral cortex and a significant murmur constituent in the record deteriorated the accuracy of location or even impaired the location algorithm. Preliminary processing of records on a Magnes device should be supplemented by special procedures for murmur elimination (Fig. 1).

Murmur was removed from initial records of biomagnetic activity by discrete wavelet transformation (a special type of linear transformation of signals and of physical data on the processes and physical characteristics of natural media and objects, reflected by these signals). Simlet served as the maternal wavelet [1]. These wavelets are characterized by properties essential for effective use as filters; for example, they form an orthonormed basis, have a compact carrier, and are symmetrical, this all allowing most effective filtration of biomagnetic data [3].

The resultant spectro- and periodograms showed the main frequency at which the activity was high: 10 and 20 Hz. The source working at a frequency of 20 Hz was more potent. The next step was filtration of biomagnetic signal (Fig. 2) for 10 and 20 Hz. The problem of sources location was solved for each type of filtered data. Sources of excitation were located in the temporal lobes of the cerebral cortex (Fig. 3).

The structure and spatial characteristics of the source are essential for realization of MEG. If the source is compact, it can be simulated by a common current dipole [4] and the problem of identification of the resultant model can be in generally solved by means of, for example, MRIAN software for Matlab system [6]. If the source is not compact or there are several sources in the system, their location is rather difficult; a sufficiently accurate initial approximation during initial fitting of the parameters or development of additional procedures for location is needed to solve the problem.

One more specific feature of biomagnetic fields is their insensitivity to transverse (for the radius vector of the source) current constituents. This leads to incorrectness (ambiguous solution) of the inverse problem. However, this is not principally important for the possibility of applying the method to solution of concrete neurophysiological problems.

Solution of the inverse problem of the sources location is based on minimization of error in the model B_i and measured B_i^e fields distribution:

$$f=\sum_{i=1}^{N} w_i(B_i-B_i^e)^2 \rightarrow \min,$$

where i is channel (pickup) No., w_i is channel weight, and N is number of channels (148 in our case).

The measure of the estimation precision in this case can be evaluated by the formula:

$$G=1-\frac{\sum_{i=1}^{N} w_i(B_i-B_i^e)^2}{\sum_{i=1}^{N} w_i(B_i^e)^2}.$$

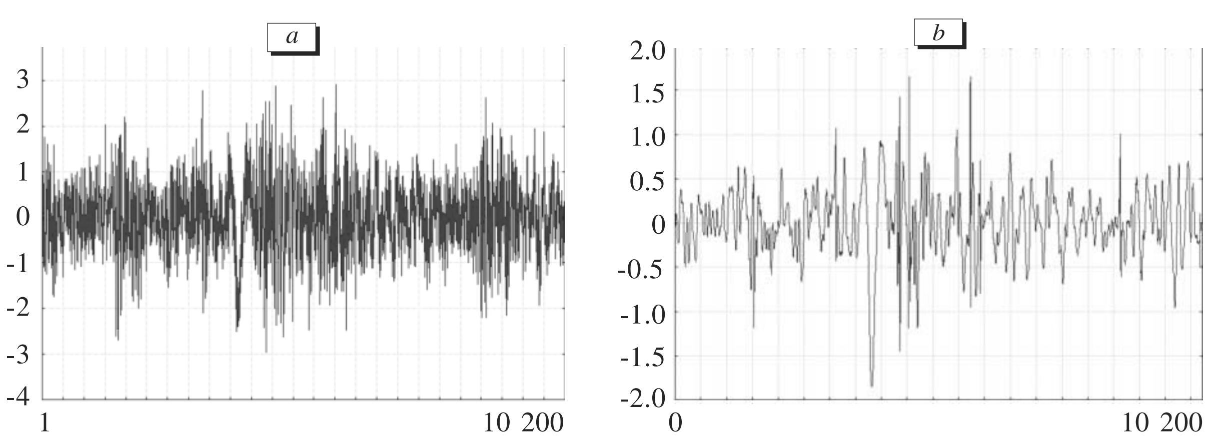

Fig. 1. The most important coefficient (harmonic curve) before (*a*) and after (*b*) murmur elimination. Abscissa: time points (1 point=1/500 sec); ordinate: expansion coefficient values.

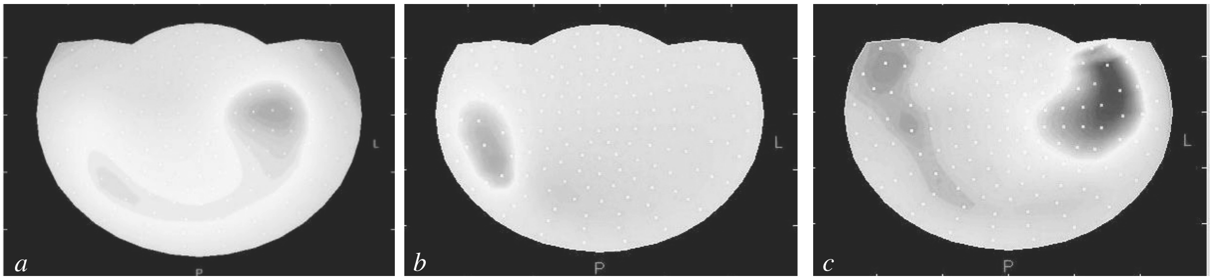

Fig. 2. Distribution of magnetic field before (*a*) and after filtration at 10 Hz (*b*) and 20 Hz (*c*) during the same moment.

The iterative approach is suggested for precise search for coordinates and amplitudes of sources. It consists in successive approximations on the base of solution of the inverse problem with one source. Due to this approach it is possible to plot the convergent procedure due to difference in the amplitudes of two sources for monolateral (one ear) stimulation.

The approach consists in the following. At stage 1 we assume that there is only one source and solve the problem of its location by means of, for example, MRIAN. The resultant solution leads to significant errors in the plotted model $B_I^{(1)}$ and initial experimental B^e data. Then we assume that the resultant error is caused by the field from the second source. Hence, the problem of location is solved with one source for B^e-$B_I^{(1)}$ field distribution. The located source generates model field $B_I^{(2)}$. At the next stage the successive approximations of B^e-$B_i^{(1)}$ and $B_i^{(2)}$ fields are adjusted, where i is the number of iteration. For our case with expanded sources with a great difference in amplitudes, the procedure is confined to the true values of coordinates $r_0^{(1)}$ and $r_0^{(2)}$ and the current moments $Q^{(1)}$ and $Q^{(2)}$. The resultant error is:

$$\Delta_l = \sum_{j=1}^{N_s} |B_{l,j}^{e} - B_{l,j}^{(1)} - B_{l,j}^{(2)}| \to 0,\ l \to \infty.$$

For additional verification of results of analysis of biomagnetic signal we carried out the fraction and correlation analysis of the biomagnetic signal. Lesser value in comparison with the normal correlation dimension can indicate high activity in this case [7]:

$$D_c = \lim_{\varepsilon\to\infty} \left(\frac{\ln C(\varepsilon)}{\ln \varepsilon}\right),\quad C(\varepsilon) = \lim_{m\to\infty} \frac{1}{m^2} \sum_{i,j=1}^{m} \theta(\varepsilon - \rho(x_i, x_j)),$$

$$\theta(\alpha) = \left\{ \frac{1,\ \alpha \geq 0}{0,\ \alpha < 0} \right\} x_i$$

e.

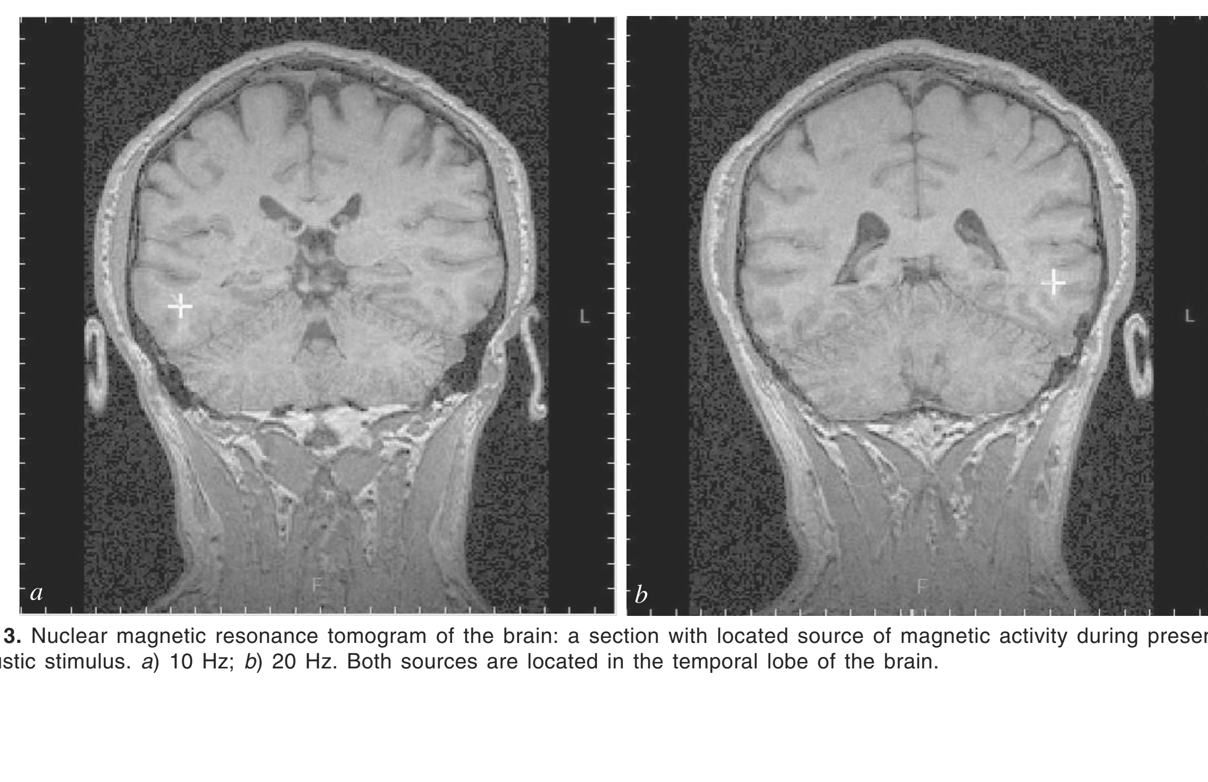

Fig. 3. Nuclear magnetic resonance tomogram of the brain: a section with located source of magnetic activity during presentation of acoustic stimulus. *a*) 10 Hz; *b*) 20 Hz. Both sources are located in the temporal lobe of the brain.

Hence, the D_c dimension is determined by the correlation integral $C(\varepsilon)$, characterizing the number of x_i,x_j pairs of points at a distance of $\rho_{i,j}=\rho(x_i x_j)<e$.

This is deduced from presumable determination of the system's response to the stimulus. In this case the simplicity of the stimulus, regularity of external stimulus presentation leads to a rather simple response, which can result in a lesser dimension of the signal of the evoked activity in comparison with basal values (presumably basal stochastic activity). The mean difference in correlation dimension normally and during acoustic stimulus presentation is 0.8-1.1.

Analysis of the dimension of the system's attractor indicates the regularity of evoked activity in the acoustic cortex, which is explained by the simplicity of the stimulus and determination of the system generating the response to stimulus. However, the nonlinearity of the system leads to transformation of the sources frequencies in comparison with the stimulus (stimulus frequency 7 Hz, frequencies of sources in cerebral cortex 10 and 20 Hz).

The created iterative location procedure is converged to the true coordinates and amplitudes of sources and permits the location with an accuracy of 2-5 mm. This accuracy provides better quality of mapping of the functional areas of human brain.

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