Using a 7-Channel SQUID Magnetomoter to Detect Scattering of the Cortical Brain Response to Continuous Rhythmic Visual Stimulation

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Abstract—Magnetic responses of the brain to rhythmic visual stimulation are measured at frequencies of ~10 Hz using a 7-channel SQUID magnetoencephalograph. Despite the stationarity of the stimulation, the responses of the brain demonstrate the constant instability of the amplitude and spatial distribution of the magnetic field. The signal from the eyes is periodically redirected to different parts of the cortex, although the stimulation is always the same.

INTRODUCTION

Interest in the effect rhythmic visual stimulation has on the activity of the brain has a long history, and the subject has been thoroughly studied [1]. To this day, there have been numerous experiments whose results have been used to understand how intrinsic brain activity correlates with such external influences as visual stimuli [2]. Although rhythmic visual stimulation is even used in medical commissions for obtaining driver's licenses, the details of interaction between intrinsic rhythmic activity of the brain and external stimuli remains unclear. Researchers hope that rhythmic visual alpha-stimulation at frequencies of ~10 Hz could influence the cognitive functions of the human brain [3]. This concept implies that the brain responds to an external stimulus via resonance activation of intrinsic electrical oscillators in the cortex. However, it is unclear whether the observed process is in each case induced oscillations or simply a sustained response to a stimulus [2]. Despite this uncertainty, frequency markers are a widely used technique in which a secondary parameter of a produced image (e.g., the type of noise pattern) is modulated at various frequencies of ~10 Hz. In experiments using a 306-channel magnetometer, it is possible via time and sensor averaging to determine, though not quite accurately, which regions of the brain receive signals of a certain frequency and how they behave over time [4]. Familiarity with the technique of magnetic measurements and procedures for processing signals forces us to consider that cortical processes differ from the picture received after averaging procedures. We therefore measured brain activity in response to a rhythmic flashing light using a 7-channel SQUID magnetometer.

EXPERIMENTAL

We selected four men (19, 25, 65, and 77 years old) with alpha rhythms of ~10 Hz and sustained responses to optical stimulation with eyes closed. The test subjects passed a preliminary clinical EEG examination. All test subject gave their informed consent to participate in the experiments. The study was approved by the Kurchatov Institute's local ethical committee on biomedical research.

Magnetoencephalography (MEG) was performed at the Kurchatov Institute in a shielded room with a vibration-resistant foundation [5]. The walls of the room were 5 cm thick, made of pure aluminium, and suppressed interference by 3000% at an industrial frequency of 50 Hz. A superconducting helium 7-channel second-order gradiometer was used [6]. Receiving elements of measuring coils with dimensions of 2 cm^2, located at the vertices and in the center of a regular hexagon with a radius of 3 cm, registered the normal component of the magnetic field perpendicular to the plane of the loop. The receiving coils that served as the base were 5 cm tall, with receiving and compensating loops wound around them. The range of measurement is shown in Fig. 1. Each test subject laid face down with his forehead against a height-adjustable rest. A round light-emitting diode 5 mm in diameter was placed half a meter below his face. A manipulator with six degrees of freedom brought the MEG cryostat to
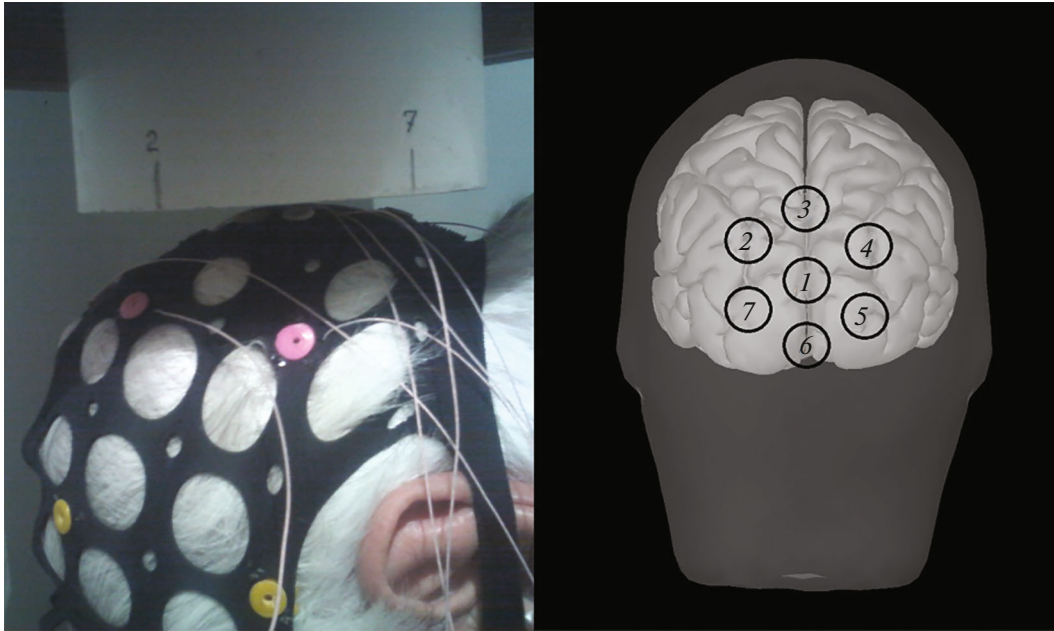
Fig. 1. View of the magnetometer placed above the occipital part of the test subject's head. The figures denote the positions of measuring coils.

the occipital part of the head and ensured positional precision. The test subject's comfort was a priority when making measurements. Voice commands was used to make the test subject open or close his eyes. A video system allowed us to monitor the experiment.

Flashes from a light-emitting diode were formed by PC multimedia player files with an additional power amplifier if needed. Impulses at a carrier frequency of 11 025 Hz were packed in the wav (waveform audio file) format to create packs with cycles of 1 Hz repeating at frequencies of 10 and 13 Hz. The light was at the level of the indicators of household appliances, and a specific level was selected for the comfort of each test subject. The overall duration of stimulation did not exceed 5 min.

MEG signals were converted from analog to digital at a frequency of 1 kHz. MEG data were available for continuous observation, filtration, and Fourier transforms of the signals. The device was controlled and MEG signals were recorded using electronics from Krioton (Russia), the manufacturer of the magnitometer [6]. An NVX-55 electroencephalograph by Neurobotics (Russia) was used in parallel with MEG, as an auxiliary mode for recording 15 EEG channels from the occipital part of the head, positioned according to the 10/20 system; one ECG from the sternum center; and one registering channel of control impulses for synchronizing MEG and EEG data in subsequent processing. The obtained MEG and EEG data were available for all traditional mathematical means of data processing, including MEG inverse solutions using the MRIAN software [7].

RESULTS AND DISCUSSION

Figure 2 shows the magnetic signals of 7 magnitometer channels in time-dependent amplitude–frequency relief. The colors reflect the magnitudes of Morlet decomposition using Brainstorm software [8]. MEG data were preprocessed with multiscreen band filtering to distinguish respones to the stimulus frequency and its whole-number harmonics. The 5−15 Hz range was chosen for a frequency of 10 Hz. The proper signal from channel no. 1 (positioned as shown in Fig. 1) is given as well for purposes of comparison; it has the typical form of an intrinsic rhythm. The amplitudes of the signals received from each channel changed constantly and substantially. Continuous external stimulation at the frequency of each test subject's characteristic rhythm was applied throughout the recording sessions, so the instability of the amplitude suggests the real-time correlation between the external stimulation and the signals generated by the brain was also unstable. It was not additional noise. It is possible the average values mask variations and create analytical correlations between stimulus and response, but we are interested in the dynamics of the process.

Constant variations in amplitude at a frequency of 10 Hz could be a consequence of the poorly understood mechanisms of resonant external stimuli with the intrinsic rhythmic activity of the brain, as was noted above in the Introduction. This is why similar measurments were made at the 13 Hz frequency of stimulation, which differed substantially from each test subject's intrinsic rhythm. The results are shown in Fig. 3. Again, we see the same ragged rhythm. The
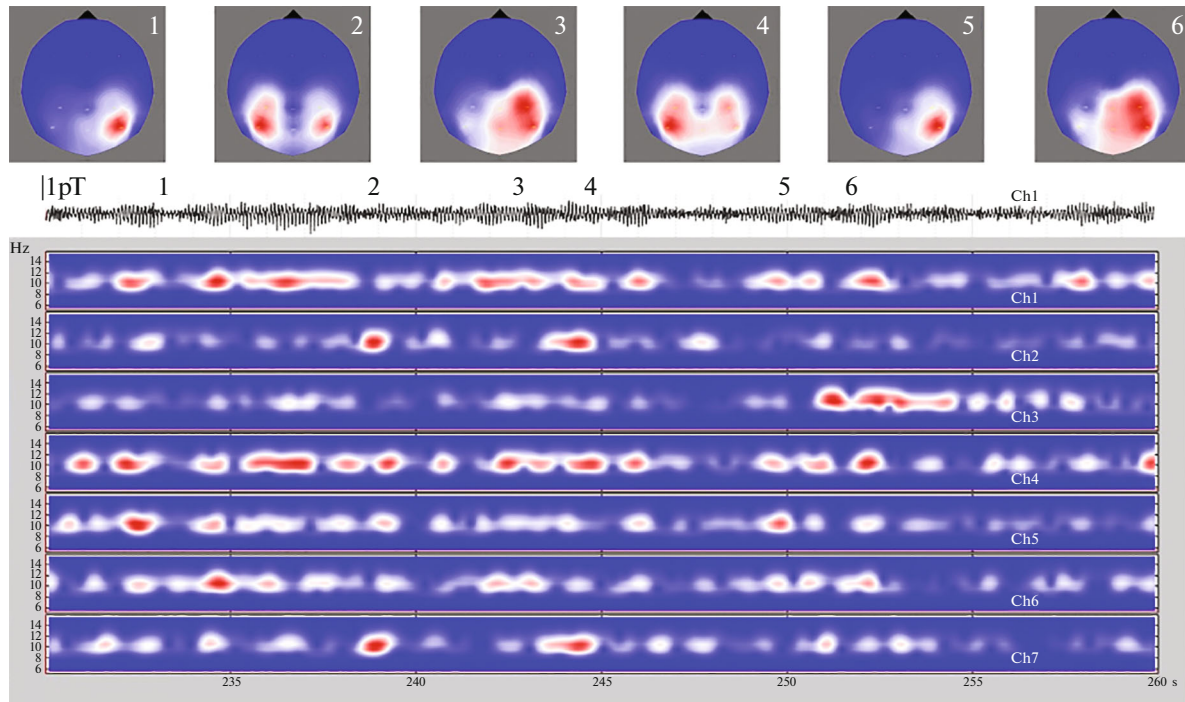
Fig. 2. Temporal dependence of a magnetic signal in the seven channels of magnitometer. Time is displayed in seconds. The amplitude of the current is in color, and the frequency is shown vertically. The maximum amplitude is in red. There was continuous stimulation at a frequency of 10 Hz, which coincides with the intrinsic rhythm of the test subject. The amplitudes of the signals from all channels changes strongly over time. The signal configuration for the first channel is in black, and the amplitude scale is shown. Maps of the magnetic field amplitude distribution were built for the occipital part of the head for the moments denoted by numbers 1–6. These distributions vary considerably, though some of them are similar.
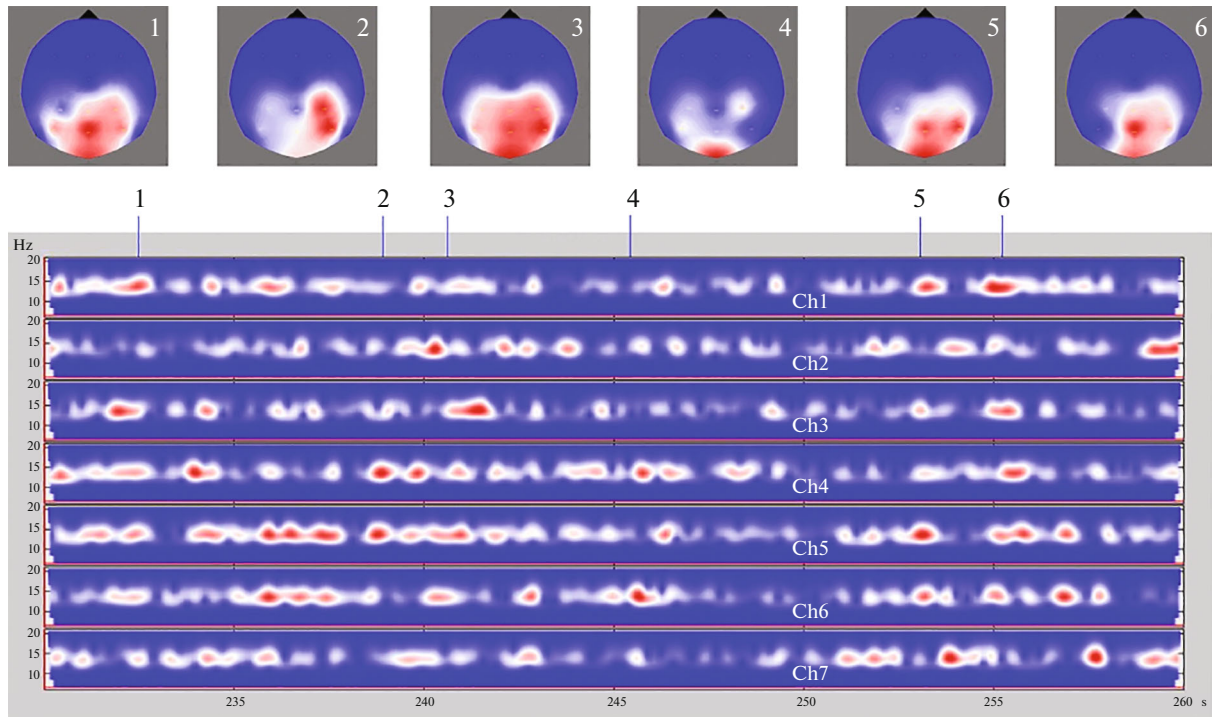

Fig. 3. Same as in Fig. 2, but with optical stimulation at a frequency of 13 Hz, which differs from the brain intrinsic rhythm.

obtained signal amplitude changes constantly from the highest one possible to virtually zero. These changes occurred in different channels virtually independently of one another.

BrainStorm software was used to calculate amplitude maps of the magnetic field in the occipital part of the head. The field maps proved to be quite different at different moments in time. Sometimes the reliefs were similar, as at moments 1 and 5 or 3 and 6 shown in Fig. 2. Sometimes the amplitude distribution is quite typical, as in maps 3 and 4 in Fig. 2. This was the magnetic field from the source positioned just below the center of the coil system (i.e., in the primary visual cortex). It is assumed that signals from the eyes' retinas were sent there. However, numerous other variants of field distribution indicate electrical activity of neuronal ensembles quite far from the primary visual cortex, and without signals from the primary visual cortex that are similar in amplitude. Different averaging procedures can be used to identify the regions most receptive to external visual rhythmic stimulation of the brain, but the dynamics of the processes associating different regions of the cortex would be lost. We believe it is necessary to distinguish the typical time gaps lasting ~700 ms that divide cortical activity during continuous stimulation into periods in which the brain uses different functional modes.

Below, we present data on one test subject. The other test subjects demonstrated similar behavior. Signals obtained using a the 306-channel magnitometer in the experiments with frequency markers in [4] are identical in form, but that experiment was to perform another task.

We can see that under the conditions of continuous and stationary external stimulation of the sensory organs (eyes), the magnetic signals generated by the brain are in no way stationary, while their source does not have a precise location in the cortex. At the same time, numerous studies using EEG show unmistakably that the strongest responses to visual stimulation were registered by the occipital electrodes. It should be remembered, however, that due to averaging the properties of the layers covering the hemispheres (cerebro—spinal fluid, skull, scalp) and the rugged relief of the cortical surface, we could only register a very indistinct area in the occipital part of the head where active neuronal populations are located. All of them generated the signal registered by the occipital electrodes, with the inputs from different groups overlapping strongly. Magnetic measurements suggest that the reaction to flashing light is scattered across various areas of this rather large part of the brain, while there was virtually no reaction at times in the primary visual cortex, which receives the most neuronal impulses from the eyes. The destination of the activating impulses probably depends on how the intrinsic brain system categorizes the stimuli, and its decision is based on this.

This unstable reaction of the brain to identical stimuli is more typical than exceptional. It is seen very clearly in magnetic measurements, both in motor actions and the perception of repeated words [9, 10]. What could be the reason for this instability? Continuous optical stimulation is a stable condition of the external environment, such as air temperature, posture, or anticipating a command. There is no evidence that the intrinsic brain system is occupied with these flashes at all times. The same applies to standard neurophysiological experiments in which repeated identical stimuli were produced. Reviewing such situations is not a purely academic issue; the field of creating autonomous agents capable of decision-making depends on how their internal control systems will be organized. Such research uses protozoans as model organisms [11]. Analyses of behavior show that even such relatively simple organisms as insects simultaneously use several operatiing modes or set of rules at any point in time. They compete within their control system so that only the winner gets to achieve its program of actions. An original source says "There is parallel activation of several rules at any given time, and these rules compete to determine behavior" [12]. This apparently applies to humans as well [13]. Though some instability is usually seen in periods when no actions are performed, humans are ready to perform various kinds of tasks. This instability could result from competition between different yet quite stereotypical modes of behavior. Their number is not great; probably no more than 10. It may be said that a decision-making system is constantly working in the brain, and this is how it maintains readiness to perform a task in one of several standard ways. The most likely candidate for the system that organizes attention and prepares the performing of tasks are ensembles of cortical and thalamic neurons that produce synchronized alpha-rhythm oscillations [14]. MEG allows us to monitor the functioning of this system in detail.

CONCLUSIONS

Magnetic measurements allow us to approach the task of exploring the decision-making system in the human brain. All of the necessary conditions are in place. At the moment, only magnetic encephalography allows us to work with the characteristic times and spatial resolution needed to study the decision-making system using test subjects in contact with the researcher.

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