

MAGNETOENCEPHALOGRAPHY, A NON-INVASIVE METHOD OF BASIC AND APPLIED BRAIN RESEARCH - REPORT OF THE AIVO-GROUP IN HELSINKI

O. V. Lounasmaa

Low Temperature Laboratory, Helsinki University of Technology, 02150 Espoo, Finland

Abstract. - A brief review is given on neuromagnetic measurements at the Helsinki University of Technology. Four subgroups are active in the AIVO-project: multiSQUID instrumentation, mathematical treatment of the data, neurophysiological measurements, and studies of signal processing in the brain.

Electric currents carry information from one nerve cell to another in the brain. When many neighboring neurons act in concert, weak (30-500 ft) magnetic fields are produced which can be measured non-invasively outside the skull. The magnetic field detector used is the ultrasensitive Superconducting QUantum Interference Device, the SQUID. In a typical experiment, the subject receives some sensory stimuli, for example tone pips, weak electric pulses, or flashes of light. Several tens of milliseconds later a rapidly changing magnetic field can be recorded. On the basis of the temporal evolution of the field distribution it is possible to follow changes in the location of the cortical area which is activated by the stimulus; this is usually the main purpose of magnetoencephalographic (MEG) measurements.

Electroencephalography (EEG), the measurement of electric potentials by means of electrodes attached to the scalp, is a well known clinical method. MEG and EEG are closely related to each other. An important advantage of magnetoencephalography is that the field measured outside the head is mainly generated by currents that flow in the brain tissue itself. Distortions in the observed magnetic field pattern caused by currents in the skull and the scalp are thus small. In EEG, the field map must be constructed by means of the measured surface potentials which often are rather badly distorted. As a consequence, MEG has a better spatial resolution than EEG.

During the last few years considerable progress has been made in the development of various imaging methods, such as X-ray tomography, NMR imaging, and positron emission tomography. X-ray and NMR imaging provide accurate, three-dimensional structural information, but they tell nothing about temporal changes in the activity of the brain. The time resolution of positron emission techniques is tens of seconds. MEG and EEG, in contrast, both provide information with millisecond resolution. A further very important advantage of these two methods is that they are completely noninvasive. Nothing is put into the subject's head: no X-rays, no high magnetic field, no radio-frequency field, no radioactive isotopes. One

measures only what comes out of the brain as a result of natural stimuli.

Owing to the smallness of the MEG signals, rejection of external magnetic disturbances is of extreme importance. Noise is caused, for example, by fluctuations in the earth's magnetic field, by moving vehicles like cars and elevators, by radio, TV, and microwave transmitters, and by the omnipresent powerline field and its harmonics. The MEG measurements in Helsinki are performed inside a magnetically shielded enclosure of $2.4 \times 2.4 \times 2.4 \text{ m}^3$ inner dimensions. The room employs for shielding three layers of aluminum, which attenuate very effectively the high-frequency band of the external magnetic noise, and three layers of mu-metal for shielding at low frequencies, which are particularly troublesome in MEG measurements.

Magnetoencephalography is under active development in Helsinki on a broad front. Four subprojects are being pursued.

1) A serious drawback of the MEG method at present is the long time that is needed to construct the topographic field map from which the activated cortical location can be calculated. Measurements must be made at many points and, at each site, the stimulus must be repeated 50-100 times in order to obtain a reasonable signal-to-noise ratio by averaging. An instrument which measures the whole magnetic field pattern at once is urgently needed. A home-built system of seven dc SQUIDS, constructed by the subgroup presently led by Matti Hämäläinen, has been available in Helsinki since early last year; the SQUIDS were provided by the IBM Corporation. This instrument, with a sensitivity of $5 \text{ ft}/\sqrt{\text{Hz}}$ and a circular measuring area of 9.6 cm diameter, currently is the best in the world. A 24-SQUID device, employing Finnish sensors, is under development and should be ready by the end of 1988. We have used, since the summer of 1983, a four-channel SQUID instrument. This apparatus was the first multi-SQUID installation in use for brain research.

2) When more and better MEG data become available, the mathematical treatment of the results must

be improved; this subproject is led by Risto Ilmoniemi. Methods will be developed for feeding other types of information into the analysis, for example, simultaneously measured EEG recordings. Advanced signal analysis techniques will be applied to reduce coherent noise. Computer programs for on-line data acquisition and processing have been written. The limits of the dipolar model are being studied and more complex solutions of the inverse problem are under investigation. A collaborative program has been started with Prof. Jukka Sarvas (Nevanlinna Institute, University of Helsinki) on the mathematical interpretation of MEG.

3) The main aim of our work involving actual MEG measurements is to find the limits of the method as a tool in neuroscience. For example, by stimulating peripheral nerves, the subgroup of Riitta Hari has succeeded in differentiating between activities at the primary and secondary somatosensory cortices, which has not been possible by electric scalp recordings; activity patterns have been studied in detail following lower or upper limb stimulation. Cortical areas activated by painful stimuli have been found also. Spatial and temporal changes in the response of the auditory cortex have been investigated extensively. For example, new stimulus-specific responses have been found to fricative consonant/vowel transitions in simple words and to amplitude and frequency modulations of a continuous tone. Neural sources of several evoked-potential deflections have been localized. Recent work is focused on the effects of stimulus changes and of different tasks on the response of the human auditory cortex. Collaboration with Prof. Risto Näätänen's group (Department of Psychology, University of Helsinki) is concentrating on studying neuronal mechanisms of cognitive processes.

4) By investigating the spatiotemporal course of MEG signals it should be possible to study some aspects of signal processing in the brain. Basic research of this type may, in the future, be one of the most important fundamental applications of magnetoencephalography. This fourth subproject is led by the author.

Rapid advances in magnetoencephalography are expected during the next 2-3 years when multi-SQUID devices become generally available. The value of MEG

as a clinical tool and as a method for basic neurophysiological studies can then be assessed reliably. At present magnetoencephalography shows considerable promise.

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