Medical Applications of SQUIDs in Neuromagnetism

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Activity in the brain involves small electric currents which flow in the neural network. These currents generate tiny magnetic fields which can be measured outside the skull using arrays of sensitive superconducting quantum devices or SQUIDs. Magnetoencephalography (MEG) has emerged a technique (see Fig. 1) to enable non-invasive utilization of the magnetic data in basic research and medical studies [1] with a time resolution of 0.5 ms and spatial accuracy of 5-6 mm under favourable conditions.

Neuromagnetic fields are only 50-500 fT in strength. It is therefore, necessary to employ data-averaging techniques and measurements made in a magnetically shielded room using gradiometric superconducting flux transformers to convey signals to the SQUIDs. From the measured magnetic field distribution it is possible, by making suitable assumptions, to calculate backwards the cortical area which was activated by a sensory stimulus such as a sound, image or a touch. Spontaneous brain activity like the 10 Hz α-rhythm can also be investigated.

Fig. 2 shows the responses which resulted from air puffs to the back of the subject's right hand. One can see how the active region in the brain changes with time in the sequence A → B → C → D while the puff of air is analyzed by the brain. The hand area of the left primary somatosensory cortex (A) responds first, with opposite deflections at 32 and 65 ms after the onset of the stimulus, followed by the second somatosensory cortex at left (B, 85 ms) and at right (C, 98 ms). A late response arises in the posterior parietal cortex (D, 108 ms).

Magnetic resonance imaging (MRI) and positron emission tomography (PET) are well known, but relative novel methods for studying the brain. MEG has two important advantages over these techniques: 1) the MEG method is completely non-invasive since high magnetic fields or radioactive markers are not needed; 2) the time resolution of MEG is 0.5 ms, many orders of magnitude higher than for functional MRI or PET.

In comparison with electroencephalography, *i.e.*, the measurement of scalp potentials, MEG has a superior spatial resolution because the magnetic field distribution is less affected by inhomogeneities in the head than electric potentials measured on the scalp.

Exploration of the human brain is of the utmost intellectual interest. All humanity depends on our minds. PET and MRI do not have sufficient time resolution to investigate information processing in the brain. This is a field of cortical study where MEG will have an important future, especially now that instruments that cover the entire head are available commercially.

References

[1] R. Hari & O.V. Lounasmaa, *Science* **244** (1989) 432.; M. Hämäläinen, *Rev. Mod. Phys.* **65** (1993) 413.
[2] N. Fross *et al.*, *Electroencephal. Clin. Neurophysiol.* **92** (1994) 510.

Fig. 1. Helsinki University of Technology's magnetoencephalography (MEG) installation. During experiments the double doors to the shielded room housing the apparatus must be tightly closed. The concave, helmet-shaped bottom of the helium dewar containing the SQUID-based field measuring devices must be brought as close as possible to the subject's head. The instrument employs 122 planer flux transformers with a figure-of-eight configuration located on 61 integrated circuit chips that incorporate the SQUIDs. Each unit records the orthogonal tangential derivatives of the magnetic field component B_r normal to the bottom of the dewar. The signal has its maximum value right above the source in the brain (see Fig. 2). The first whole-head-covering instrument has been in regular use since September 1992. It is available commercially from Neuromag Ltd. of Helsinki. A similar device is manufactured by CTF Systems Inc. of Vancouver, Canada.

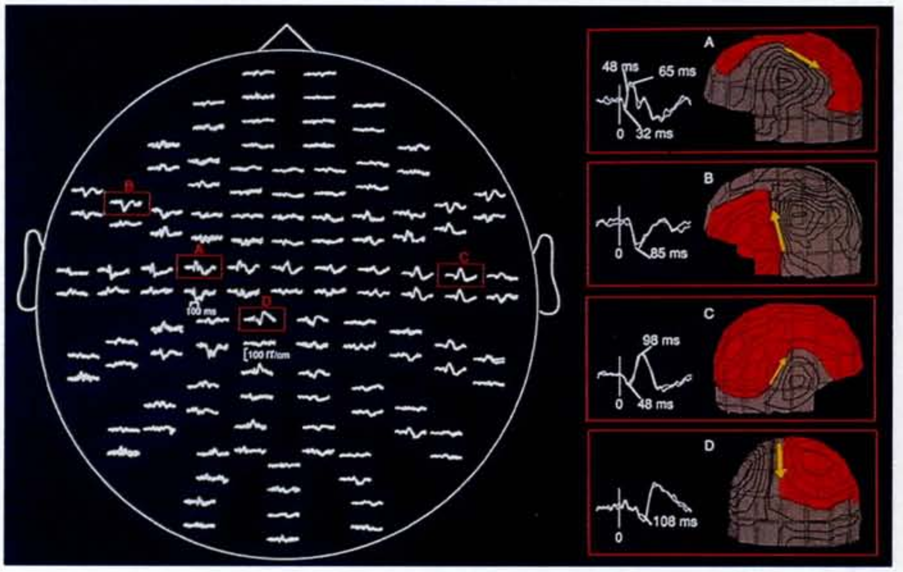

Fig. 2. *Left:* Somatosensory responses elicited by air puffs [2]. Two independent recordings superimposed; head "flattened" using the zenithal equidistant projection; subject's nose pointing up. *Right:* Enlarged magnetic field *versus* time recordings and topographic field patterns on the head (A and B from the left side; C and D from the back); the field emerges in the shaded regions. The evoked locations in the brain are at the centres of the arrows. The isocontours are 40 fT apart.