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Theoretical Limits of the EEG Method are not Yet Reached

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When the British neurophysiologist Richard Caton 1875 first recorded the electric activity of the brains of rabbits and monkeys directly from the brain tissue, he could not have imagined just how valuable a diagnostic tool, electroencephalography, he had discovered [1]. When recording the first human EEG on the scalp in 1924, the German psychiatrist Hans Berger apparently understood the value of this method, because in the 1920s he published several clinically oriented papers from the application of the EEG [2].

For a long while the EEG method remained, in principle, at the level where Hans Berger used it. It included a set of electrodes, whose fixing on the patient's scalp was time consuming and cleaning the head after the session was unpleasant for the patient. The instrument included amplifiers and a multi-channel pen-recorder, which registered the detected activity. The diagnosis was mainly based on the intuition of an experienced electroencephalographist.

David Cohen recorded the first magnetoencephalogram, MEG, in 1968 with an induction coil magnetometer [3] and later in 1970 with a SQUID magnetometer[4]. The era of MEG had started. Much hope was given to the success of this new method. At that time it was believed that

- because of Helmholtz's Sentence [5], the sources of the EEG and MEG should be independent and therefore the information of these signals should be similarly independent [6],
- because the skull has high electric resistivity but is transparent to a magnetic field, the MEG should have better spatial resolution and the understanding of the sources of the signal would be easier,
- because no electrodes are needed, the MEG recording session would be more pleasant for the patient.

All these benefits were believed to compensate the more than an order of magnitude higher price of the MEG instrument.

But what was said above, does not form the whole truth. At the Ragnar Granit Institute we have shown that the theoretical reasons, believed to be favourable for the MEG, are not true. Furthermore, the electrode technology of the EEG has developed so fast that the practical nuisances of the EEG method are now history.

We have shown that the independence of the bioelectric and biomagnetic phenomena concerns the independence of the lead fields, not the signals [7, 8]. And even for the lead fields this is true only in cases they are correctly designed. For instance, the lead field of a bipolar EEG lead is very similar to that of a planar gradiometer MEG lead and therefore the signals are strongly interdependent [9].

We have also shown that despite the high resistivity of the skull, the spatial resolution of a single unipolar EEG electrode is five times better than that of a single MEG coil [8]. When using combinations of electrodes and combinations of coils, the situation is not necessarily so favourable for the EEG, nor is it more favourable for the MEG either. But the fact is that the MEG can record only the tangential components of the electrical sources on the cortex while the EEG records all three orthogonal components. It is true that the spherical skull does not affect the tangential lead fields of the MEG but the lead fields of the EEG are already well known and the effect of the high resistivity skull on the EEG can be eliminated.

The electrodeless measurement of the MEG, on the other hand, requires a static position of the subject while the EEG electrodes give him/her rather good freedom to move the head and to relax. With a modern EEG electrode net the positioning of a large number of electrodes, such as 128, no longer needs more than 10 minutes. And the electrodes are free from paste and do not cause any inconvenience to the patient.

The price of the multichannel EEG instrument is modest and its immunity to noise, when compared to MEG, is so good that recordings can be made in any neurophysiological laboratory, even during an MRI session!

Have the limits of the EEG-method now been reached? On the basis of our theoretical calculations, the distance of the EEG electrodes can be reduced, at least down to 20 mm, which corresponds to the 256 electrode system. Theoretically, this distance can still be halved and the spatial resolution doubled, but the signal to noise ratio will slightly decrease and the mechanical size of the electrodes may present difficulties [8].

What is the future outlook for the EEG-instrument? The future EEG-instrument will have over 500 electrodes, which can be easily fixed to the head with a sensor net. The electrodes will give the subject full freedom to move the head and to relax. The recorder electronics will sense the electrical parameters of the tissues through the impedance of the electrodes and thus calculate a detailed electric potential distribution on the cortex. This new technology will produce so much more information from the electric activity of the brain that the analysis of this information will be the next challenge of this technology.

Now when the new millennium is about to start, almost 125 years after the invention of the EEG, 75 years after the birth of the clinical EEG, 30 years after the invention of the MEG, the electroencephalography is stronger than ever before and will, without doubt, continue to be the most important non-invasive method for investigating the activity of the brain in real time.

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