Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

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**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

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ELECTROPHYSIOLOGICAL METHODS OF THE STUDY OF THE NERVOUS- AND MUSCULAR SYSTEM

Az ideg- és izomrendszer elektrofiziológiai vizsgálómódszerei

LECTURE 10

MAGNETOENCEPHALOGRAPHY

(Magnetoenkefalográfia)

BALÁZS DOMBOVÁRI and GYÖRGY KARMOS

- **In this lecture the students will learn:**
  - Definition of magnetoencephalography
  - The origin of the MEG signal
  - The basic function of MEG
  - The basic equipments for MEG measures.
  - How does a typical MEG raw data look like
  - Source localization of MEG
  - Temporal and spatial resolution of MEG
  - Some features/benefits of MEG
  - Research and clinical applications

Magnetoencephalography (MEG):

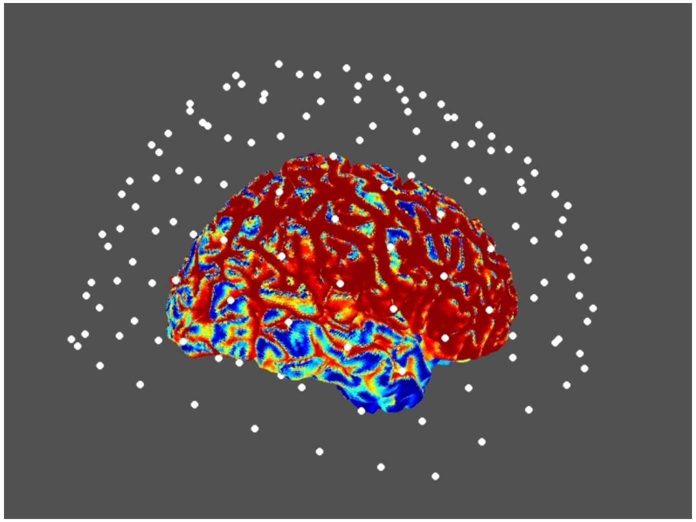
is a non-invasive neurophysiological imaging technique that measures the magnetic fields generated by neuronal activity of the brain.

MEG is a direct measure of brain function, unlike functional measures such as fMRI, PET and SPECT that are secondary measures of brain function reflecting brain metabolism.

The MEG was first measured by University of Illinois physicist David Cohen in 1968, using only a copper induction coil as the detector.

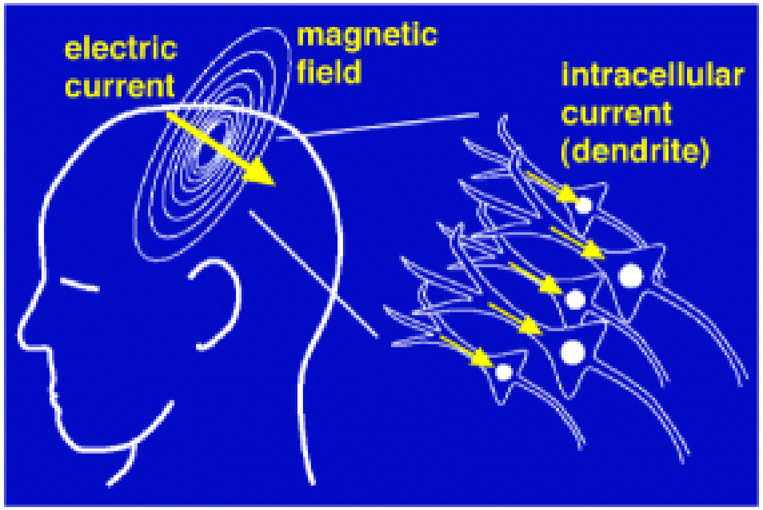
THE ORIGIN OF THE MEG SIGNAL

MEG can estimate electrical activity in the brain from sensors outside the head (dots). The red/blue regions show areas of the cortex to which MEG is most/least sensitive.



THE ORIGIN OF THE MEG SIGNAL

The MEG (and EEG) signals derive from the net effect of ionic currents flowing in the dendrites of neurons during synaptic transmission.



In accordance with Maxwell's equations, any electrical current will produce an orthogonally oriented magnetic field. This field is measured with MEG.

THE ORIGIN OF THE MEG SIGNAL

The net currents can be thought of as current dipoles which are currents defined to have an associated position, orientation, and magnitude, but no spatial extent.

According to the right-hand rule, a current dipole gives rise to a magnetic field that flows around the axis of its vector component.

SUPERCONDUCTING QUANTUM INTERFERENCE DEVICE

The magnetic fields outside the head due to electrical activity within the brain are in the hundreds of femto (10-15) Tesla, that is approximately 100 million time smaller than the earth's magnetic field.

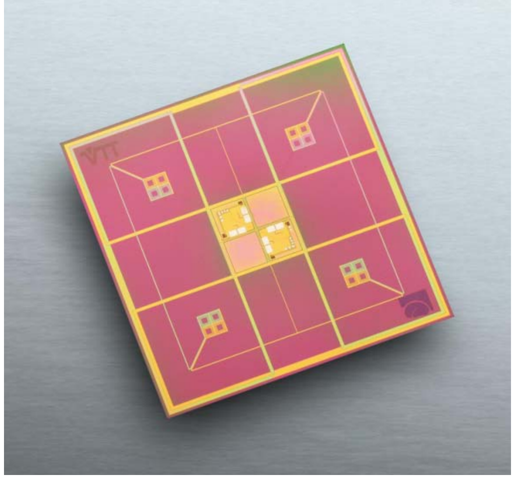
MEG measurements are conducted externally, using an extremely sensitive device called a superconducting quantum interference device (**SQUID**, Clarke 1994).

These devices convert the sub-quanta changes in magnetic flux into voltage changes.

MAGNETIC FIELDS

Tesla	
10^{-4}	
	HEARTH (STEADY)
10^{-5}	
10^{-6} µT	
	URBAN NOISE
10^{-7}	
10^{-8}	
	LUNG PARTICLES
10^{-9} nT	
	HUMAN HEART
10^{-10}	
	HUMAN SKELETAL
MUSCLE	
	FETAL HEART
10^{-11}	
	HUMAN EYE (STEADY)
	HUMAN BRAIN (ALPHA)
10^{-12} pT	
	HUMAN BRAIN RESONSE
10^{-13}	
10^{-14}	
	SQUID NOISE
10^{-15} fT	

MEASUREMENT WITH MEG



Typically the SQUIDs are coupled to superconducting coils or flux transformers which are situated as close as possible to the subject's head (within 2cm typically).

Magnetic field changes in the flux transformers cause a change in superconducting current in the transformer coils that is passed via an input coil to the SQUID itself.

The ability to measure such small fields also makes the devices very sensitive to other magnetic field changes in the environment.

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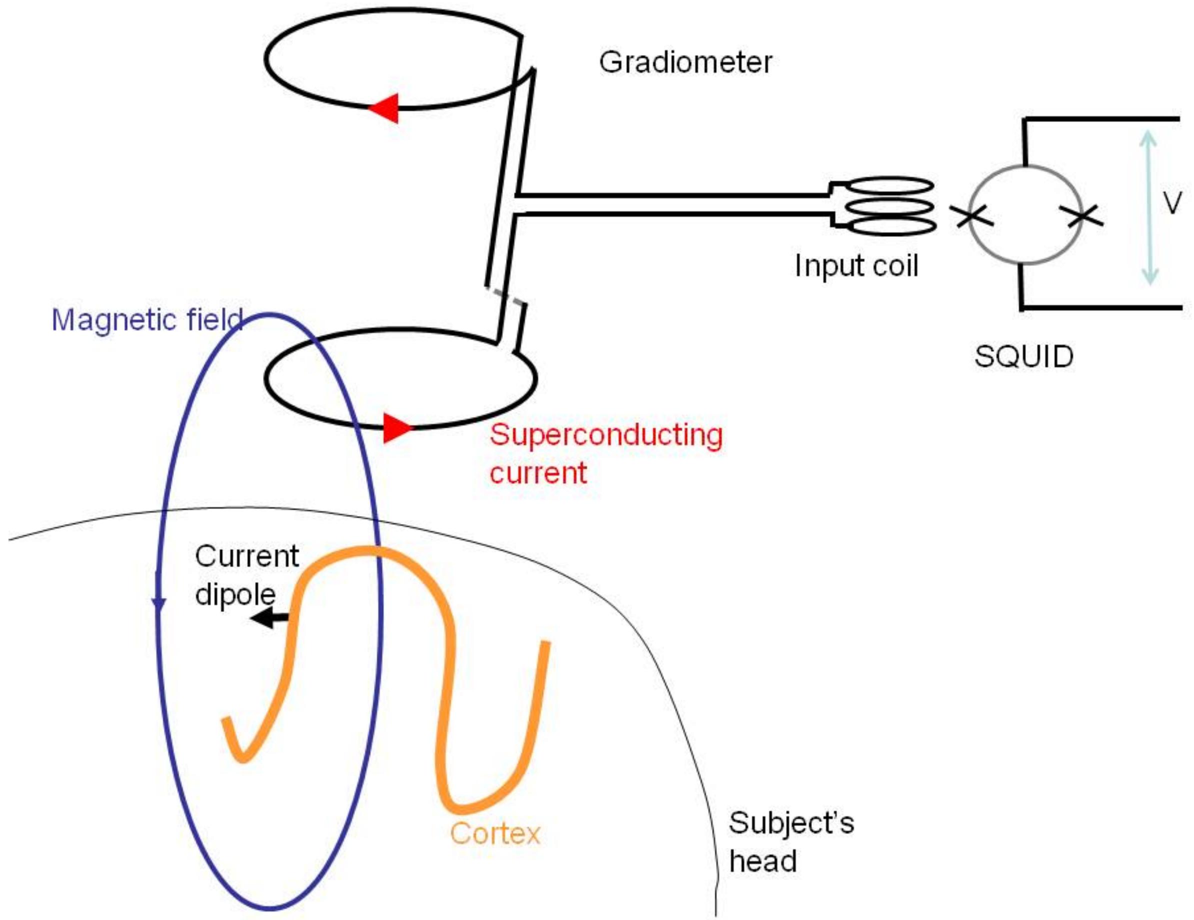
SCHEMATIC DIAGRAM OF A MEG



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BASIC EQUIPMENT OF A MEG DEVICE

In a modern MEG device, an array of more than 300 SQUIDS is contained in a helmet shaped liquid helium containing vessel called a Dewar, allowing simultaneous measurements at many points over the head.

The MEG system is operated in a shielded room that minimizes interference from external magnetic disturbances, including the Earth's magnetic field, noise generated by electrical equipment, radiofrequency signals, and low frequency magnetic fields produced by moving magnetic objects like elevators, cars, and trains.

Shielded room

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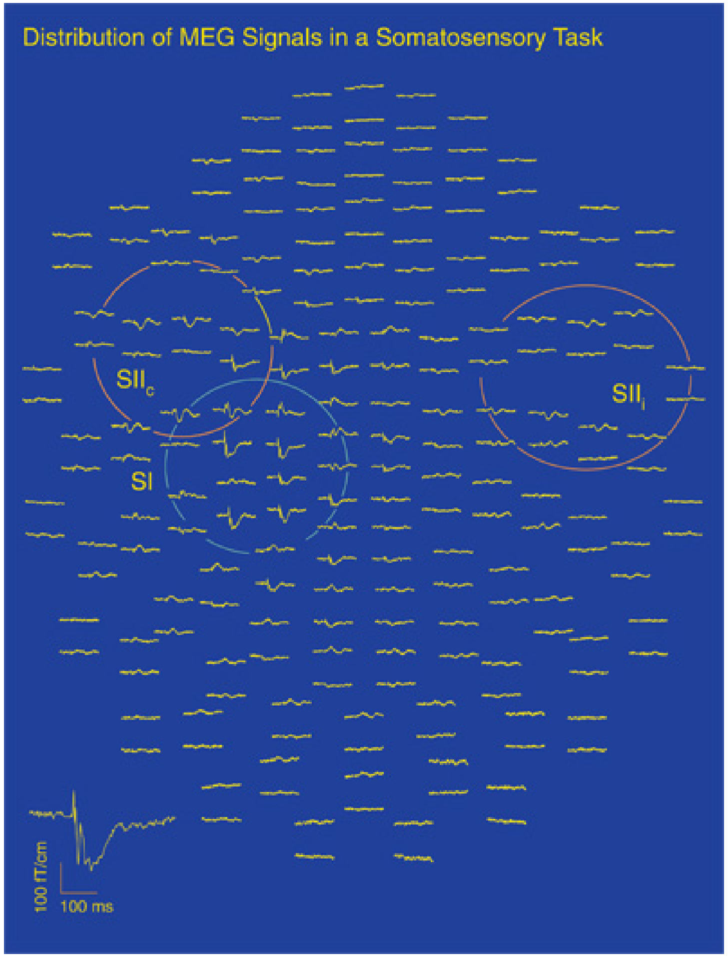
The typical MEG data



Both MEG and EEG raw data are often presented as time-dependent signals, arranged in a topographical layout. These data may either represent averages over repeated sensory stimuli or motor responses or continuous raw data. The latter are routinely employed in the analysis of abnormal epileptic activity or in the characterization of ongoing rhythmic activity.

SOURCE LOCALIZATION

INVERSE PROBLEM:

In order to determine the location of the activity within the brain, advanced signal processing techniques are used which use the magnetic fields measured outside the head to estimate the location of that activity's source.

The MEG inverse problem is theoretically ill-posed, having many solutions to a single problem. All source localization methods make assumptions about how the brain might work (e.g**: dipole fitting model, minimum norm based approaches**, see Lecture 9, 12).

SOURCE LOCALIZATION (CONT.)

FORWARD PROBLEM:

It is a situation where we know where any sources are and we are estimating the field at a given distance from them.

Or in other words this is the problem of computing what the output of the MEG sensors would be if a certain region of cortex were active. (e.g: dipolar source and volume conductor models).

THE TEMPORAL AND SPATIAL RESOLUTION OF MEG

Temporal resolution:

- Milliseconds. MEG allows real-time recording of the brain activity.

Spatial resolution:

- From several millimeters to a couple of centimeters, depending on the experiment.

WHAT ARE SOME FEATURES/BENEFITS OF MEG?

- MEG is completely noninvasive and non-hazardous.
- The data can be collected in the natural seated position allowing more life-like cognitive experiments than fMRI.
- The measurement environment is completely silent, which facilitates especially auditory studies.
- MEG has an extremely high temporal resolution (milliseconds) and also provides a good spatial resolution.
- Signals can be recorded over the whole cortex.
- There is no need to paste electrodes on the scalp as with EEG.

RESEARCH AND CLINICAL APPLICATIONS

- In research, MEG's primary use is the measurement of time courses of activity, as such time courses cannot be measured using functional magnetic resonance imaging (fMRI).
- MEG is also used to analyse accurately pinpoints sources in primary auditory, somatosensory and motor areas
- In some cases MEG should preferably be used in combination with fMRI, because there is a need to create functional maps of human cortex during more complex cognitive tasks.
- The localization of ictal and inter-ictal spike complexes with MEG is now widely used to identify epileptic foci for the surgical treatment of intractable epilepsy.

REVIEW QUESTIONS

1. What is the definition of magnetoencephalography?
2. What does it measure?
3. How does the MEG work?
4. What is a SQUID?
5. How does the data look like?
6. What is the inverse problem in the case of MEG?
7. What is the forward problem?
8. What are the clinical applications of MEG?

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