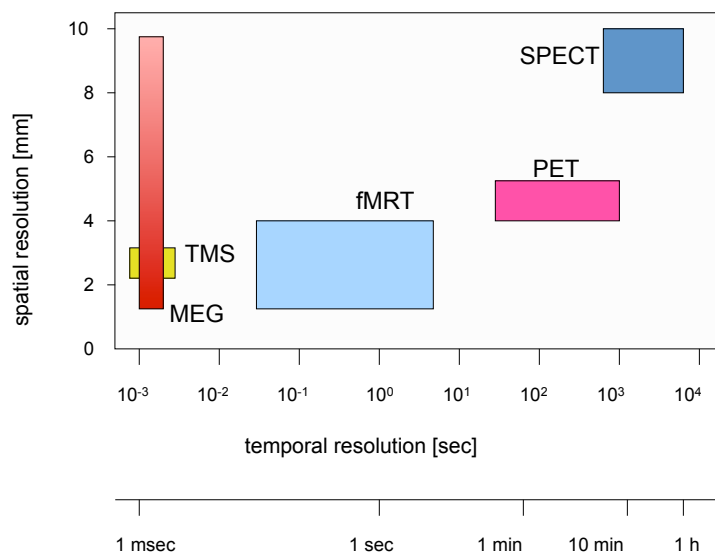
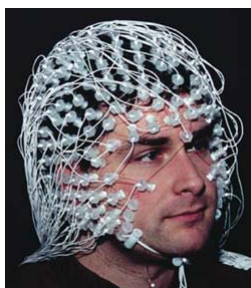


Neuroimaging Methods



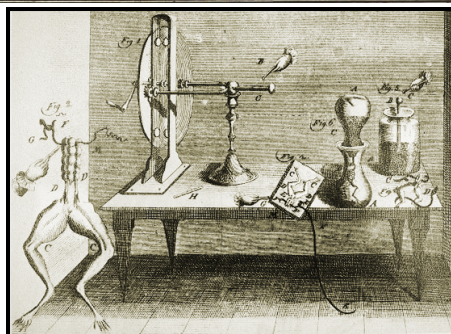
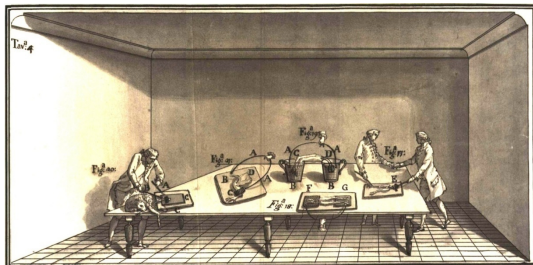
81

EEG



Electroencephalography
EEG

Luigi Galvani: Animal electricity



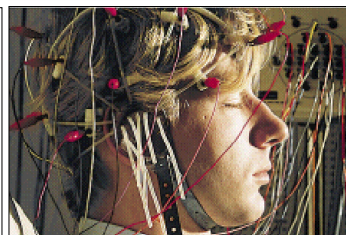
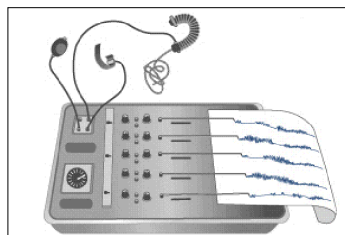
Luigi Galvani
1737 - 1798

late 18th century

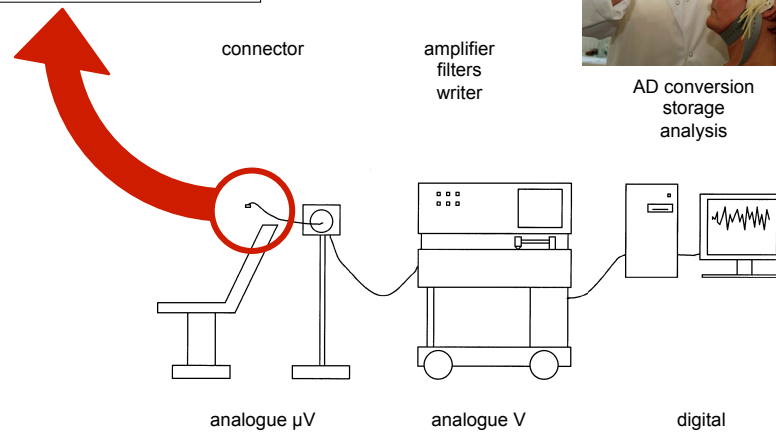
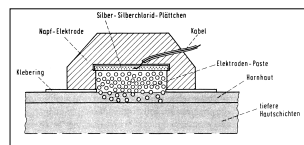
Electroencephalography (EEG)



Hans Berger
1873-1941



Electroencephalography



History



32 channel amplifier



Miniaturisation

high density
high efficiency

256 channels



wireless electrodes

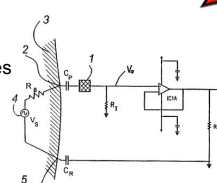


flexibility

easy to use

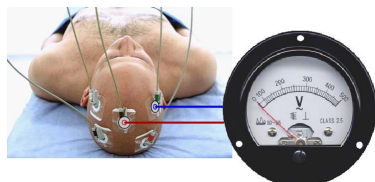
lower sensitivity to noise

dry electrodes



active electrodes

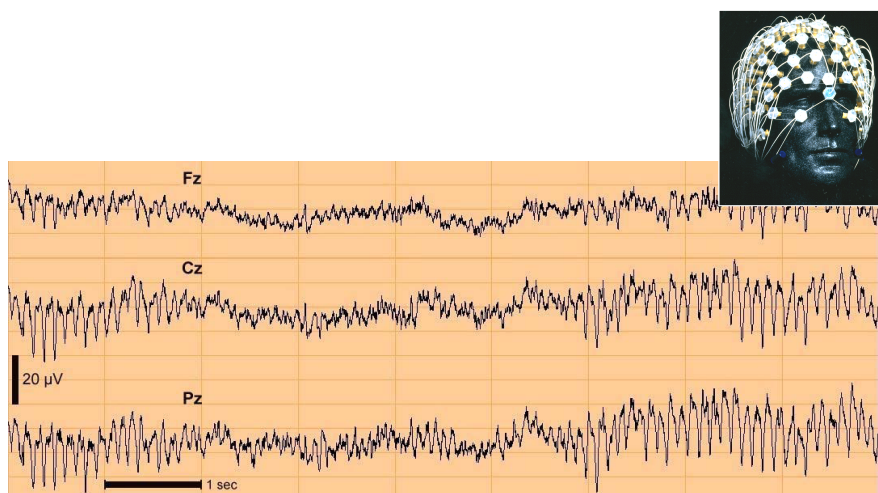
EEG Measurement



How to do an EEG recording

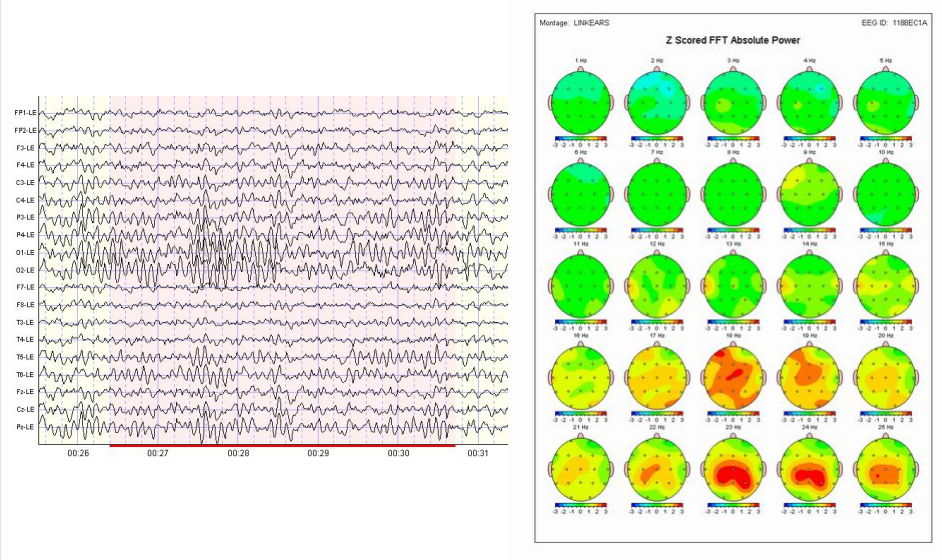
- What is the ground electrode?
- What is the reference electrode?
- What is rereferencing?
- What are clinical applications of EEG?
- What is the 10-20 systems
- Which brain rhythms do you know?

EEG Recording

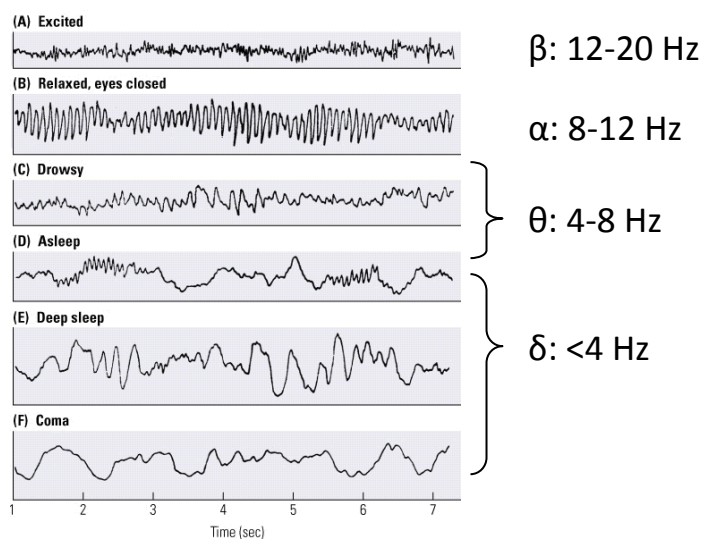


EEG-traces recorded from 3 electrodes

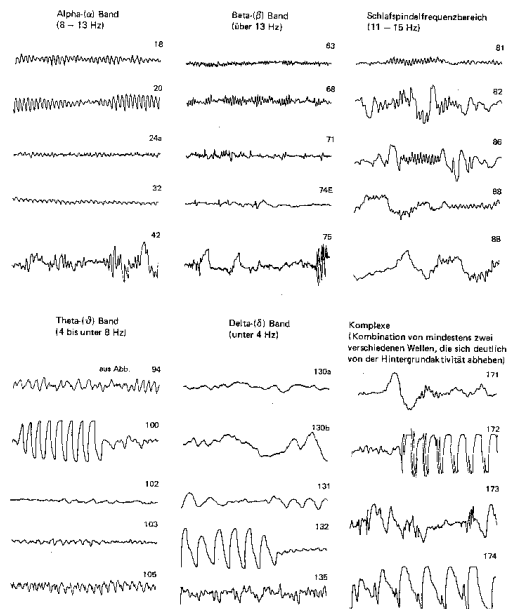
Electroencephalograph EEG



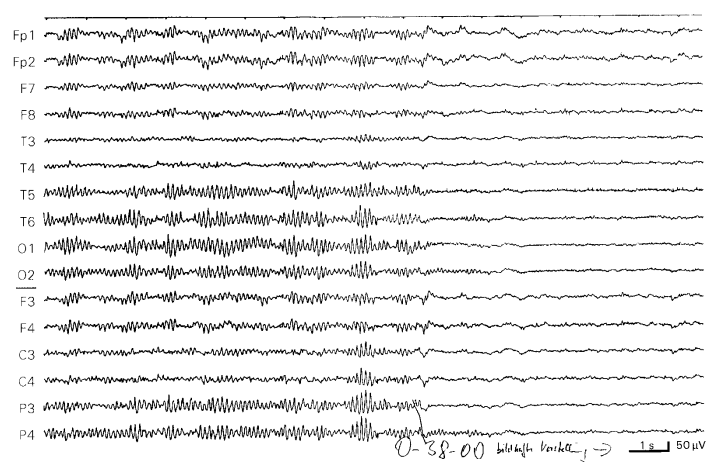
Spontaneous EEG



Individual Variability



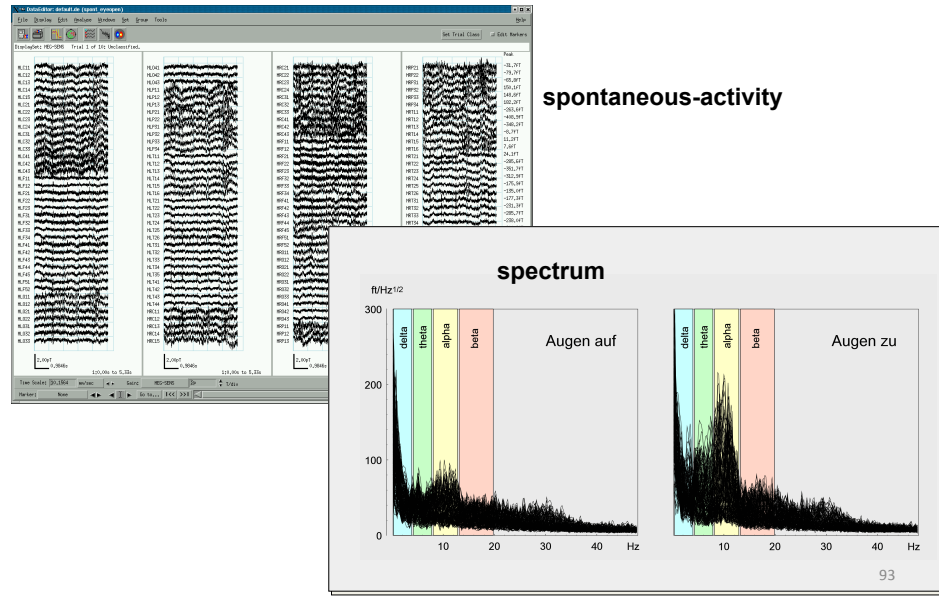
Spontaneous EEG: Alpha Block



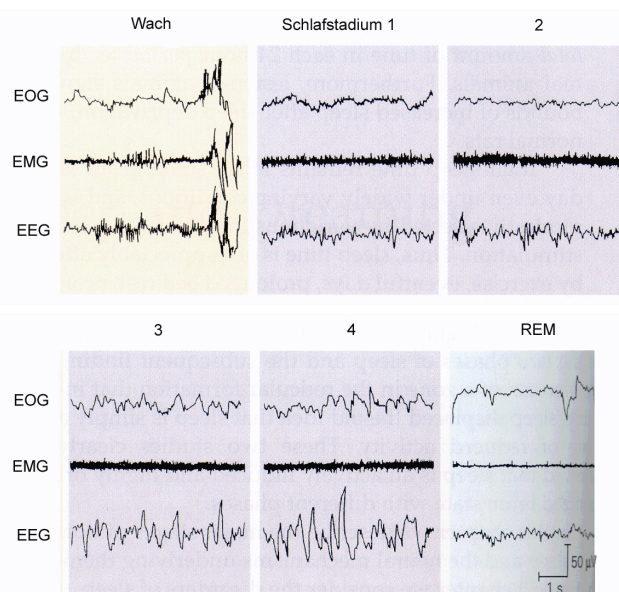
eyes closed

eyes open

Spontaneous MEG

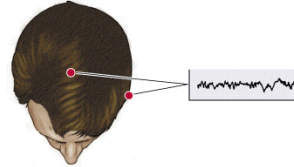


Spontaneous EEG: Sleep Stages

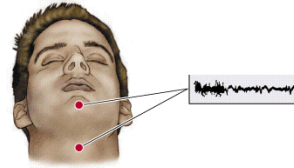


Spontaneous EEG: Sleep Stages

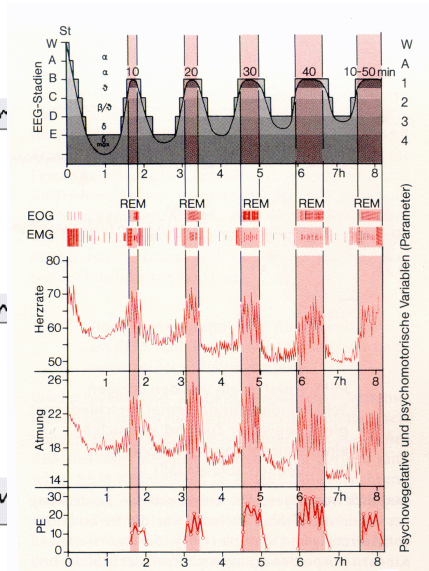
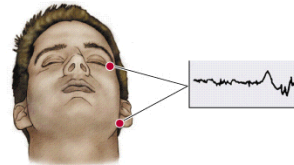
(A) Electroencephalogram (EEG)



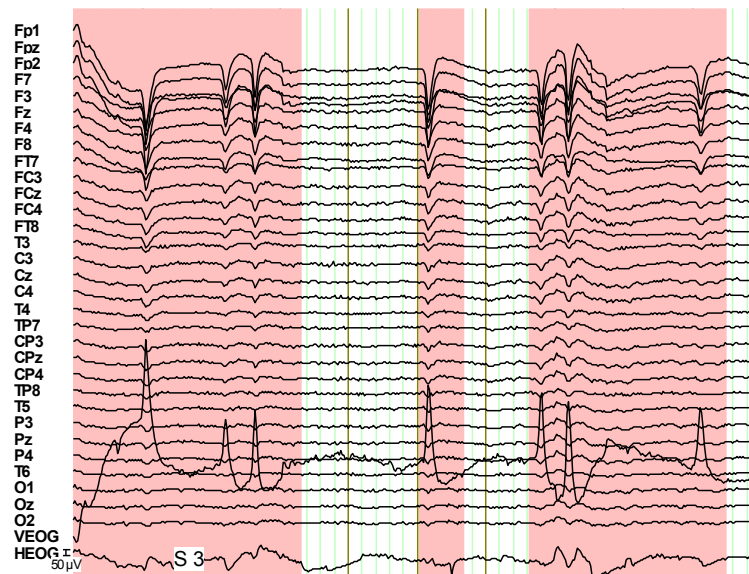
(B) Electromyogram (EMG)



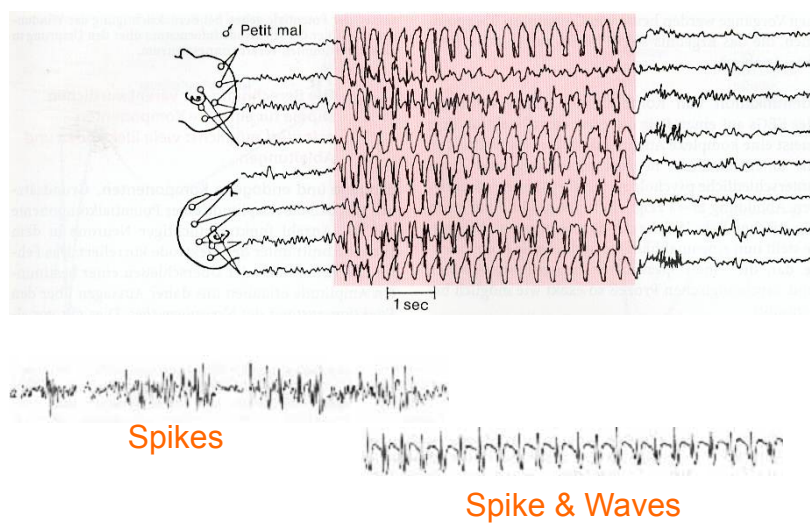
(C) Electrooculogram (EOG)



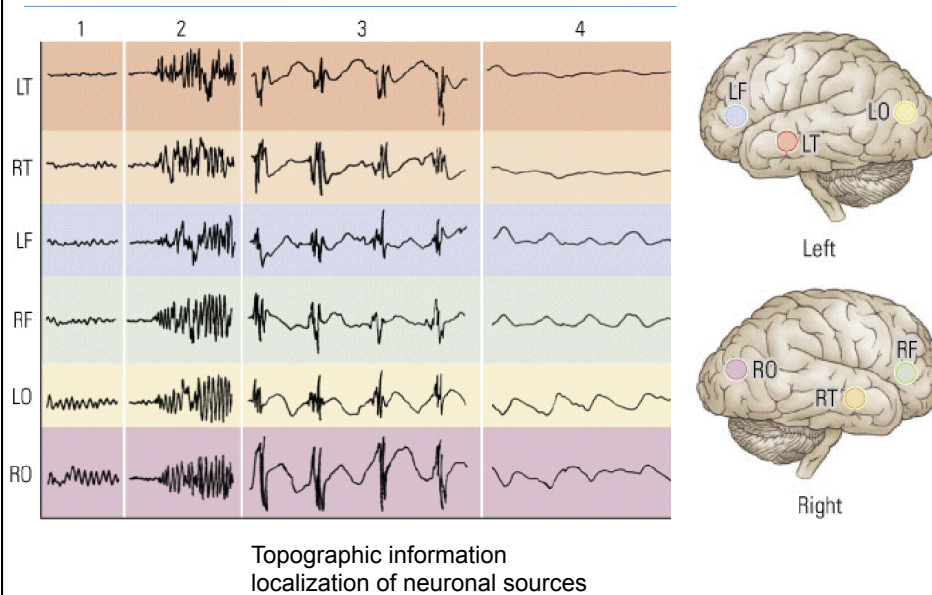
Artifacts: Eye Blinks and Eye Movements



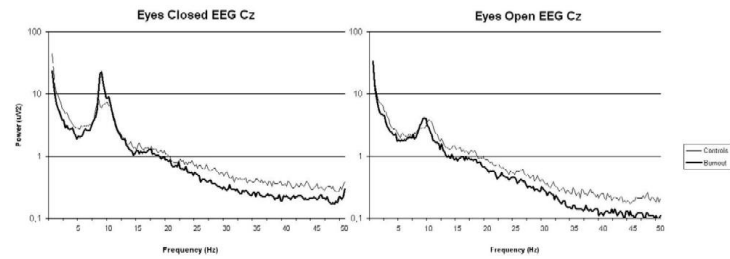
Clinical Applications: Epilepsy



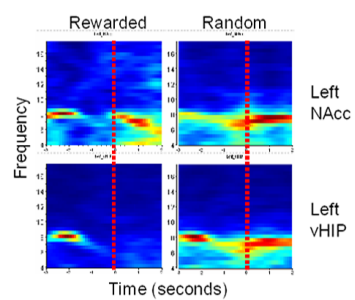
Spontaneous EEG: Epilepsy



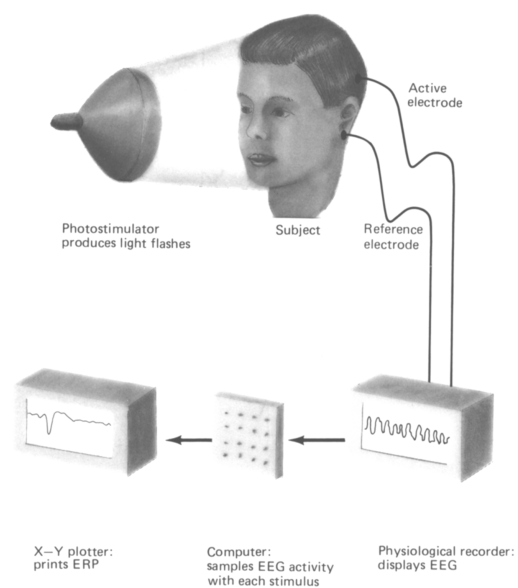
Spontaneous EEG

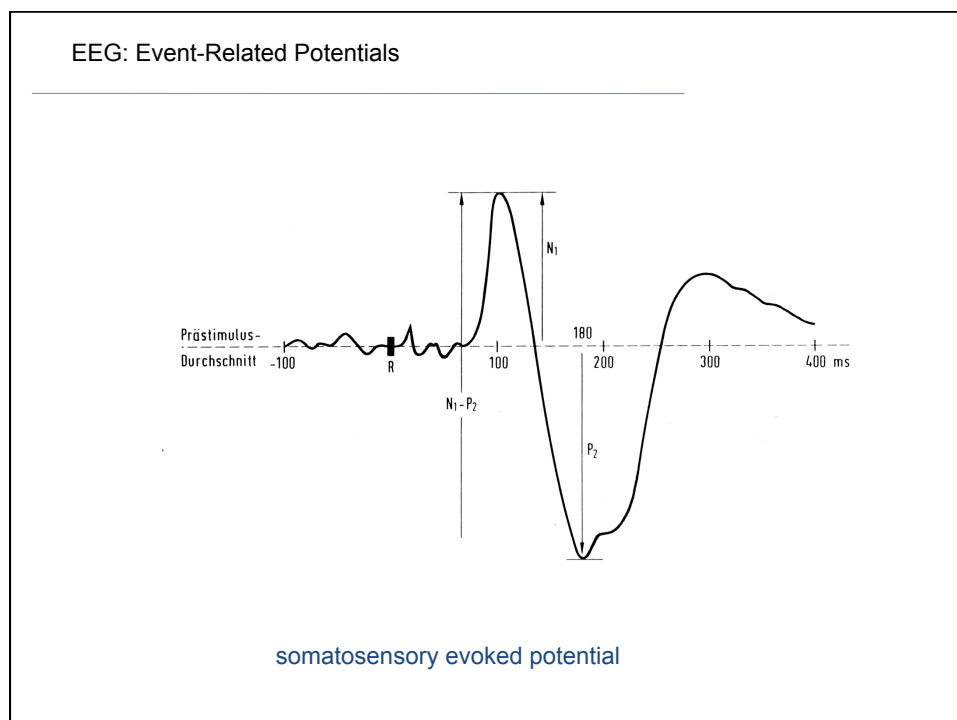
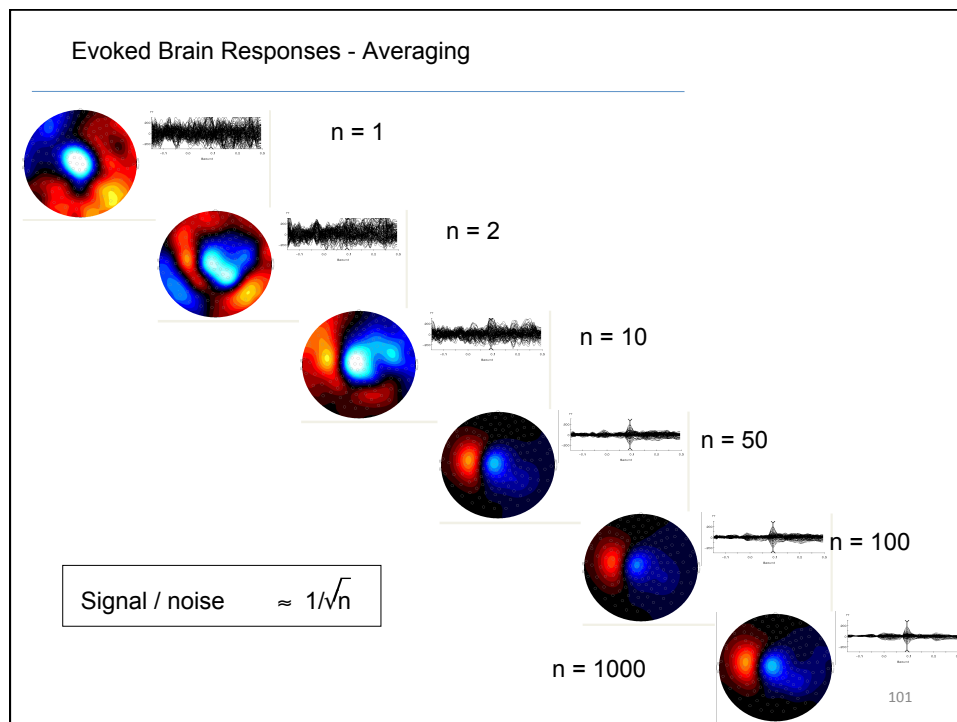


Spectrum
Fourier analysis
Low-pass filter
High-pass filter

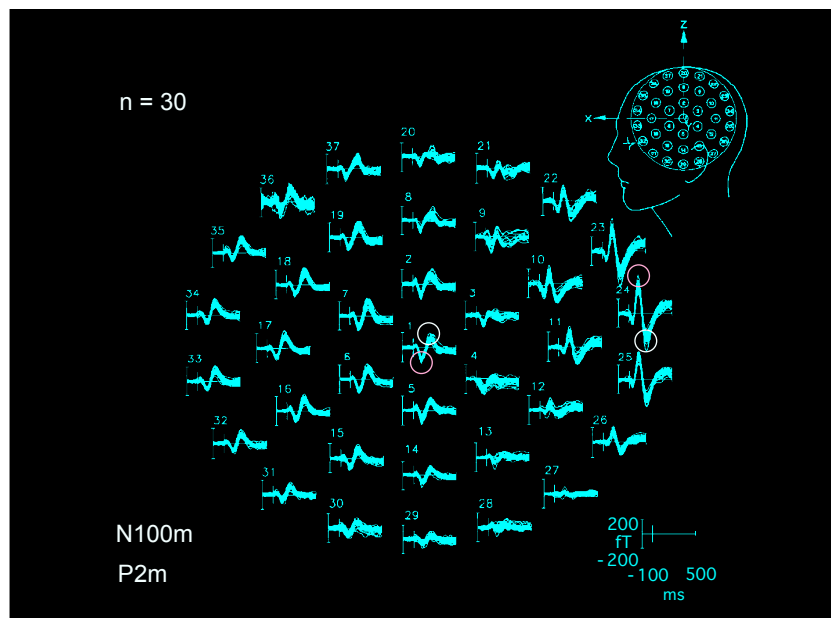


EEG: Event-Related Potentials

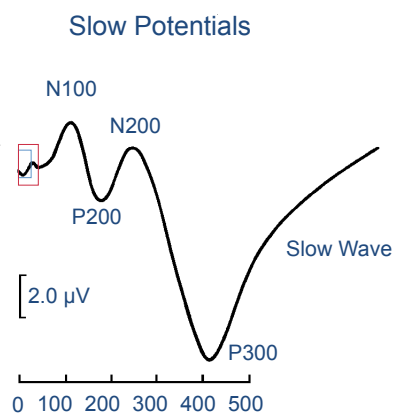
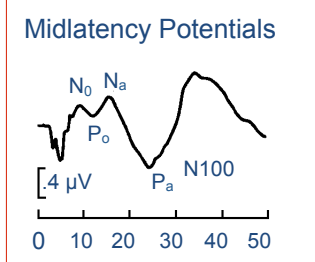
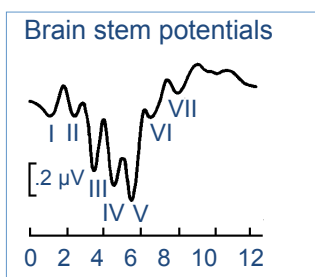




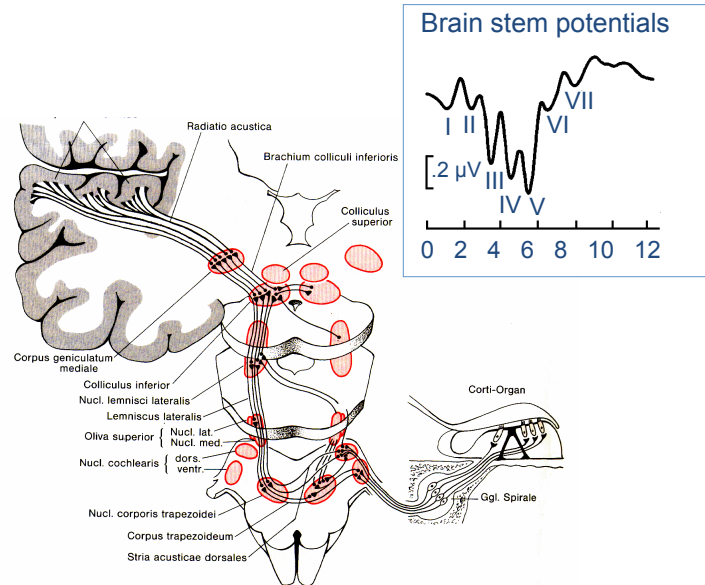
Reproducibility of MEG-Responses



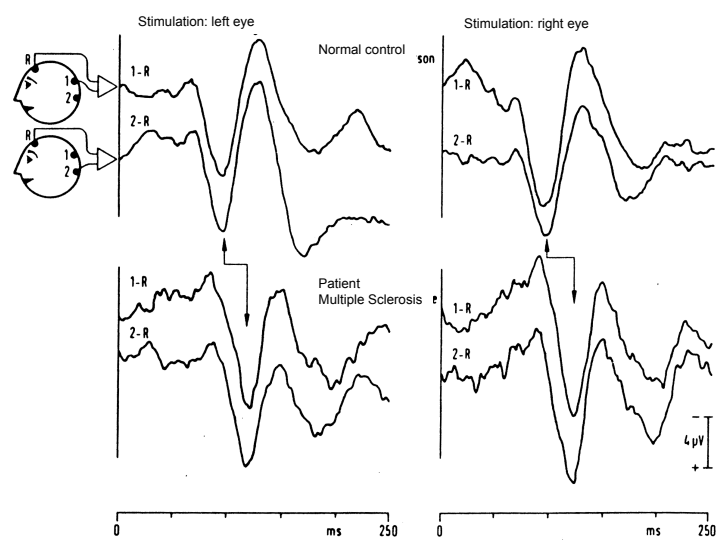
EEG: Types of Event-Related Potentials



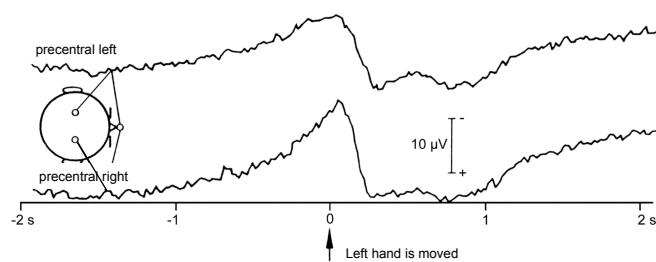
Brainstem Potentials



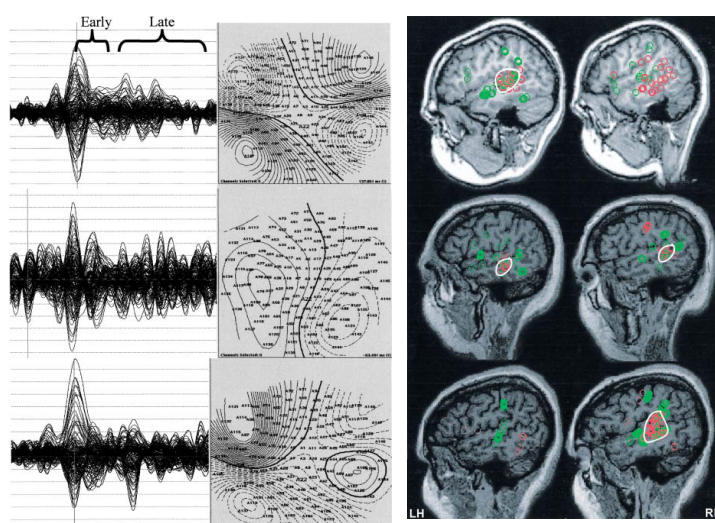
EEG Application: Multiple sclerosis (MS)



EEG: Bereitschafts-Potential



Magnetoencephalography



Papanicolaou, 2004, J.
Neurosurg

Magnetoencephalography (MEG)



Franz Anton Mesmer: Animal Magnetism

curative effects of magnetism on humans

- As a consequence of Galvani's experiments on animal electricity, also the existence of an **animal magnetism** was hypothesised by F. A. Mesmer, who tried to associate "mysterious" magnetic fields with a deep influence on human behaviour
- Mesmer theories were examined by a committee of scientists - including Benjamin Franklin - nominated by King Louis XVI, and were declared totally absurd. Nevertheless, mesmerism continued to be widespread across Europe and to be practiced in the so-called Mesmer "saloons" for at least other 50 years
- Only when the deep connections existing between electric currents and magnetic field were fully understood – thanks to the exceptional synthesis operated by Maxwell – mesmerism definitively disappeared



Franz Anton Mesmer
1734 -1815



Physiological Electro-Magnetic Signals

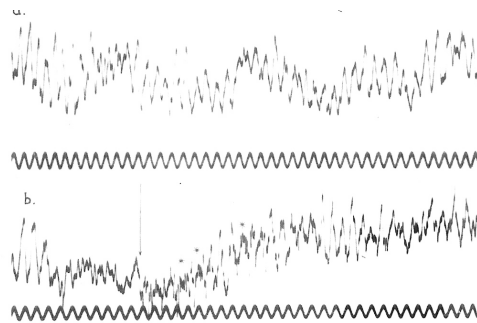
At the beginning of the 20th century electric signals associated with cardiac and cerebral activity were recorded for the first time:

- electrocardiogram (ECG) - (**Einthoven, 1903**)
- electroencephalogram (EEG) - (**Berger, 1929**)

Willem Einthoven
1860-1927



Hans Berger
1873-1941



Physiological Electro-Magnetic Signals

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Willem Einthoven
1860-1927



Hans Berger
1873-1941



Only at the beginning of the sixties, the magnetic signals associated with cardiac currents were first described (magnetocardiogram (MCG) recorded by resistive coils, **Baule & McFee, 1963**)

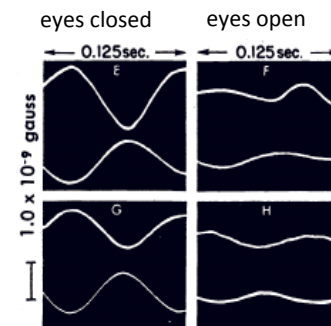
Finally, a MCG was measured for the first time using the rfSQUID developed by Edelsack, Cohen, and Zimmerman at MIT (**David Cohen et al., 1970**)



Magnetoencephalography

The magnetic field due to electric currents flowing inside the brain was first recorded in 1968 by **David Cohen** using resistive coils

Cohen, Science 1968



In 1971 David Cohen measured the spontaneous alpha rhythm using a SQUID, and the expression magnetoencephalography (MEG) was introduced



Cohen, Science 1972

Progress in Magnetoencephalography



In the eighties
the single channel...



In the nineties
from 37 to 150 channels...



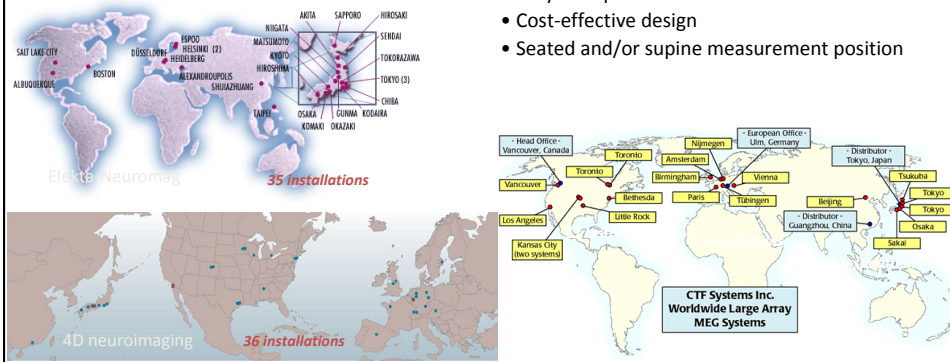
In the current millennium
the channel number is increased up to
some hundreds



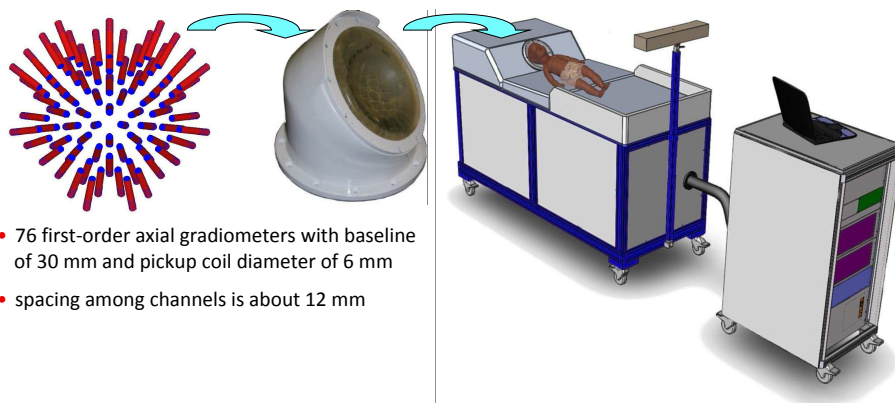
MEG-Systems World Wide

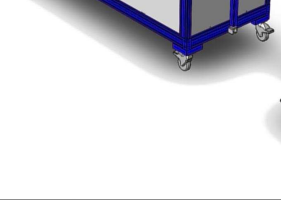
Presently there are about 100 MEG systems installed worldwide. Major companies selling whole head MEG equipment are: 4D neuroimaging, Elekta-Neuromag, Yokogawa.

- Whole head coverage
- 100+300 detection points consisting of one to three channels
- Stable and reliable LTS SQUIDS
- Easy and friendly operation
- Easy set-up and maintenance
- Cost-effective design
- Seated and/or supine measurement position

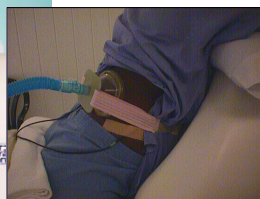


BabySQUID® Neonatal Biomagnetometer by Tristan Technologies, Inc.



- 76 first-order axial gradiometers with baseline of 30 mm and pickup coil diameter of 6 mm
 - spacing among channels is about 12 mm
- 
- The gradiometers are connected by thermal conductors to the liquid helium bath
 - the distance between the signal coils and the headrest is about 6 mm
 - the magnetic field noise $\sim 17 \text{ fT}/\sqrt{\text{Hz}}$

Fetal Magnetoencephalography



Control condition

- 6 x two minutes recording without any stimulus

Stimulation

- 1000 Hz tones, 100 ms duration
- Interstimulus interval 2.0 sec
- presentation via tube
- phone: ca 120dB
- continuous recording 250 Hz: 2 x 6 min

Fetal Magnetoencephalography (fMEG)



Fetal Magnetoencephalography (fMEG)



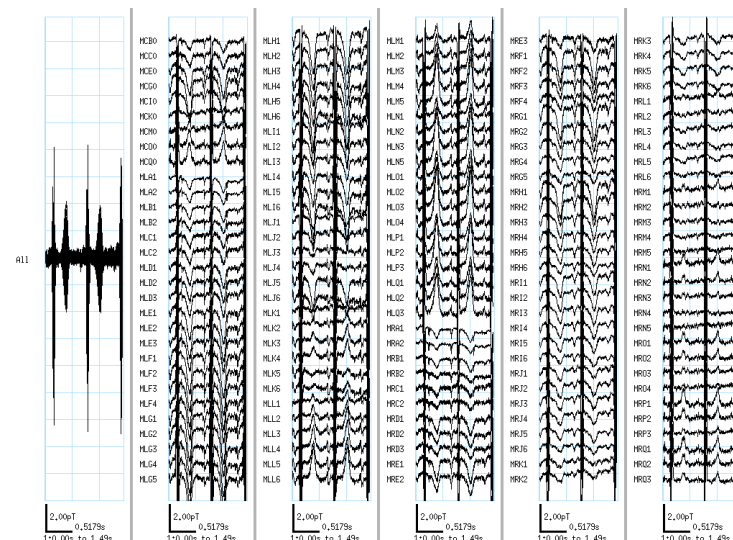
Stimulation

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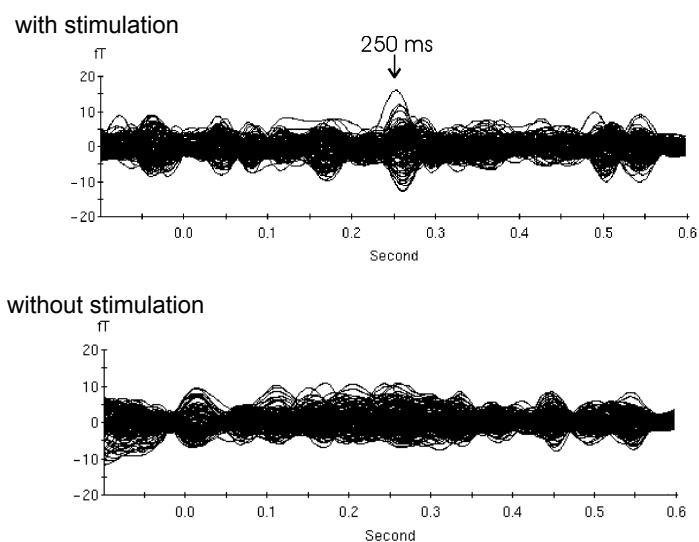
Control condition

- 6 x two minutes recording without any stimulus

Fetal Magnetoencephalography (fMEG)



Fetal Magnetoencephalography (fMEG)



New Developments: Atomic Magnetometers

Magnetoencephalography

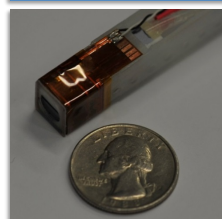


Measuring neuro magnetic fields of the brain by means of SQUID technology

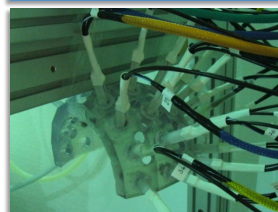
- expensive
- no flexible configurations

Atomic magnetometers

CSAM in sleeve



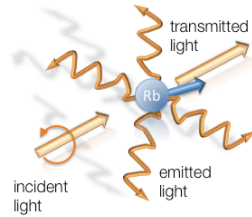
25-channel CSAM helmet



New Developments: Atomic Magnetometers

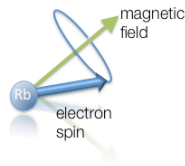
Working principle of CSAMs

1. The spins of atoms in a gas can be aligned with resonant light



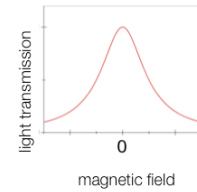
Optical
pumping

2. Atoms with spin and magnetic moment precess in a magnetic field



Precession

3. The absorption of resonant light depends on the orientation of the atomic spins

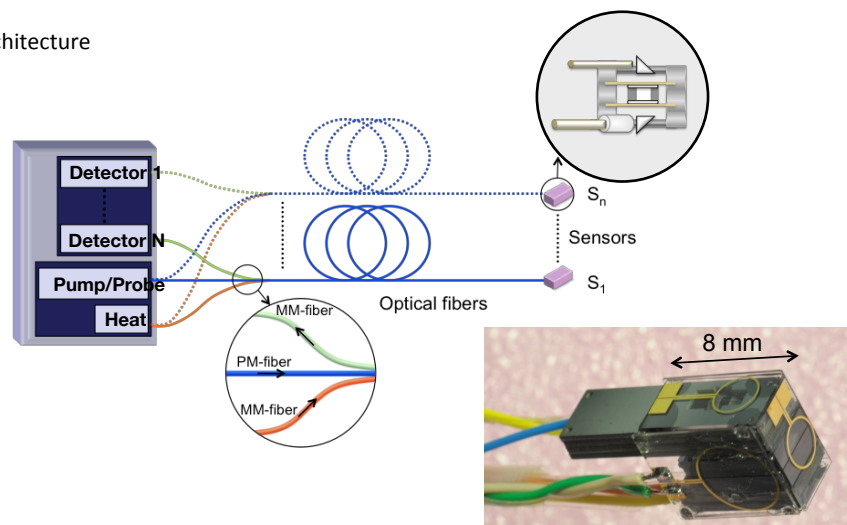


Optical
probing

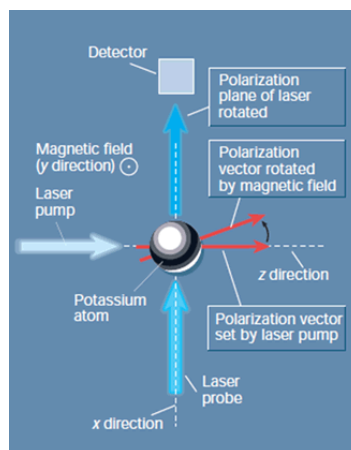
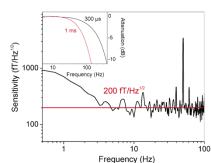
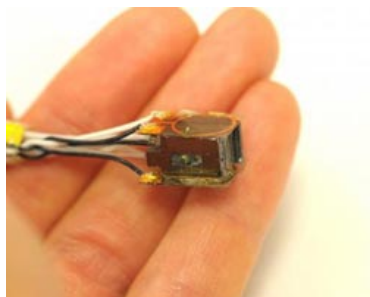
New Developments: Atomic Magnetometers

Working principle of CSAMs

Architecture

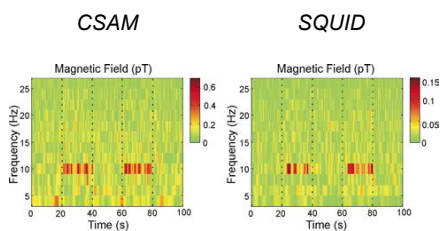


Atomic Magnetometers: Is this the Future?

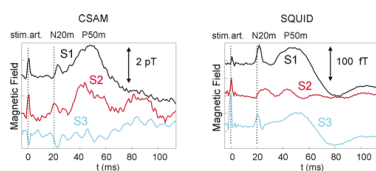


Atomic Magnetometers: Is this the future?

noise

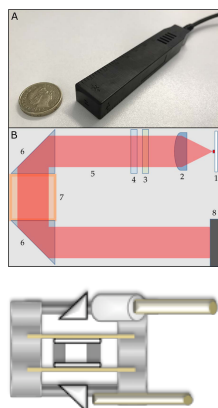


somatosensory
evoked field
(SEF)

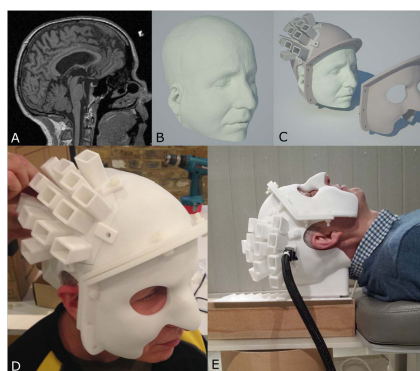


Optically Pumped Magnetometers

Sensor



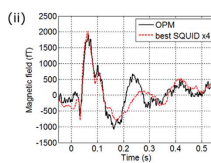
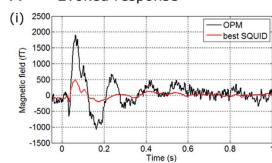
Head cast



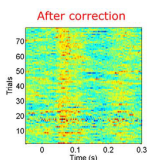
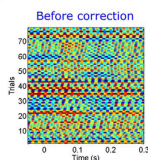
Optically Pumped Magnetometers

Median nerve stimulation: evoked response

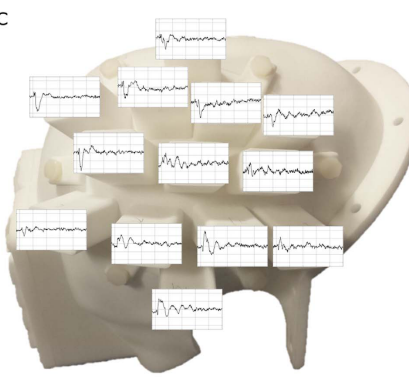
A Evoked response



(iii) Single trials



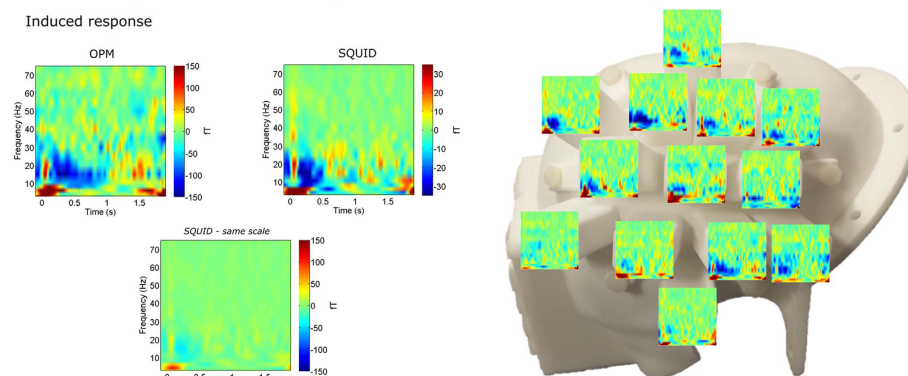
C



Optically Pumped Magnetometers

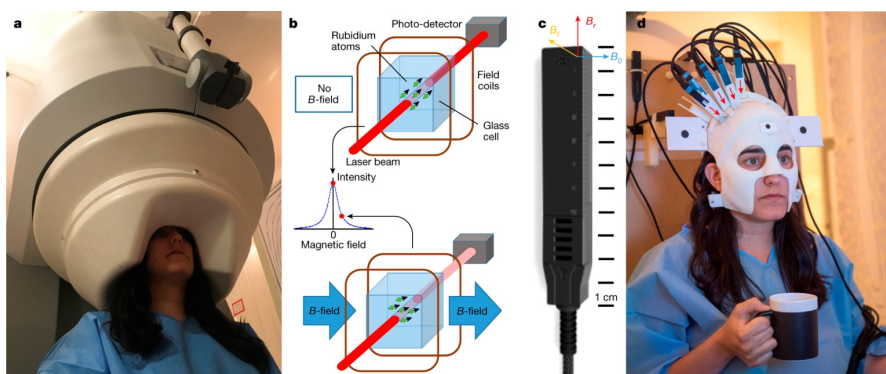
Median nerve stimulation: spectrogram

B Induced response



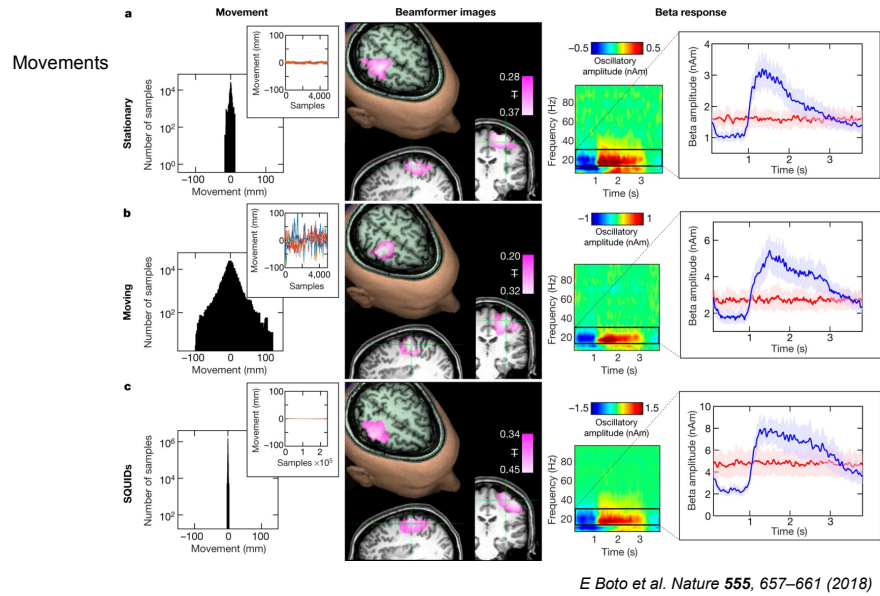
Optically Pumped Magnetometers

Movements

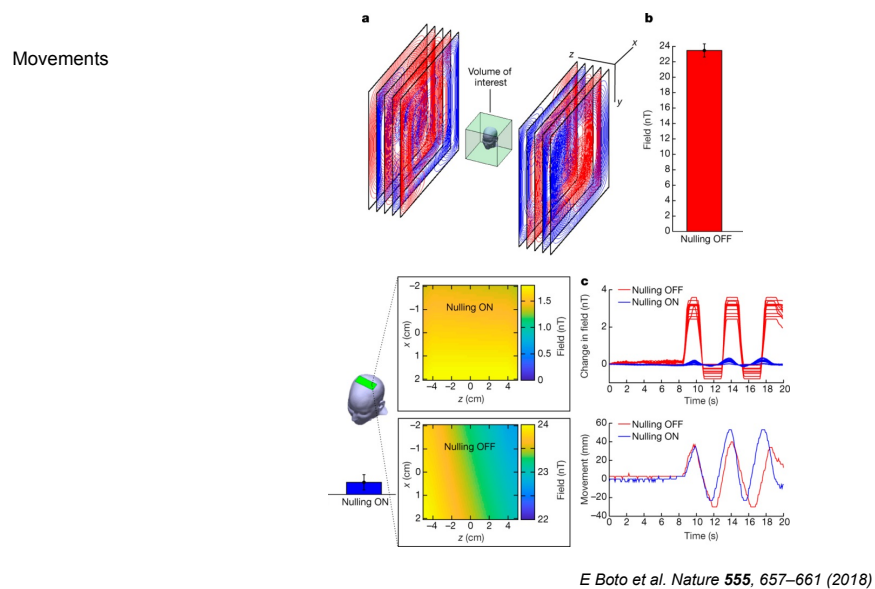


E Boto et al. Nature 555, 657–661 (2018)

Optically Pumped Magnetometers

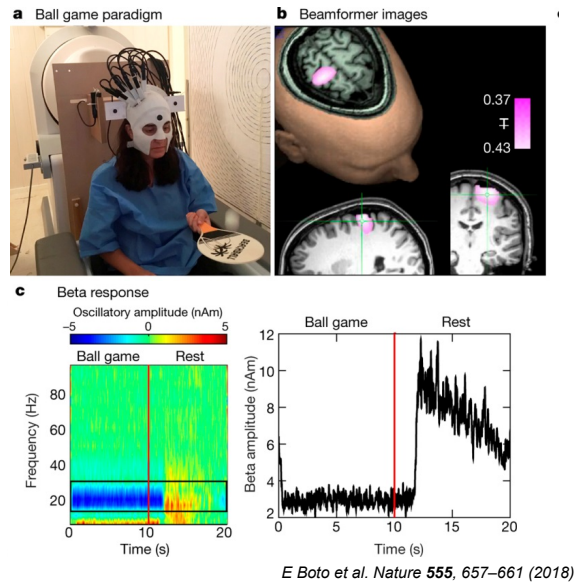


Optically Pumped Magnetometers

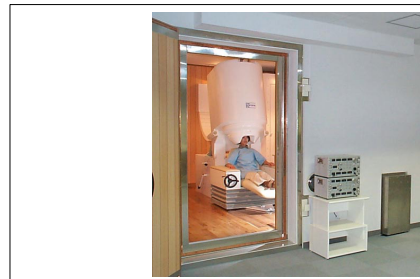
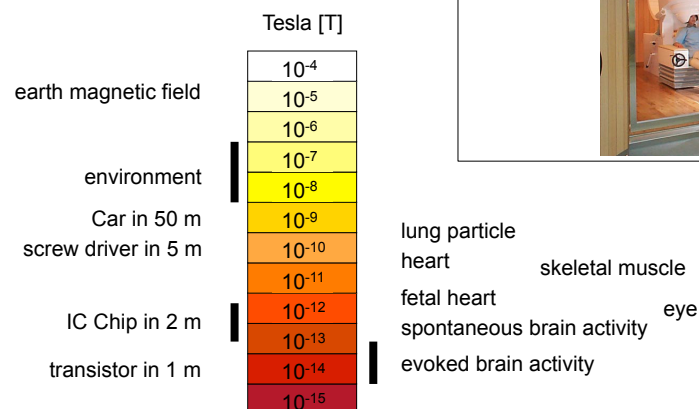


Optically Pumped Magnetometers

Movements



Strength of Magnetic Fields



Noise Suppression: Shielding



the basis of the magnetic shielded room is an aluminium frame

inner layer
copper coated
aluminium



middle layer
mu metal with
high magnetic
susceptibility



outer layer
aluminum



demagnetisation

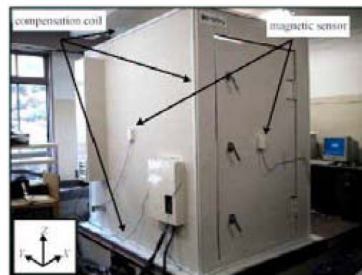


finish

Noise Suppression: Shielding



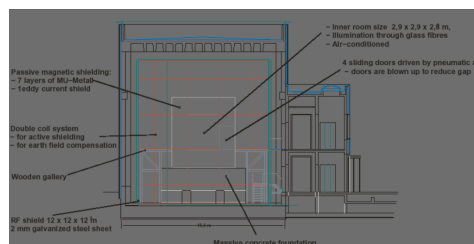
AK3B Vakuumschmelze:
3 Layer shielding



active compensation



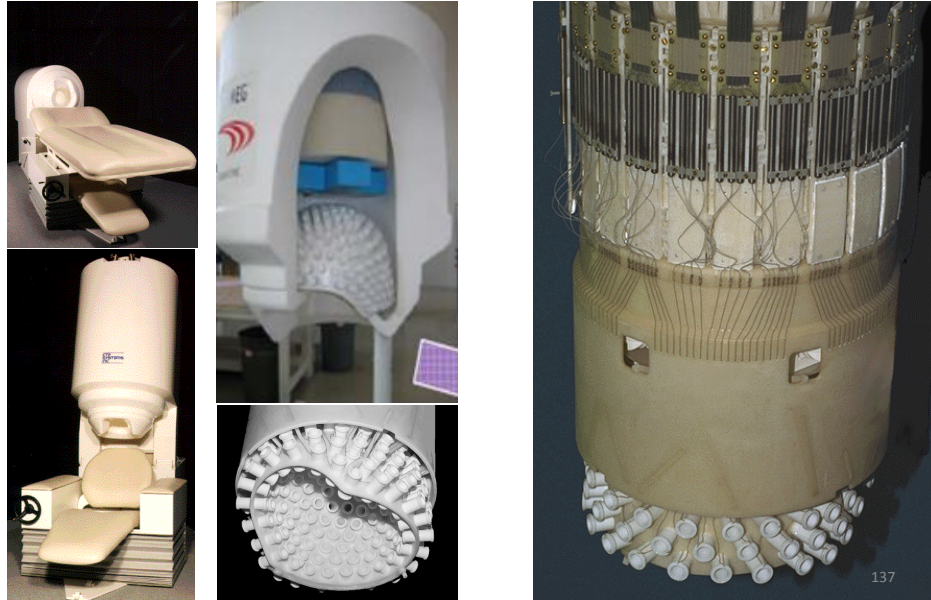
Superconductive Shielding :
Shielding factor: 10 000 bei 0.05 Hz



passive 7 layer shielding
double coil system for
- active shielding
- earth field compensation
RF-shield

136

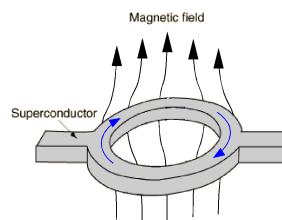
MagnetoEncephaloGraphy



SQUID: Superconducting Quantum Interference Device

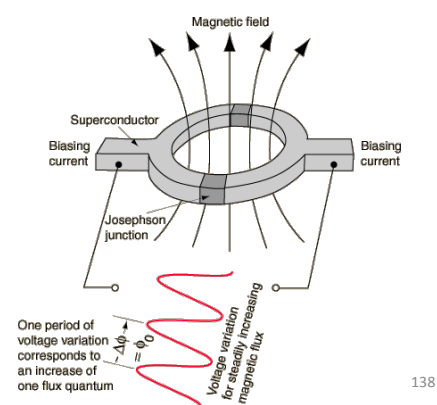
superconducting ring

- an external magnetic field creates a current in the coil
- current creates magnetic field opposite to the original field
- no magnetic field inside the ring



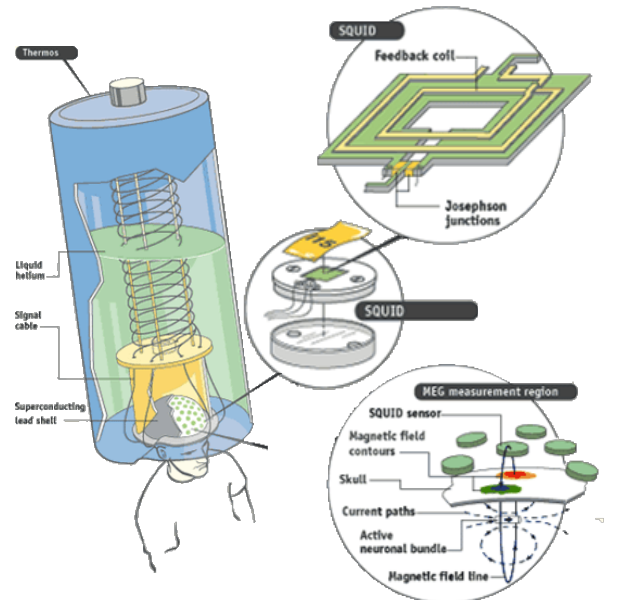
superconducting ring with Josephson junction

- differences between multiples of flux quanta
- only multiples of flux quanta can pass generate a current
- the current causes a voltage drop at the Josephson junction



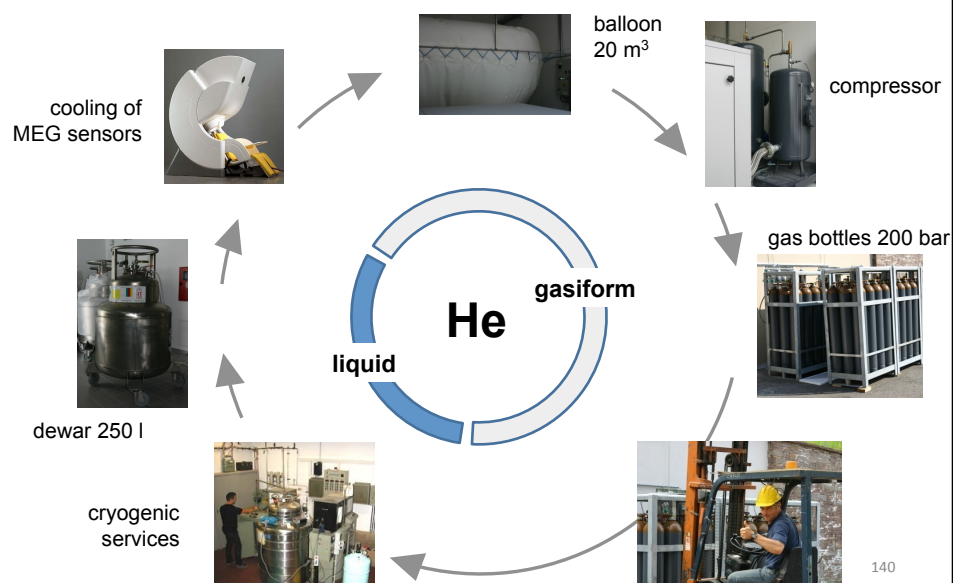
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Principle of Magnetoencephalography



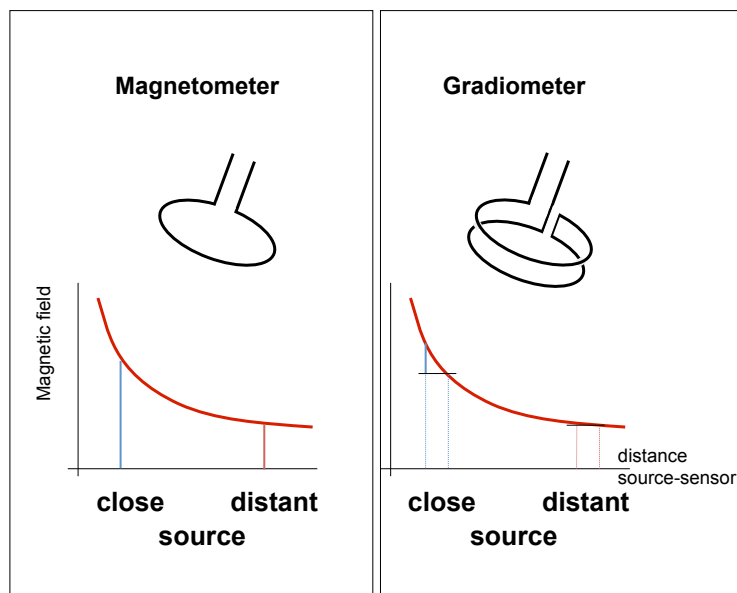
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Helium Supply and Recovery

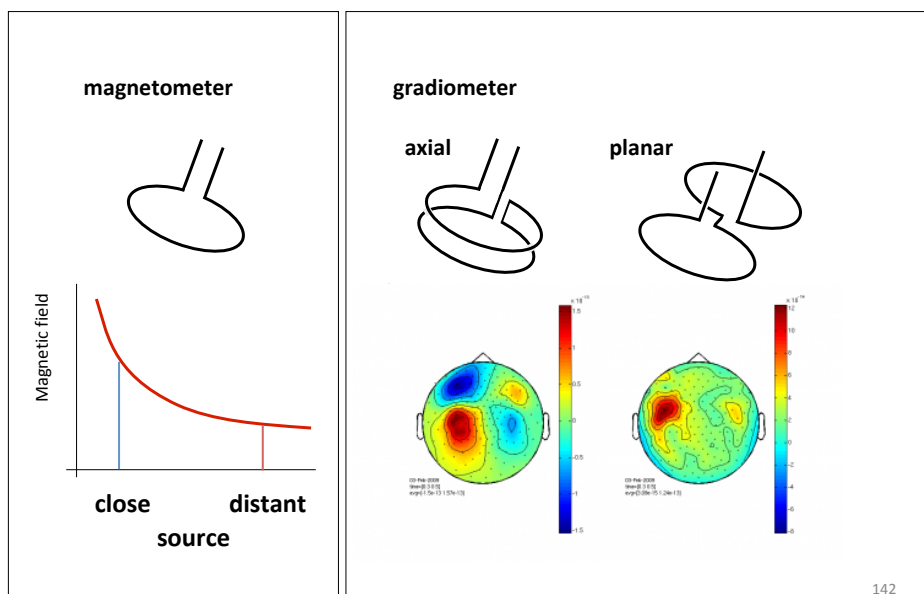


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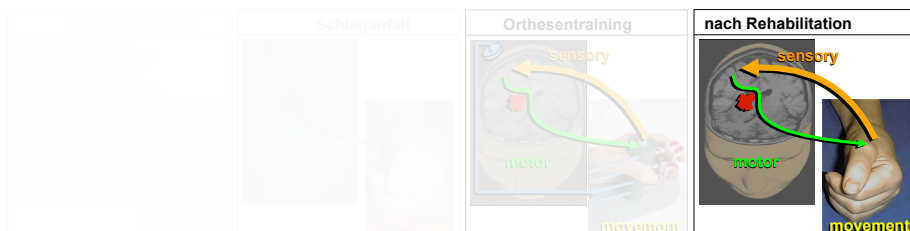
Gradiometer for Noise Suppression



Noise Suppression: Magnetometers and Gradiometers



Brain Controlled Neuroprosthesis



Brain-Computer-Interface for
the control of „Orthosis-training“:

Feedback of μ -rhythm activity

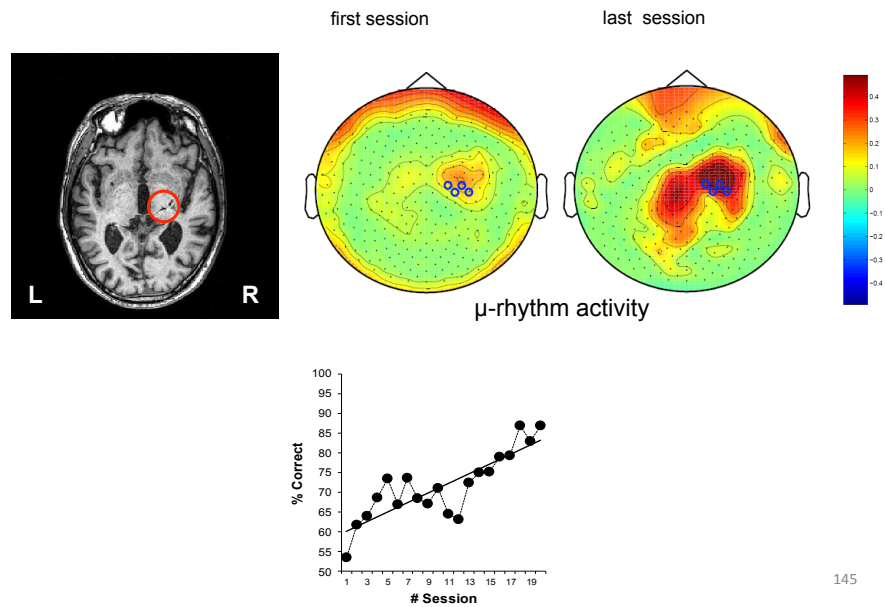
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Brain Controlled Neuroprosthesis



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Brain Controlled Neuroprosthesis



Physiological Background of EEG and MEG

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