***Elaboration di Immagini - Laurea in Bioinformatica***

*Prof. G. Menegaz*

# EEG SIGNAL PROCESSING

## *1. Recording*

***Silvia F. Storti***

*silviafrancesca.storti@univr.it*

30/04/2017

# The human brain

The lobes have specialized functions.

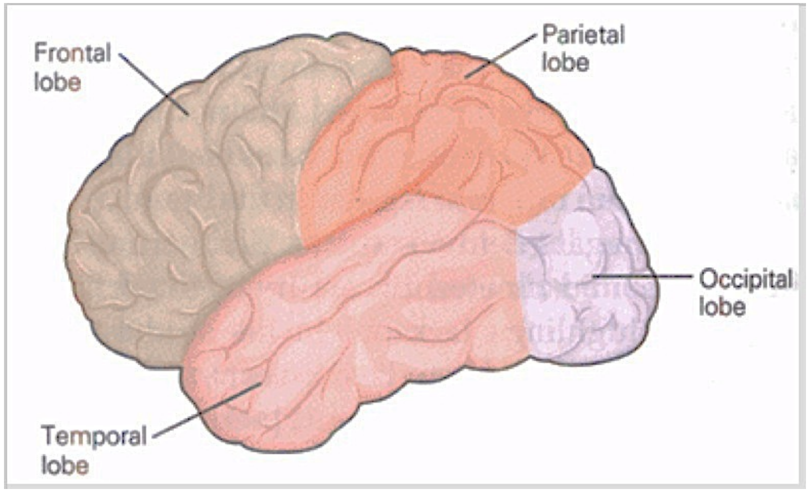
Frontal Lobe: is concerned with planning future action and with the control of movement

Parietal Lobe: is concerned with movement, with somatic sensation, with forming a body image, and with relating one's body image with extrapersonal space

Occipital Lobe: is concerned with vision

Temporal Lobe: is concerned with hearing (and through its deep structures —the hippocampus and the amygdaloid nuclei—with aspects of learning, memory, and emotion)

The four lobes of the cerebral cortex




**(Kandel, Principi di Neuroscienze)**

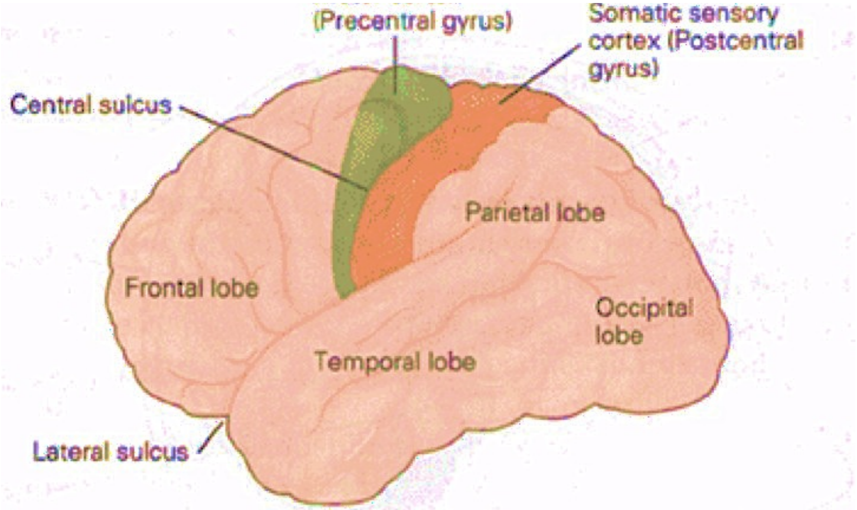
# The human brain

Each lobe has several characteristic deep infoldings.

The crests of these convolutions are called **gyri**, while the intervening grooves are called **sulci or fissures**.

The more prominent gyri and sulci are quite similar in everyone and have specific names.

For example, the **central sulcus** separates the precentral gyrus, which is concerned with motor function, from the postcentral gyrus, which is concerned with sensory function.

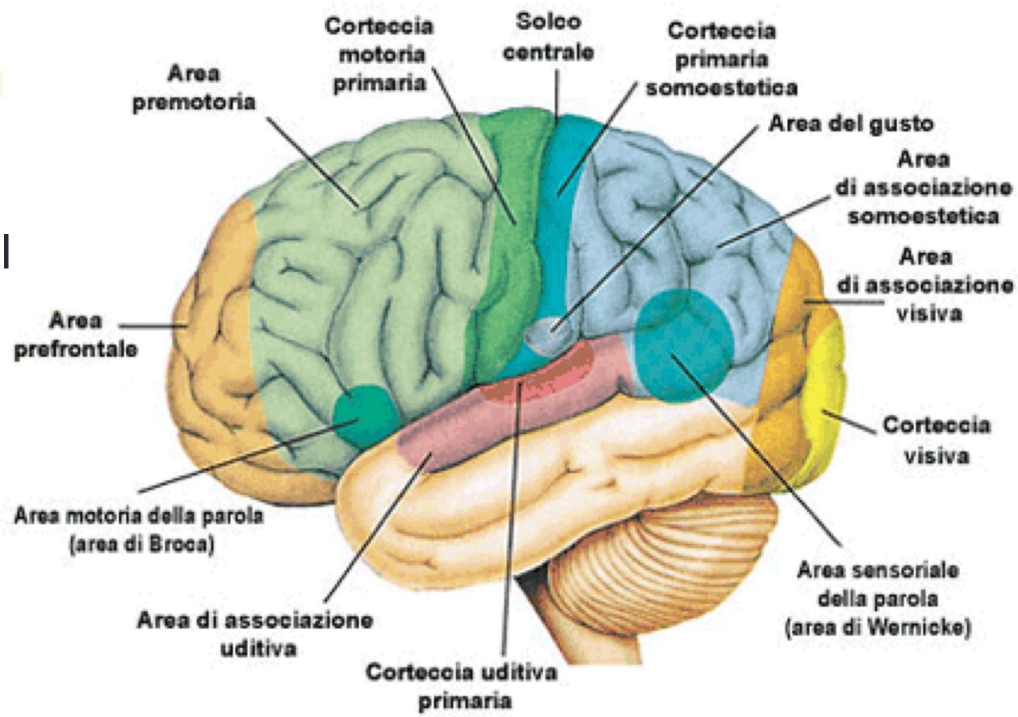



**(Kandel, Principi di Neuroscienze)**

# Functional areas of the brain

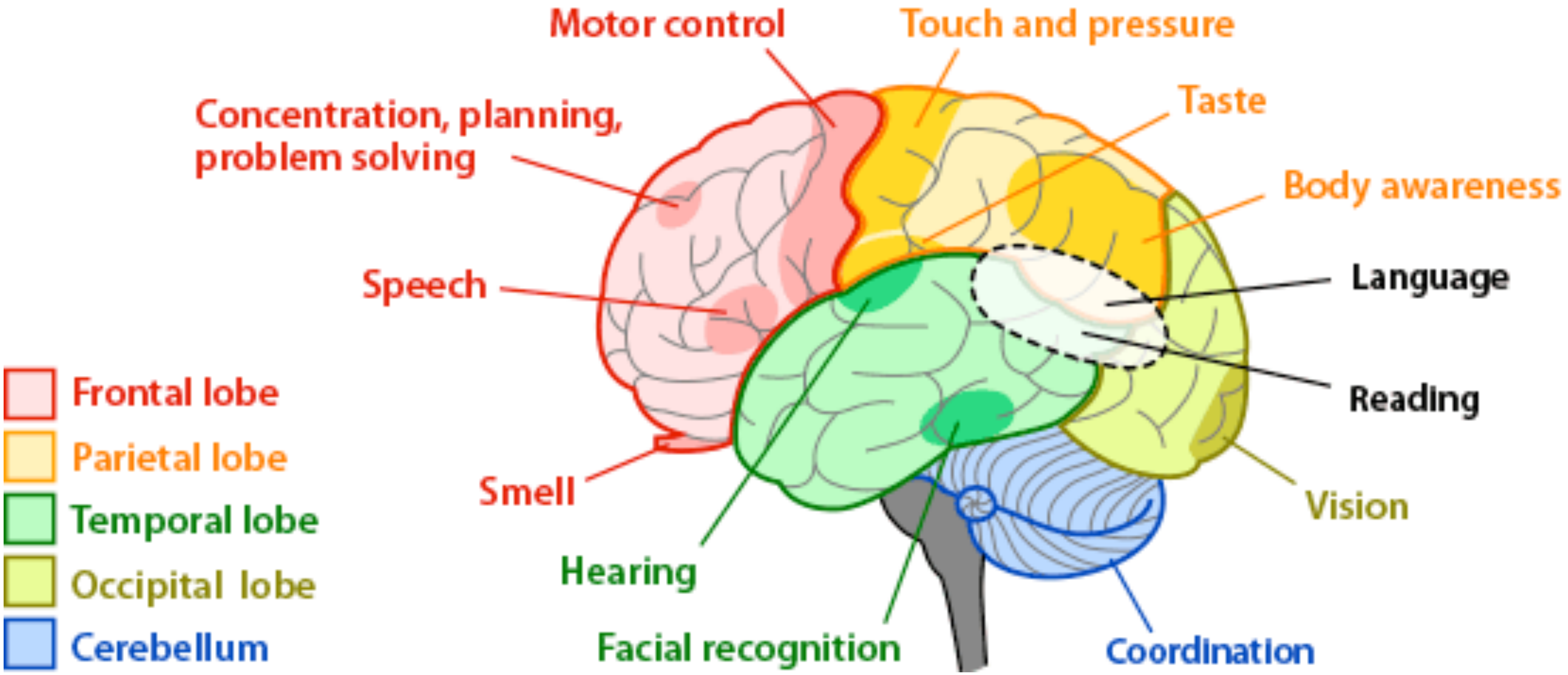
The cerebral cortex can be divided into areas specialized in different brain functions.

- the area responsible for the visual sensitivity is localized in the occipital lobe
- the area for the acoustic sensitivity is located in the temporal lobes
- the area for the sense of smell and taste is at the hippocampus level
- high level functions are controlled by the frontal lobe




(Kandel, Principi di Neuroscienze)

# Functional areas of the brain




https://socratic.org/questions/what-do-different-parts-of-the-brain-control

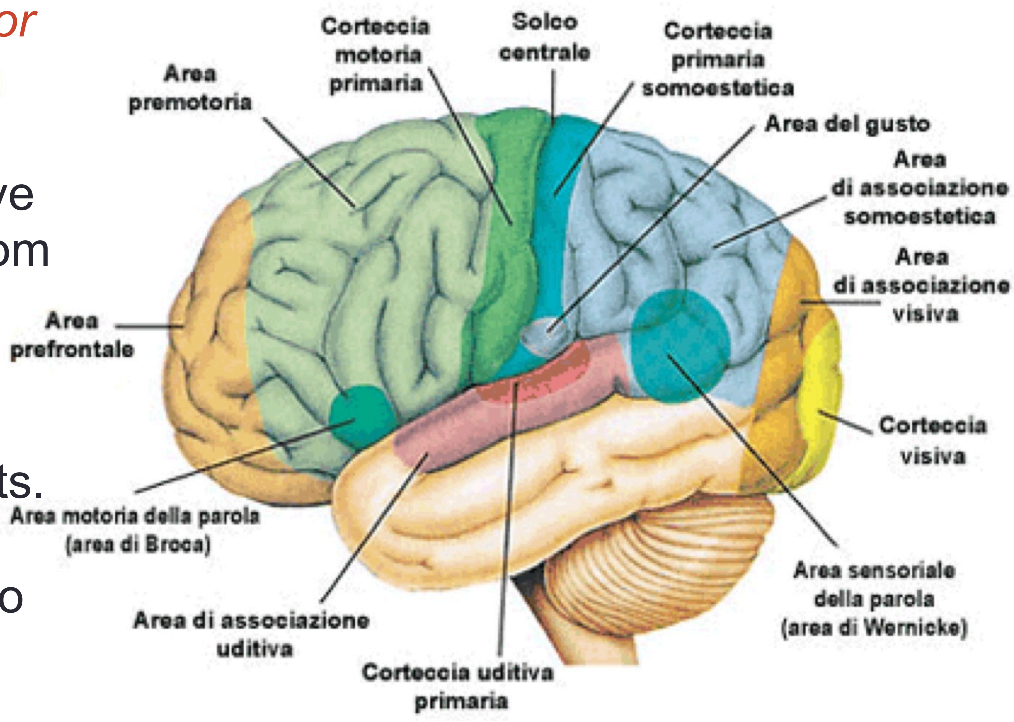
# Functional areas of the brain

According to the function, the cerebral cortex is divided into *sensory, motor* and *associative*.

The **sensory cortex** receives nerve pathways which conduct stimuli from all over the body.

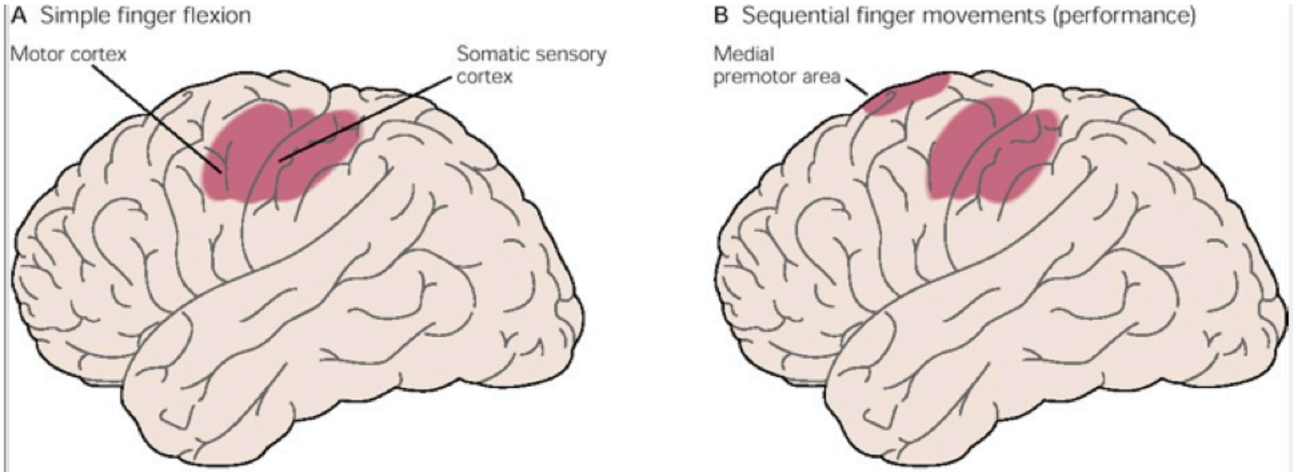
**Motor areas** generates motor impulses through the pyramid tracts.

The **association areas** are used to integrate the different sensations, their storage and to construct the complex process of consciousness, including the design, the will, awareness and judgment.

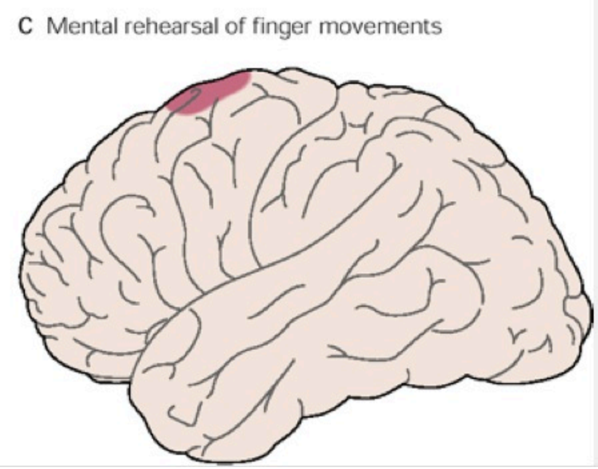



(Kandel, Principi di Neuroscienze)

# Functional areas: motor regions




Different areas of the cortex are activated during the movement or the movement imagination of simple tasks or complex sequences.

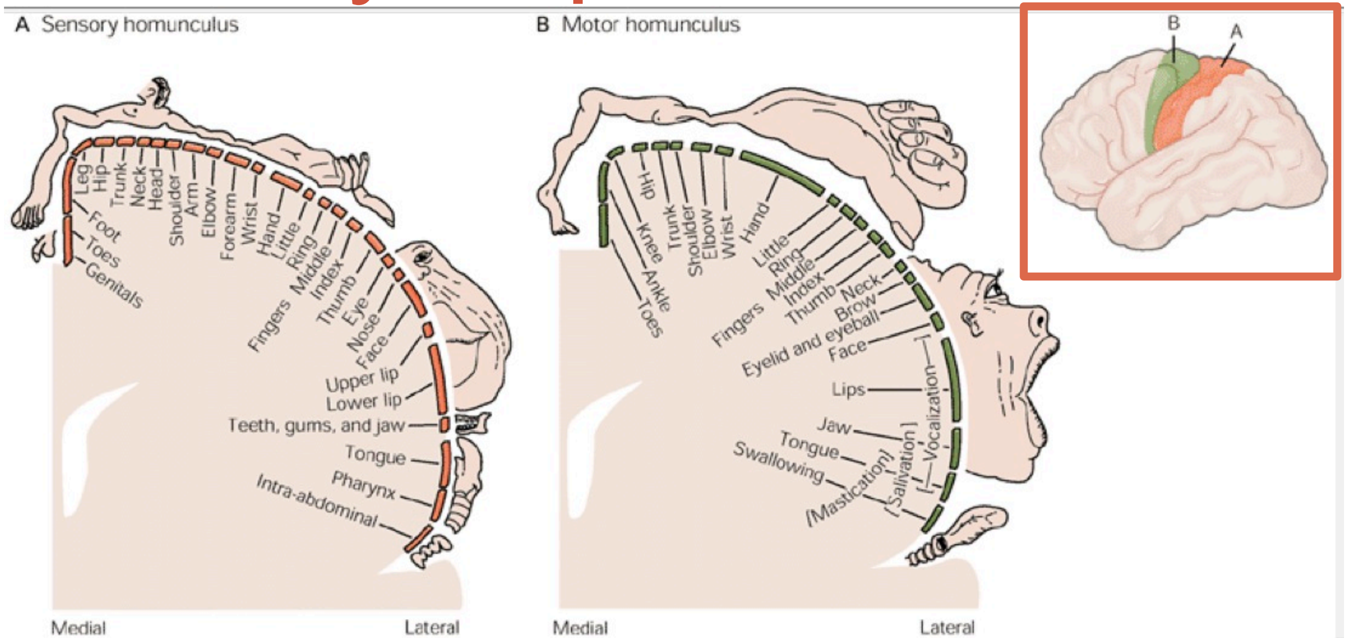



**(Kandel, Principi di Neuroscienze)**

# Motor and sensory map

**Homunculus**

- physical representation of the human body, located within the brain.
- It is a neurological "map" of the anatomical divisions of the body.



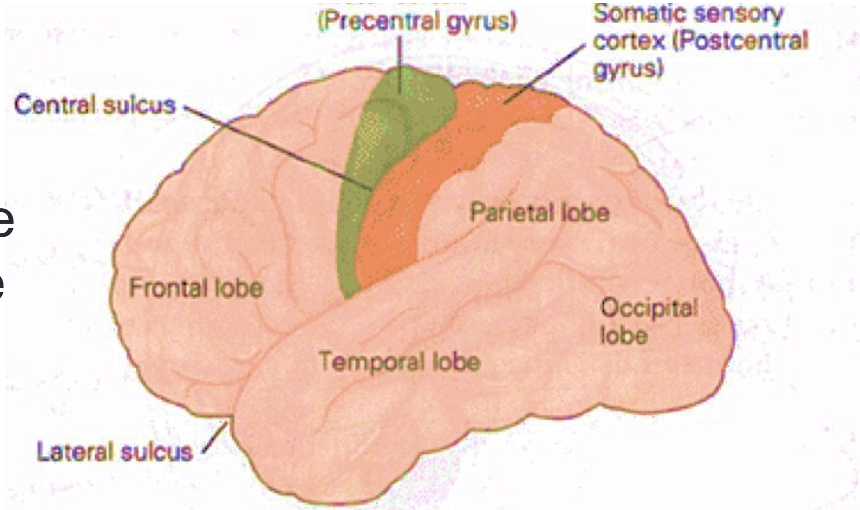

There are two types of cortical homunculus: sensory and motor.

In the sensory (left) and motor (right) cortex, areas related to specific parts of the body are present.

The area of the cortex dedicated to the processing of information by a particular part of the body is not proportional to the mass of the body part, but instead reflects the degree of innervation of the part.

e.g. sensory input from the lips and hands occupies more area of cortex than that from the elbow.

# Motor imagery

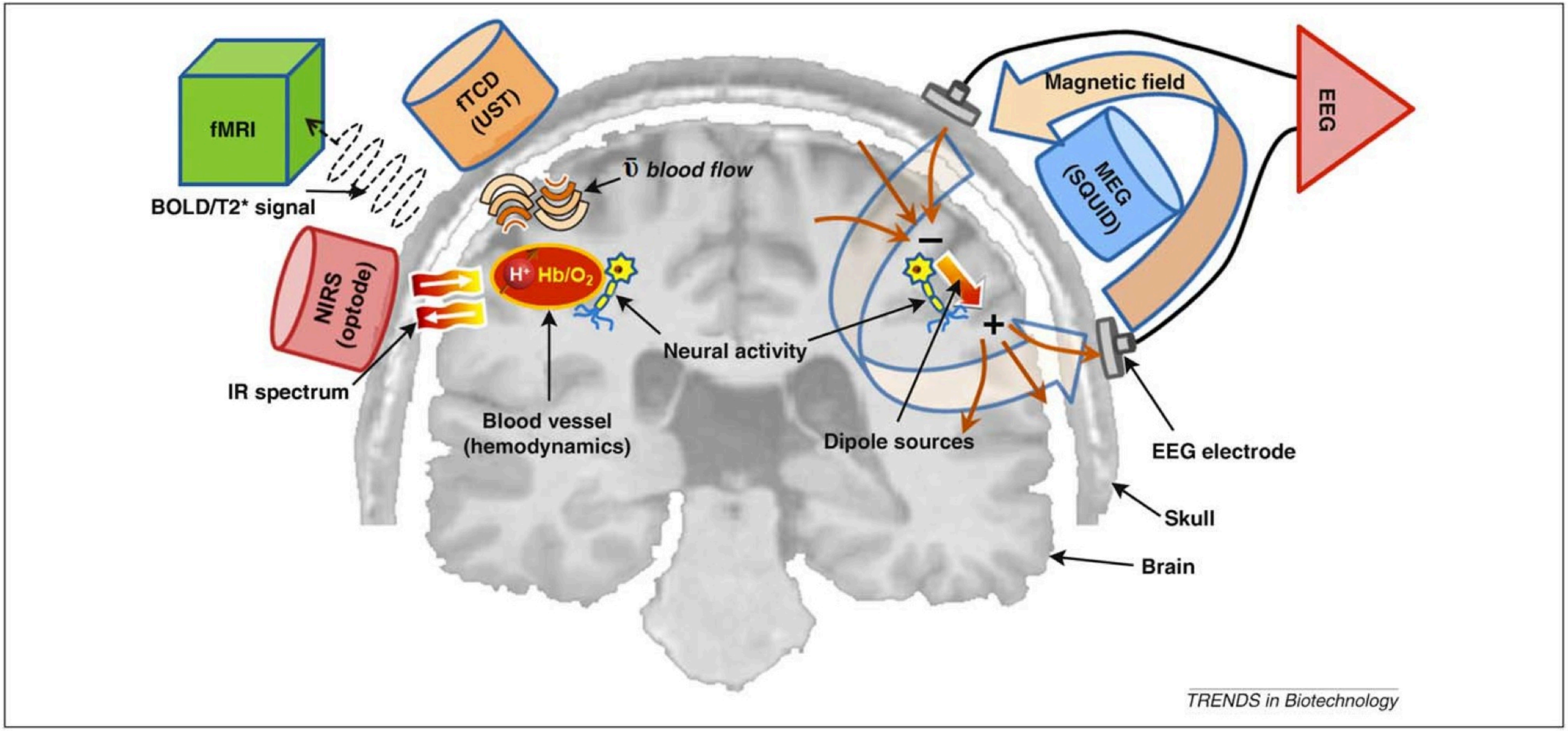



- mental imagery and movement involve very similar brain regions, used for the planning and preparation of the movement

- the motor imagery, defined as a mental simulation of the movement, is an efficient mental strategy to operate the brain computer interface

- the imagination of the movements of the right hand, left hand, foot or tongue results in a characteristic change in the brain signal over the sensorimotor cortex

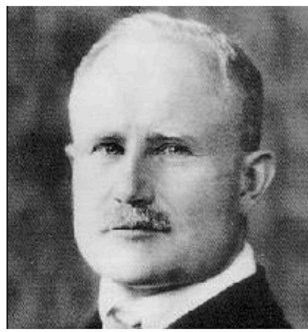
# Methods for measuring brain activity

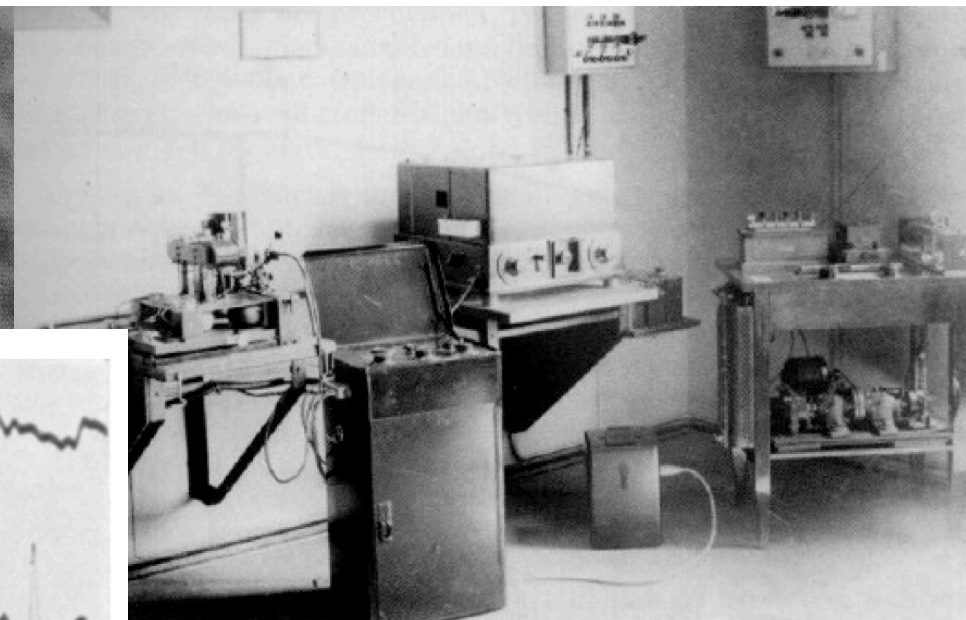


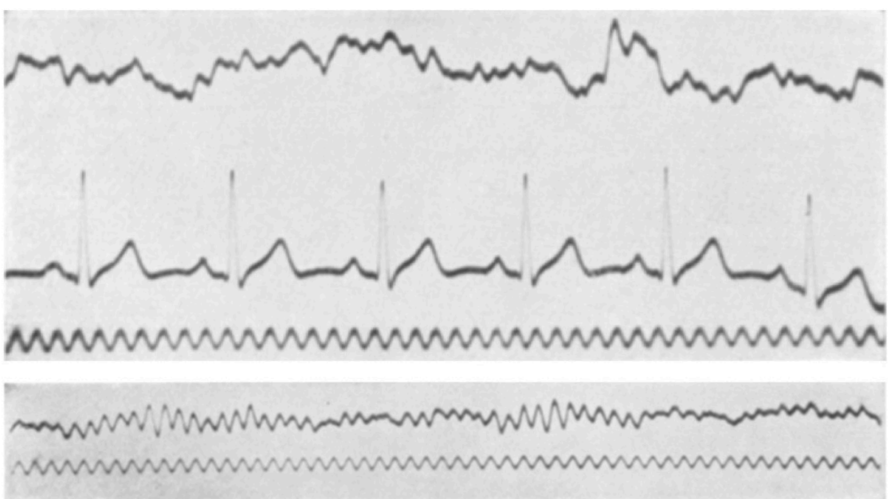

Byoung-Kyong Min et al. Trends in Biotechnology, 2010

# EEG history

1924: Hans Berger, a German psychiatrist, recorded the brain electrical activity by using an electroencephalography (EEG) (the recording of "brain waves") and discovered the alpha wave rhythm known as "Berger's wave".



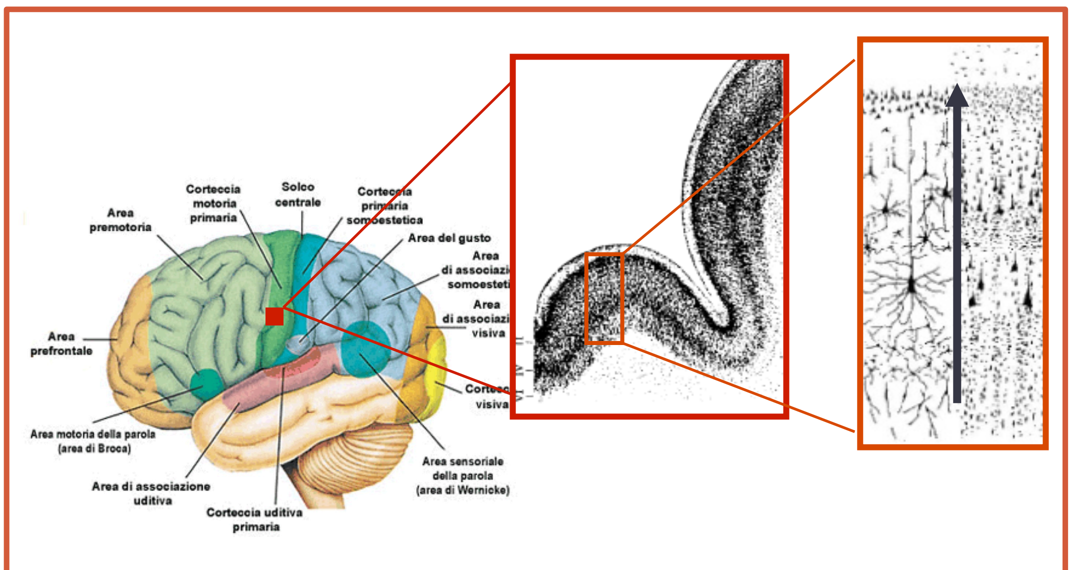


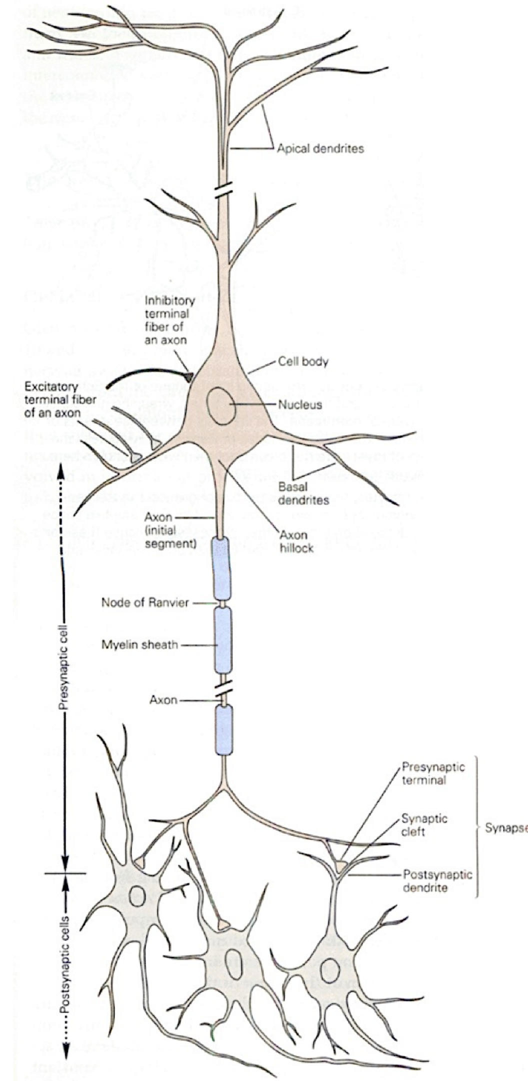


**‘das Elektrenkephalogramm’ (Berger, 1929)**

# Physiological sources of EEG activity

- EEG is the recording of electrical activity along the scalp
- EEG signals derive primarily from cortical current sources
- EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain.

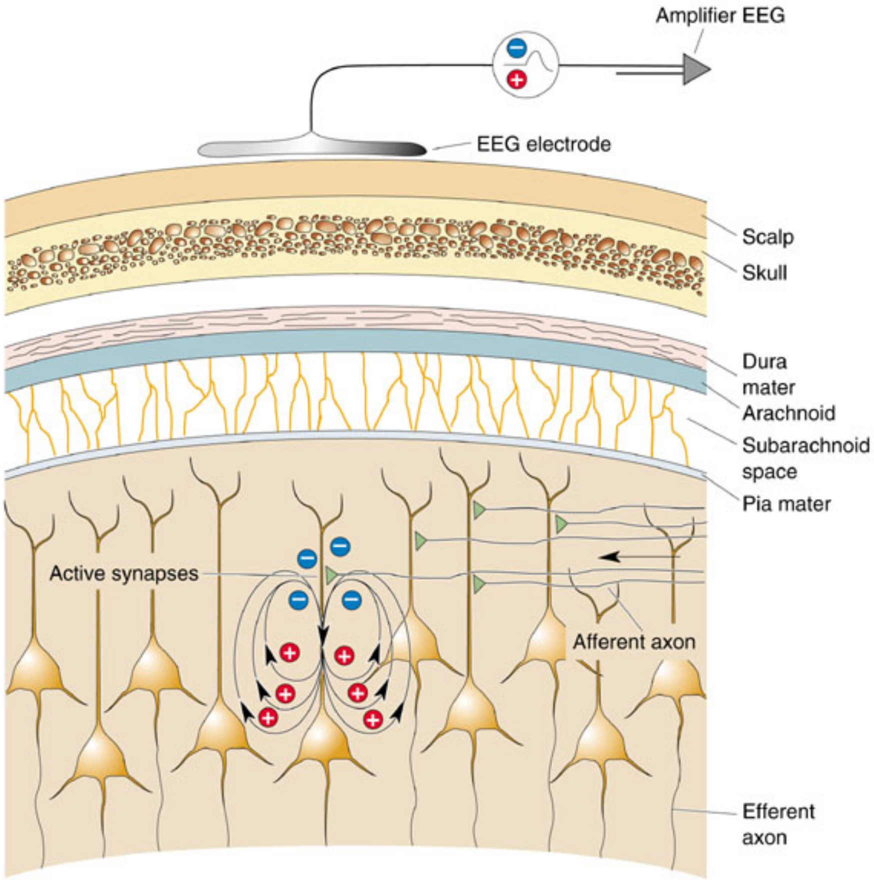


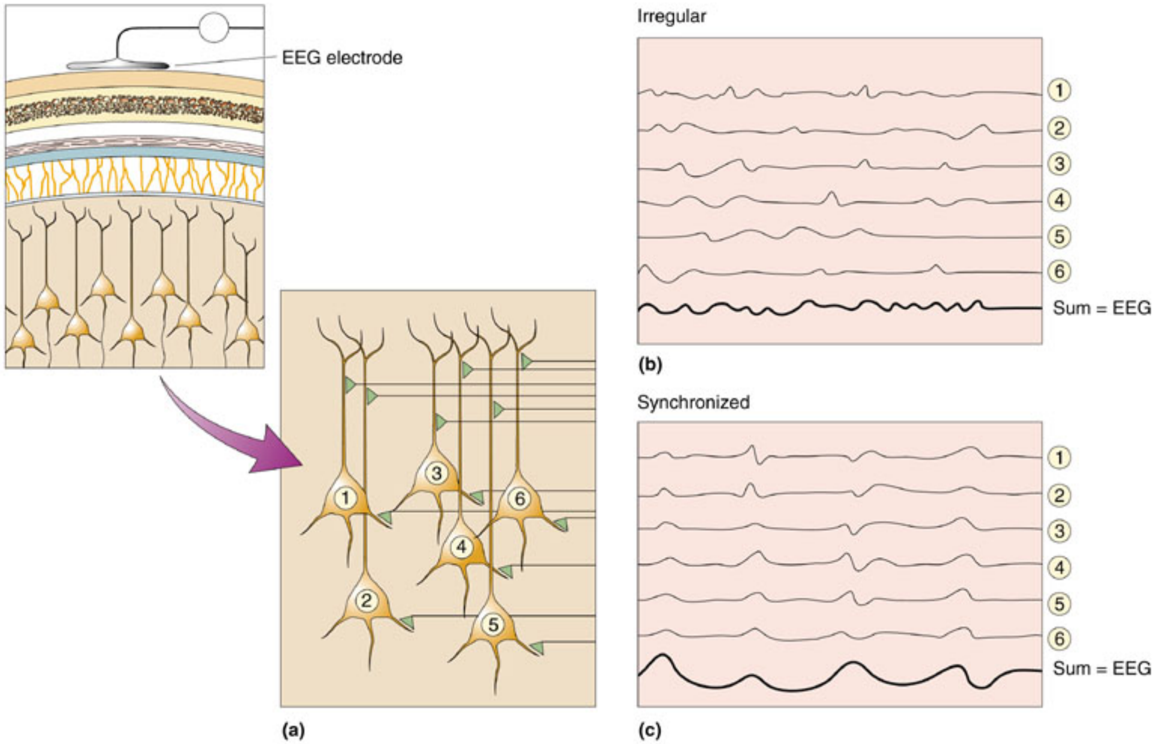
# Origin of EEG signal

Pyramidal neurons of the cortex are spatially aligned and perpendicular to the cortical surface

EEG results from the combined activity of a large numbers of similarly orientated pyramidal neurons

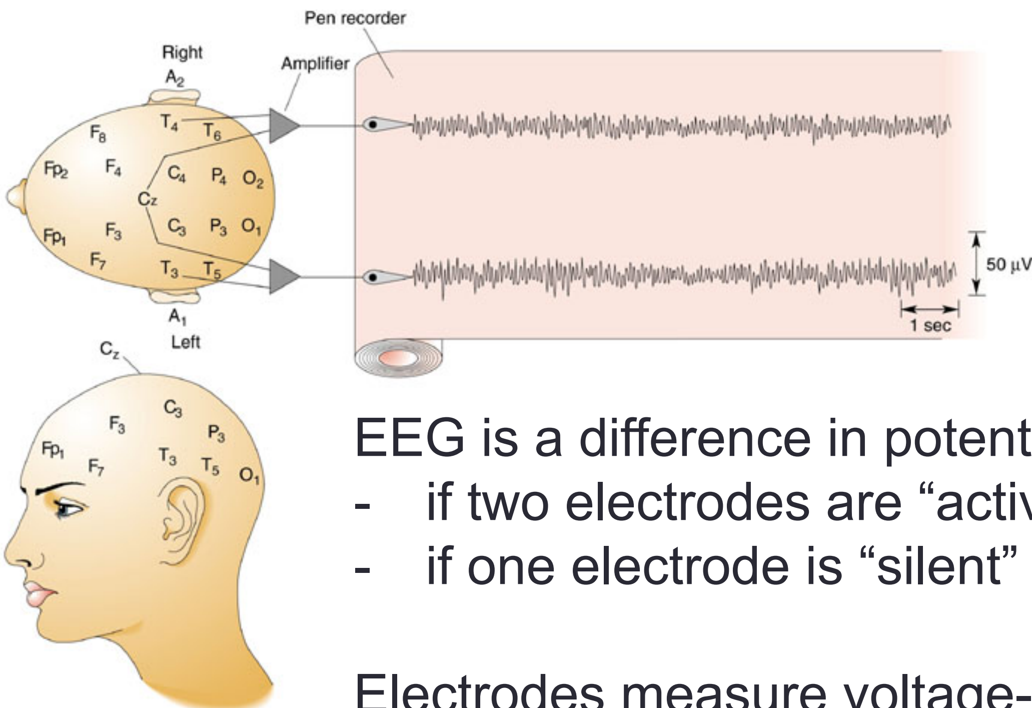


# Origin of EEG signal




- EEG requires synchronous activity across groups of cells
- synchronized neural activity produces larger signals
- EEG reflects summed post-synaptic activity of large cell ensembles
- many neurons need to sum their activity in order to be detected by EEG electrodes.

# Origin of EEG signal




EEG is a difference in potential between two electrodes:

- if two electrodes are “active” → bipolar recording
- if one electrode is “silent” → monopolar recording

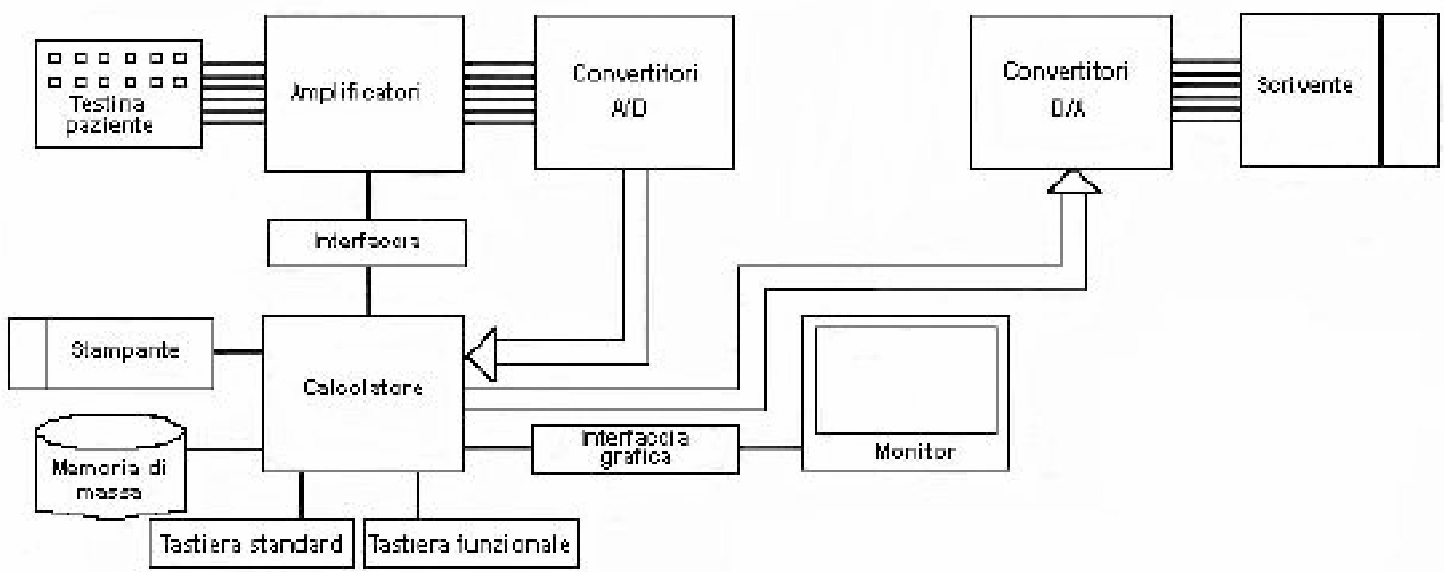
Electrodes measure voltage-differences at the scalp in the microvolt (µV) range.
Voltage-traces are recorded with millisecond resolution – great advantage over brain imaging (fMRI or PET).

# The EEG: general characteristics

- the order of magnitude of recorded events: 10-100μV
- amplification systems
- placing electrodes: international 10-20 system
- a system of switches that allows to select different combinations of derivations between the electrodes (montages)

# Digital EEG sistem

- filtering
- amplification
- sampling and analogic to digital converter
- graphical interface
- visualization of EEG traces



# EEG electrodes

The electrodes used for EEG measures can be of three types:

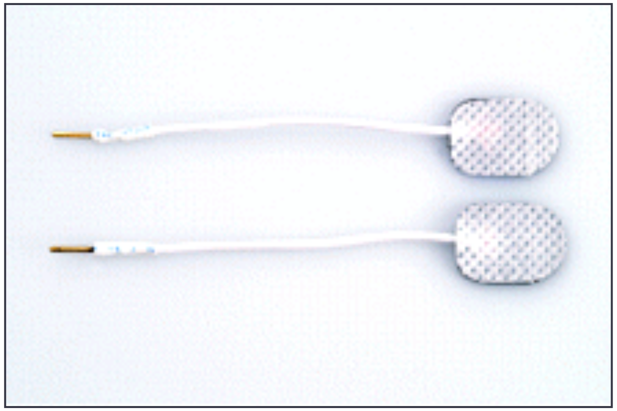
1. **Electrodes attached to the scalp for surface recordings**

***Cup electrodes***

- Ag / AgCl , diameter (0.1-1 cm)
- set directly on the degreased skin with adhesive and conductive material and filled inside with electrically-conductive paste
- economic, reliable, durable but require long preparation times

***Electrodes Stickers***

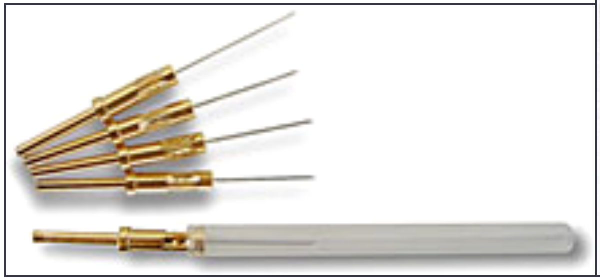
disposable electrode with solid adhesive gel and highly conductive with low impedance

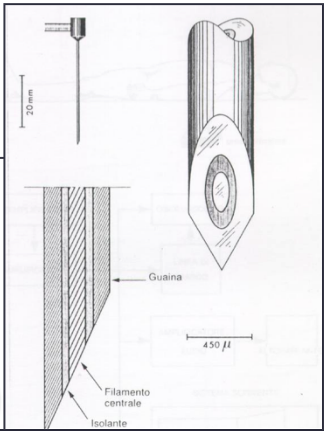


# EEG electrodes

**2. Electrodes in the cap**
- Ag/AgCl, diameter (0.1-1 cm)
- application time reduced, but precarious electrical contacts and low stability

**3. Electrodes with needle electrodes**
- disposable
- steel needles or non-chlorinated platinum, length 1-2 cm, diameter 1 mm
- placed directly under the patient's skin with a angle of 30 degree
- quick to insert, but invasive and can lead to infection



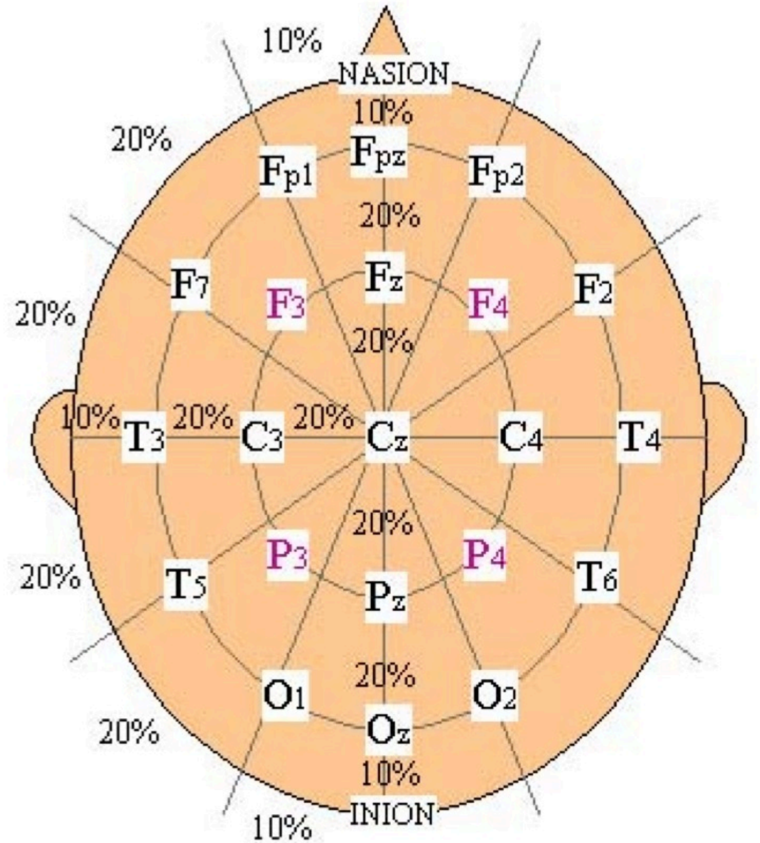


# Standard montage

**International 10-20 system**

The "10" and "20" refer to the fact that the actual distances between adjacent electrodes are either 10% or 20% of the total front–back or right–left distance of the skull.

This method was developed to ensure standardized reproducibility so that a subject's studies could be compared over time and subjects could be compared to each other.




Teplan, Measurement Science Review, 2002

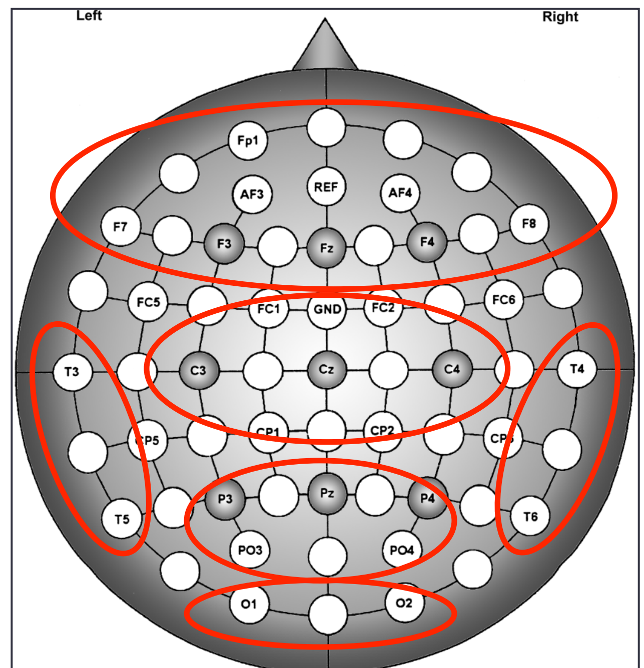
# Standard montage

Location: Frontal, Central, Temporal, Parietal, Occipital electrodes

Label: even numbers – right hemisphere

odd numbers – left hemisphere

z - central electrodes




International System 10/20

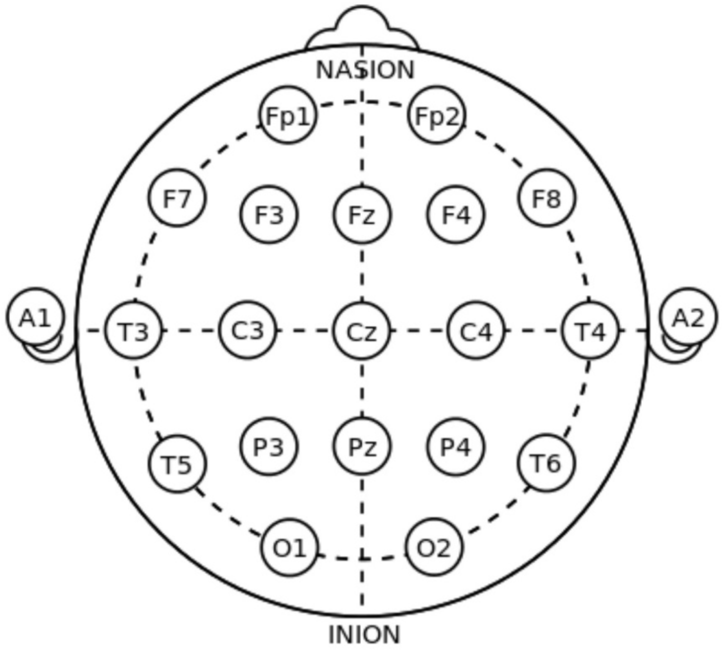
# Standard montage

Symmetry:

- antero-posterior
- between hemispheres

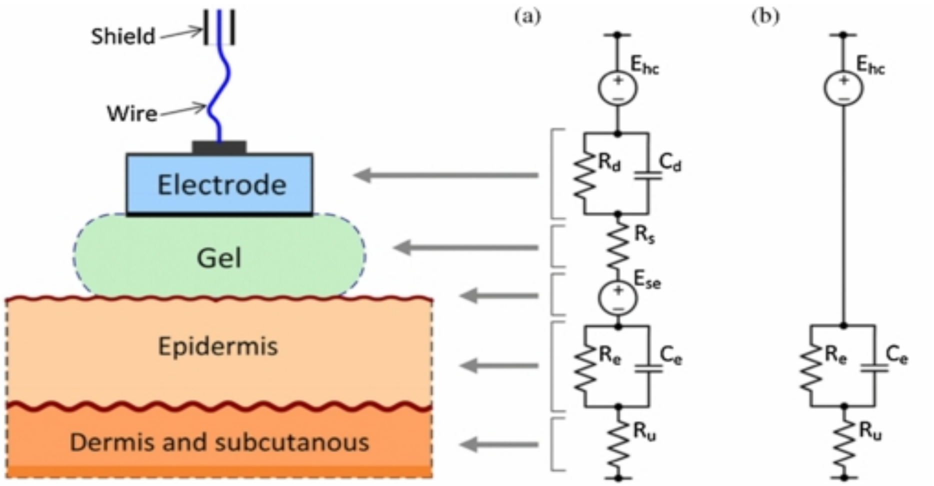
Each site has a letter to identify the lobe and a number to identify the hemisphere location.

- The letters F, T, C, P and O stand for frontal, temporal, central, parietal, and occipital lobes, respectively.
- A “z” refers to an electrode placed on the midline.
- Even numbers (2,4,6,8) refer to electrode positions on the right hemisphere, whereas odd numbers (1,3,5,7) refer to those on the left hemisphere.



# Electrode impedance

The quality of the electrode contact is quantified by its electrical impedance.




Meziane et al 2013 Physiol. Meas. 34

- dry and/or old skin creates a high impedance, which makes it difficult to acquire good readings
- clinicians rub the skin with a mild abrasive to remove the thin layer of dead skin to enable better ion flow between the tissue and the electrolyte on the electrode.
- this ensures better measurements but takes time. Problems also occur when the electrolyte dries over the course of several hours.
- the required procedure is to abrade the skin to achieve a scalp-electrode impedance of less than 5 kΩ

# Reference electrode placement

Physical references can be chosen as:

- bipolar (difference of potential between the two active electrodes)
- monopolar (difference of potential with respect to a reference electrode)

e.g. vertex (Cz), linked-ears, linked-mastoids, ipsilateral-ear, contralateral-ear, C7 reference, tip of the nose

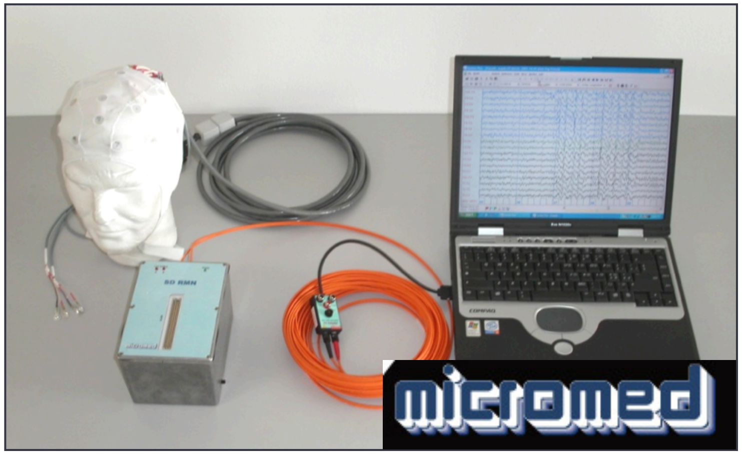
Reference-free techniques are represented by:

- average reference (difference of potential with respect to a mean value)

e.g. common average reference, weighted average reference, and source derivation

# The digital EEG system: examples





# The digital EEG system: examples

**Video-EEG**

coordinated system of video recording during an EEG

**Instrumentation:**

video camera

polygraph

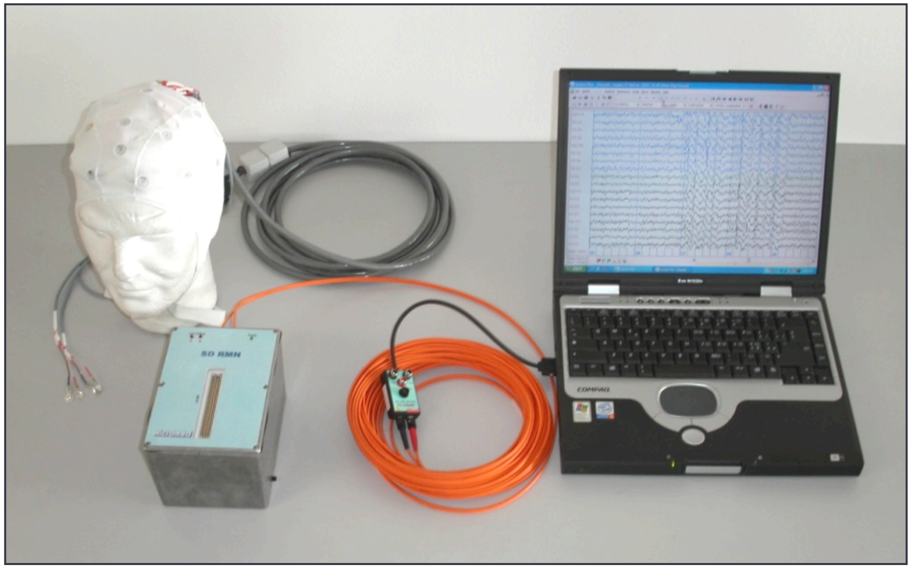
with EEG and EMG channels

**Fields of application:**

- EEG and clinical
- definition of seizures
- myoclonus and motion analysis
- indispensable tool for neurosurgery of epilepsy

# The digital EEG system: examples

**EEG-fMRI coregistration system**



**Technical characteristics of cap and amplifier**

**Cap:**

32 electrodes in Ag/AgCl (diameter: 8 mm, thickness: 0.5 mm

**Amplifier:**

range -12.8 mV and 12.8 mV

quantization of 16 bit

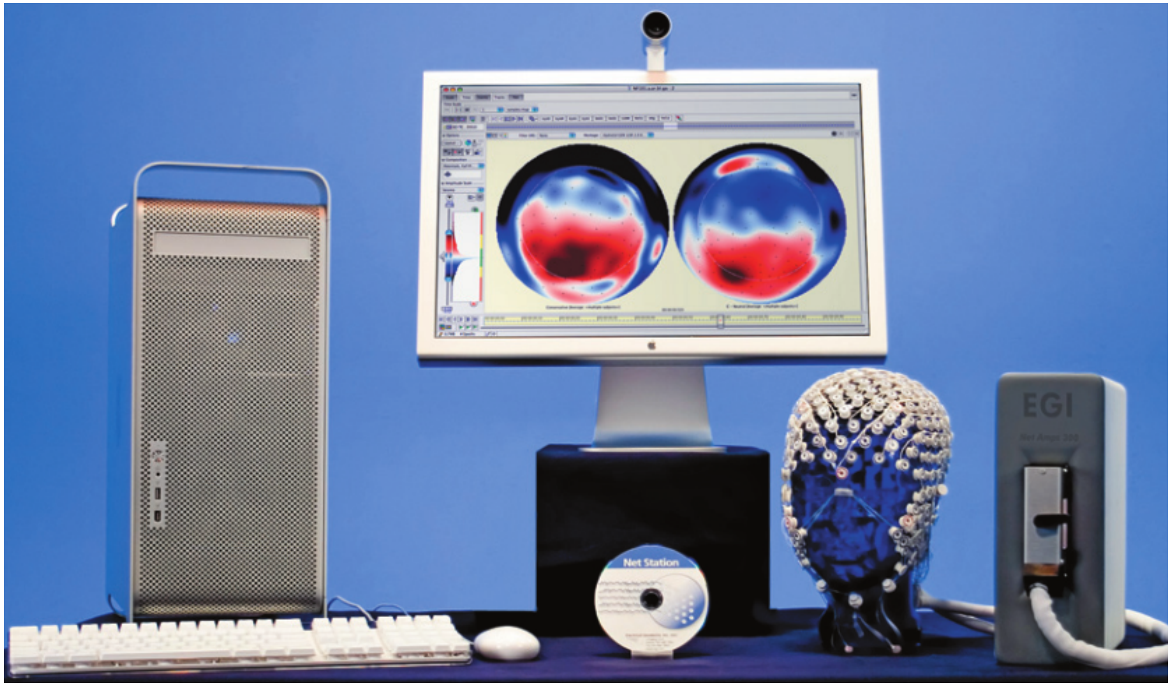
sampling frequency 1024 Hz

**Shielding aluminium amplifier**

# The digital EEG system: examples

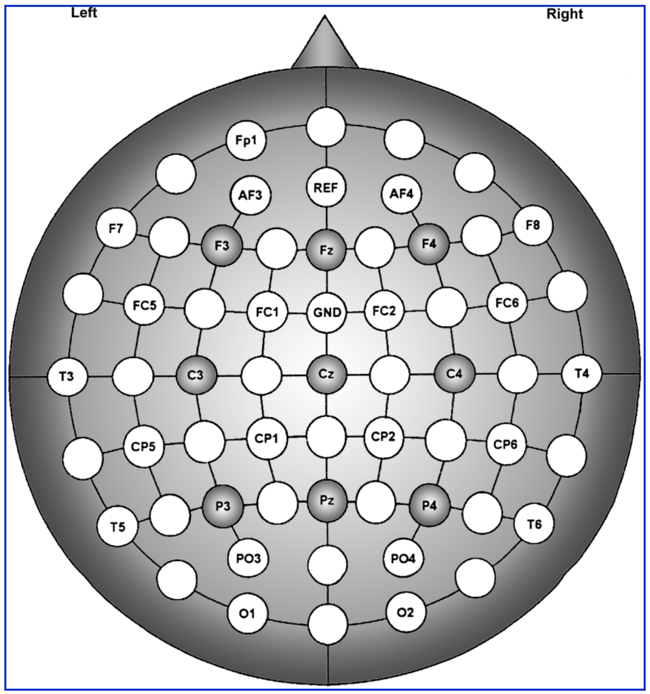
**EEG cap with 256 channels** (Electrical Geodesics Inc. Eugene, OR, USA)

- elastic tension structure and electrolyte solution
- Ag/AgCl electrodes
- application time of 10-15 minutes
- rate of acquisition (until 20 kHz)

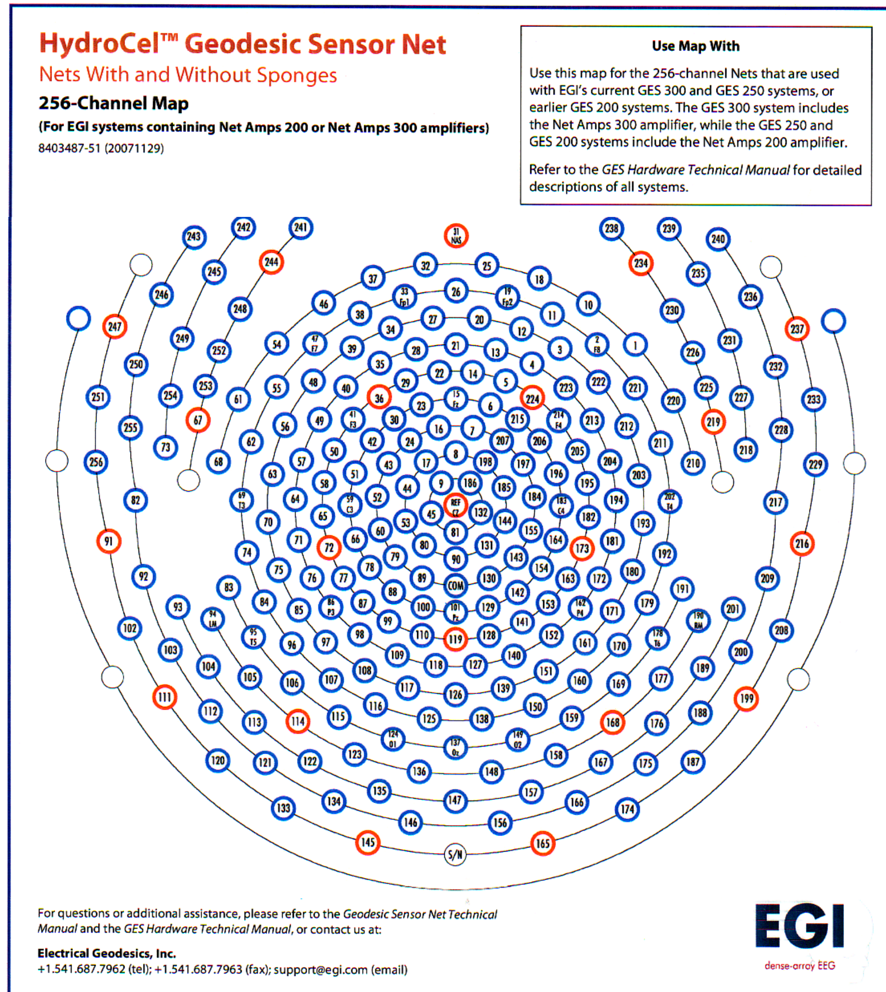



# EEG channel configuration

## Standard EEG



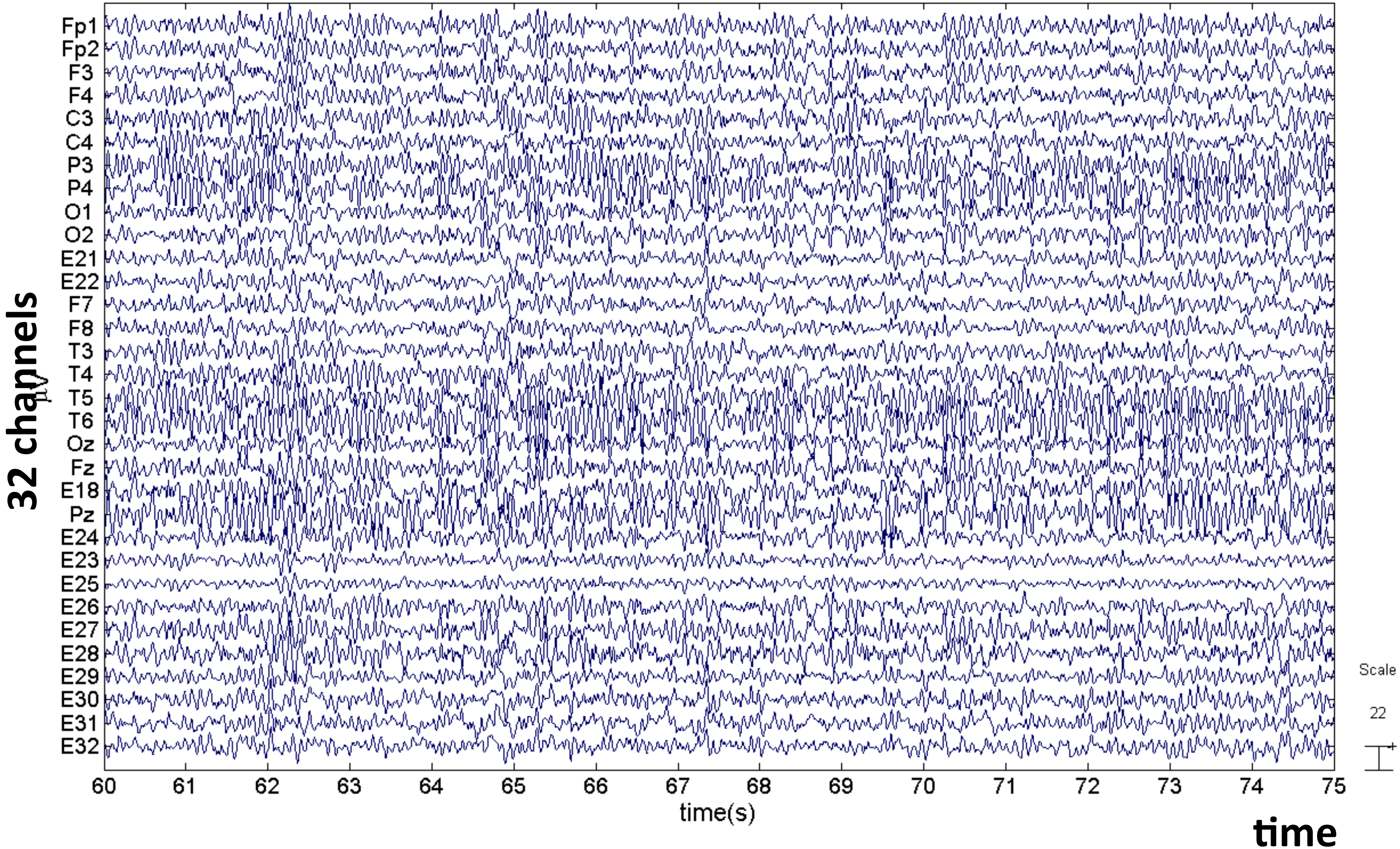

## High-density EEG



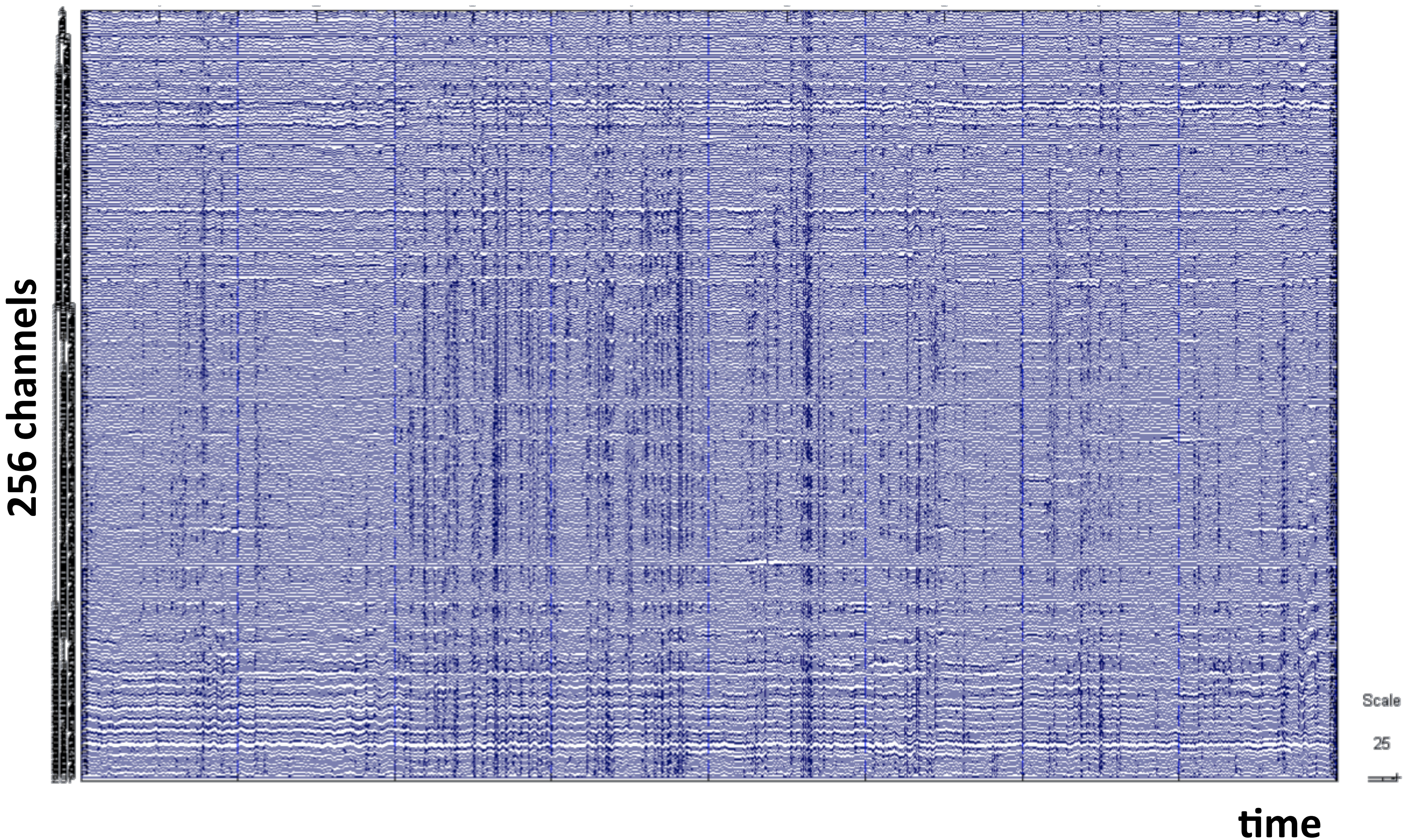

High density EEG technology is developed to enhance the poor spatial information content of the EEG activity.

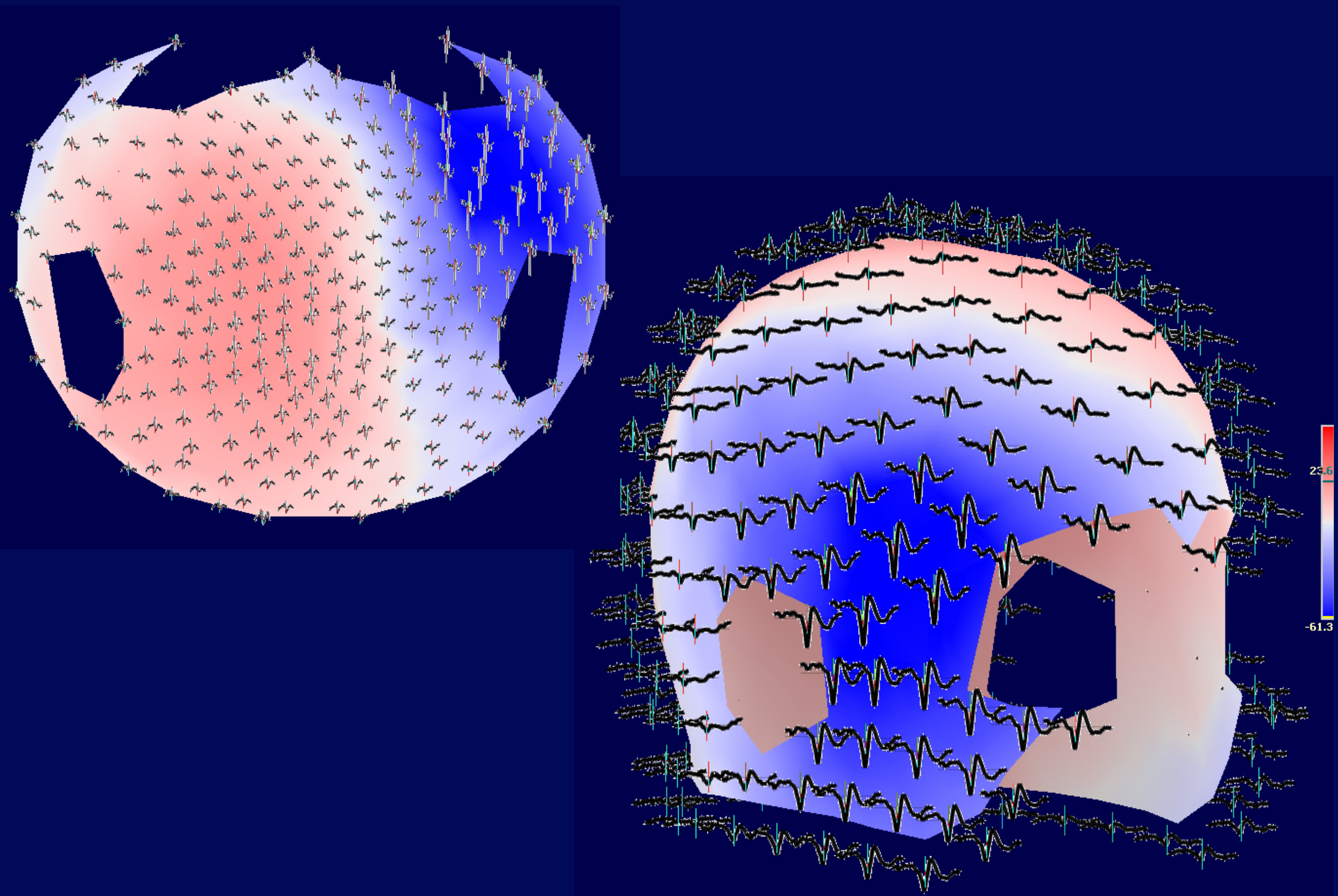
# High-density EEG cap: 256 channels

# Standard EEG - 32 channels



# High-density EEG - 256 channels

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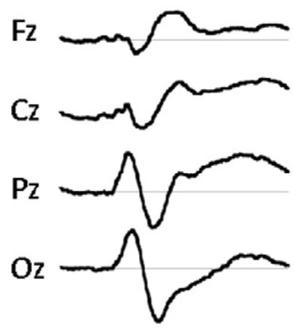
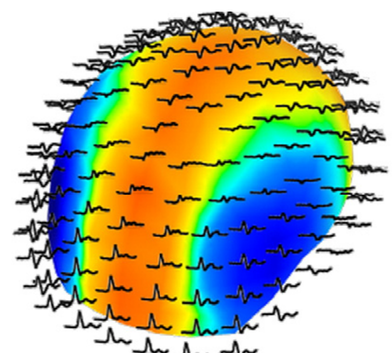
# Progression of EEG data acquisition and analyses

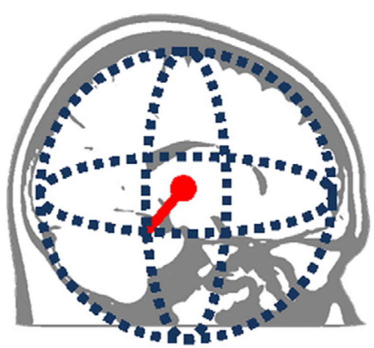
From low-density to high-density montages

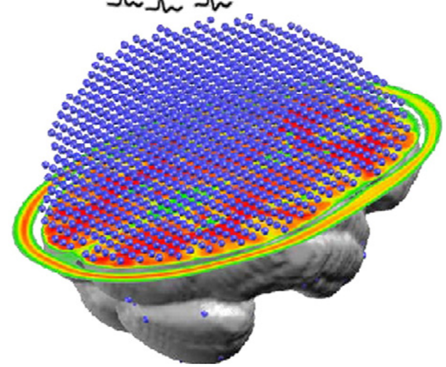
From voltage waveforms to topographic representation



From equivalent current dipole to distributed source models

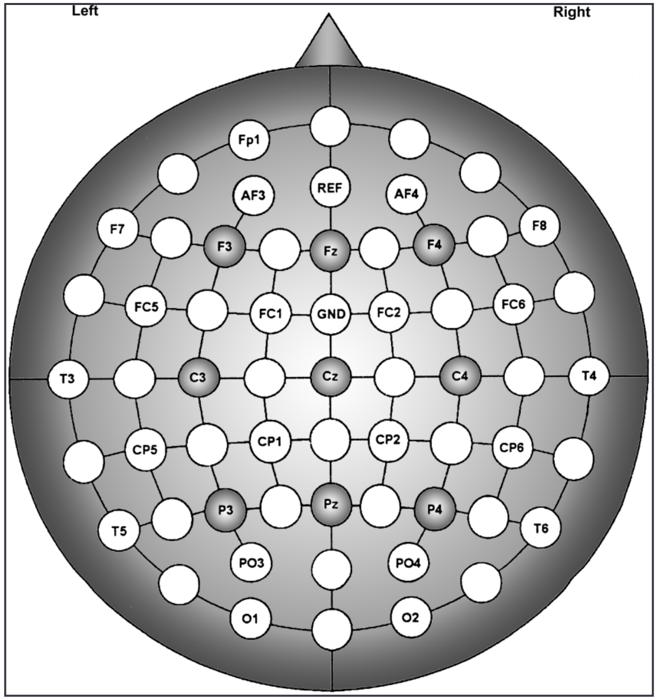




**Michel and Murray, Neuroimage, 2011**

# The EEG signal changes

It is an expression of potential changes of the brain cortex and varies from point to point in the cortical surface.



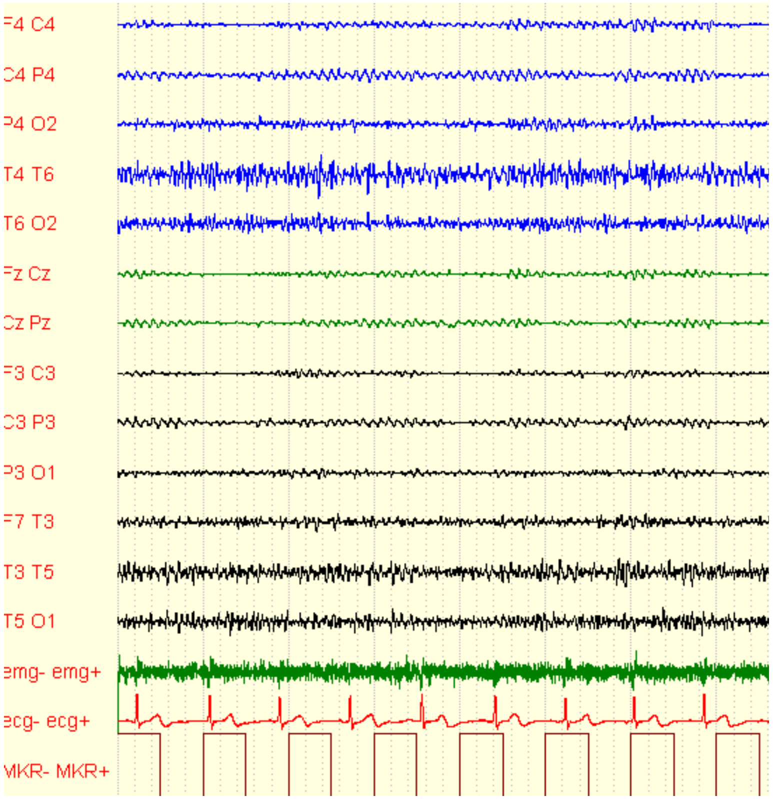

Variations due to:

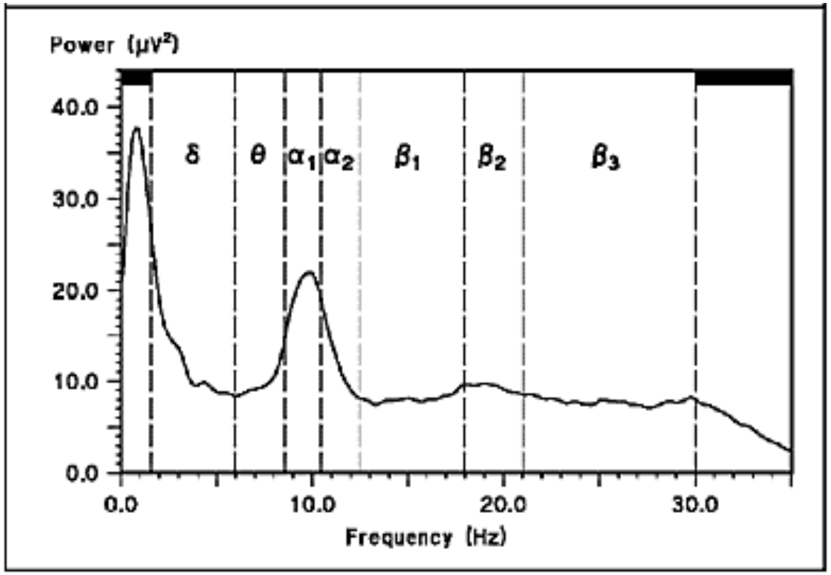
- open-closed eyes
- seated or lying
- non-thinking or mental calculation
- rest or motion

Inter-individual and intra-individual variability

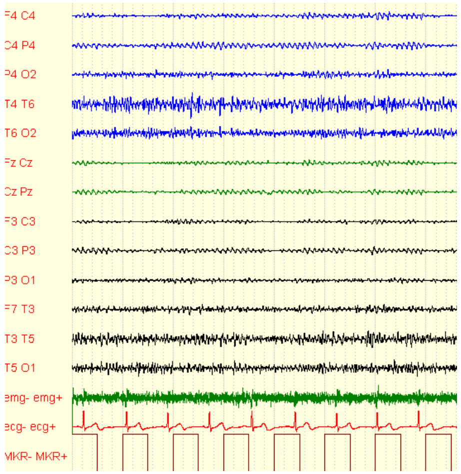
- peak variable 8-13 Hz
- age

# The brain rhythms



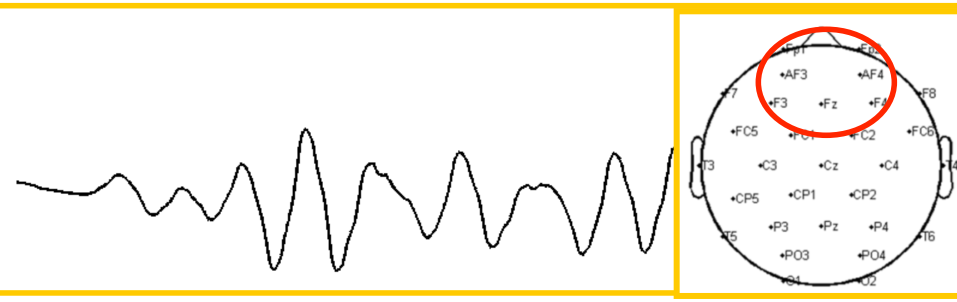




| Rhythms | Frequency (Hz) | Amplitude (μV) |
|---|---|---|
| Delta | 0.5-4 | 20-200 |
| Theta | 4-8 | 5-100 |
| Alpha | 8-13 | 10-200 |
| Beta | 13-30 | 1-20 |



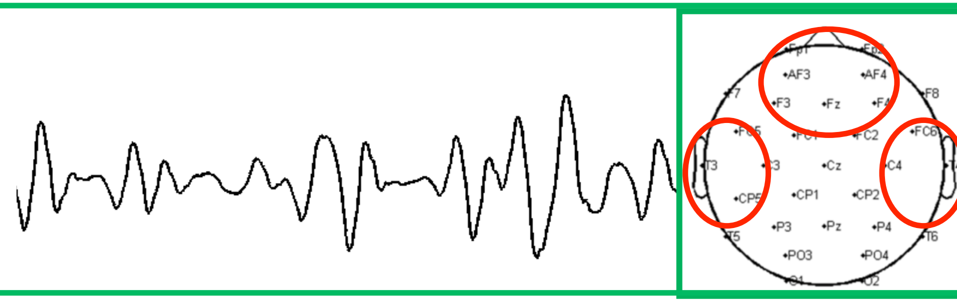
**Delta**

Deep sleep, Pathological conditions



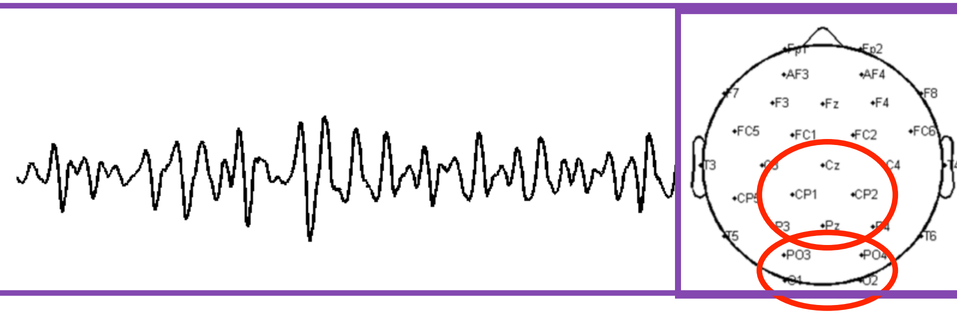
**Theta**

Sleepiness



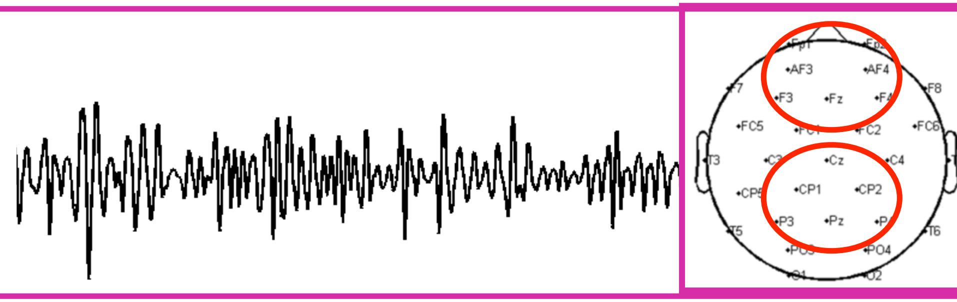
**Alpha**

Occipitally and parietally, Awake



**Beta**

Parietally and frontally, Mental activity



| Rhythms | Frequency (Hz) | Amplitude ($\mu$V) |
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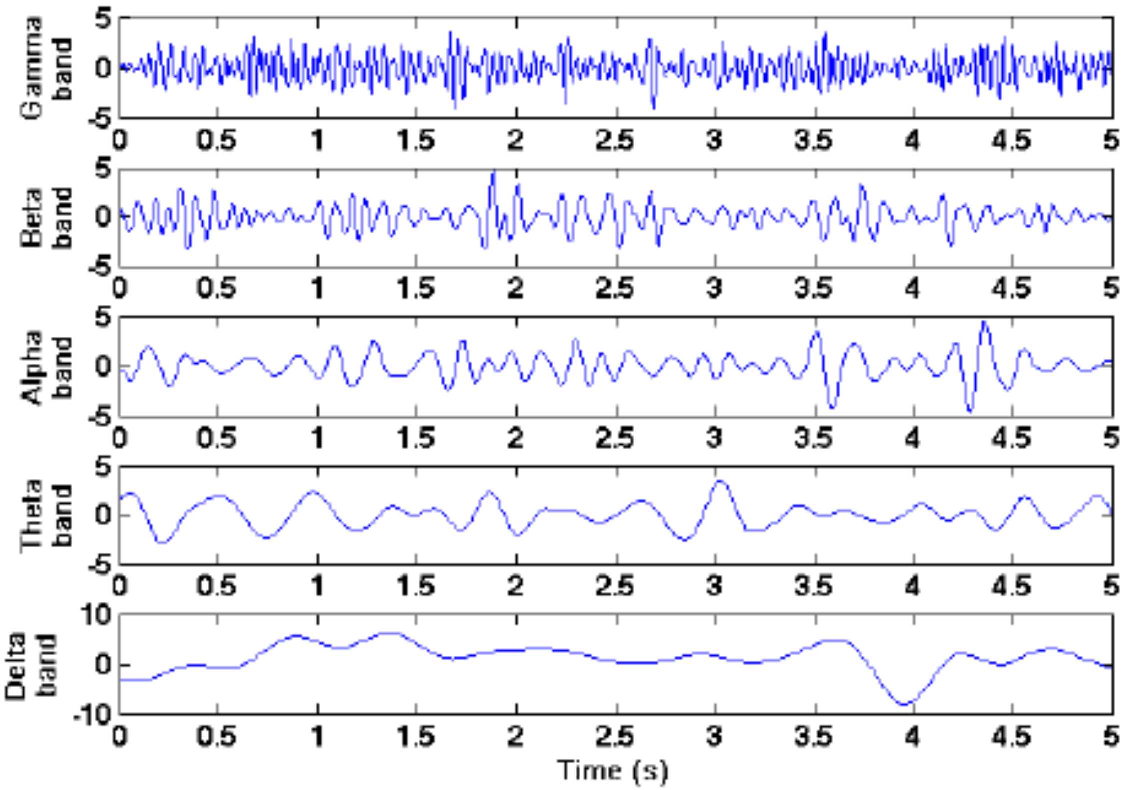
# The brain rhythms




*Abo-Zahhad et al., I.J. Intelligent Systems and Applications, 2015, 06, 48-54*

- Gamma > 30Hz (cross-modal sensory processing/memory)
- Beta 13–30 Hz (active thinking, focus, anxious)
- Alpha 8-12 Hz (relaxed or reflecting)
- Theta 4-7 Hz (idling or drowsiness)
- Delta < 4Hz (slow wave sleep)

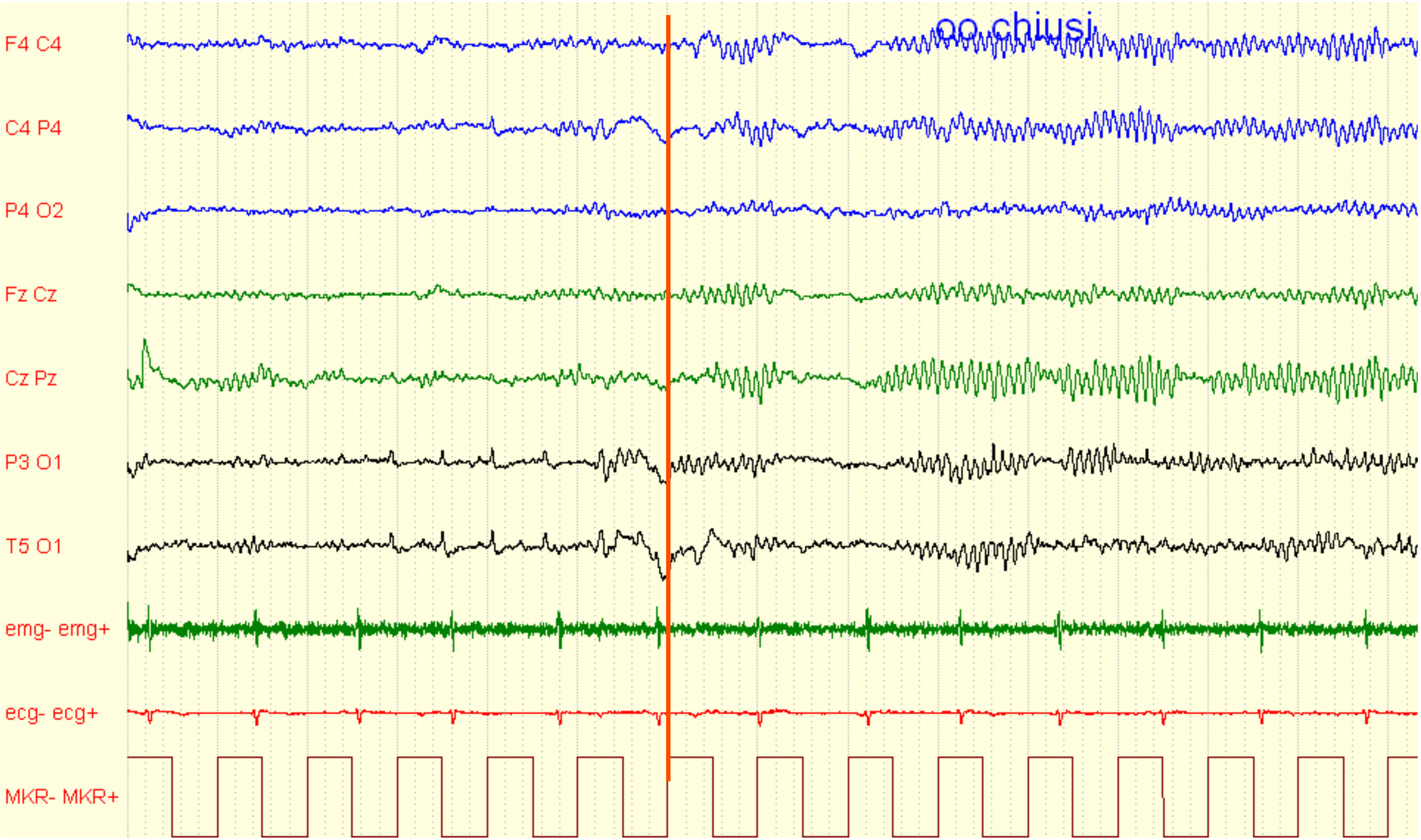
# Normal EEG

- EEG of a adult healthy person, in sensory resting and relaxed, with eyes closed presents an activity in **alpha** band localized bilaterally in the parietal-temporal-occipital regions, symmetrical, synchronous and stable

- we can observe the "responsiveness" of the alpha rhythm which is synchronously interrupted by the eyes opening and replaced bilaterally by fast rhythms

- **beta** rhythms are recorded on the frontal and central regions (rolandic), the **theta** rhythms can be observed on the temporal regions

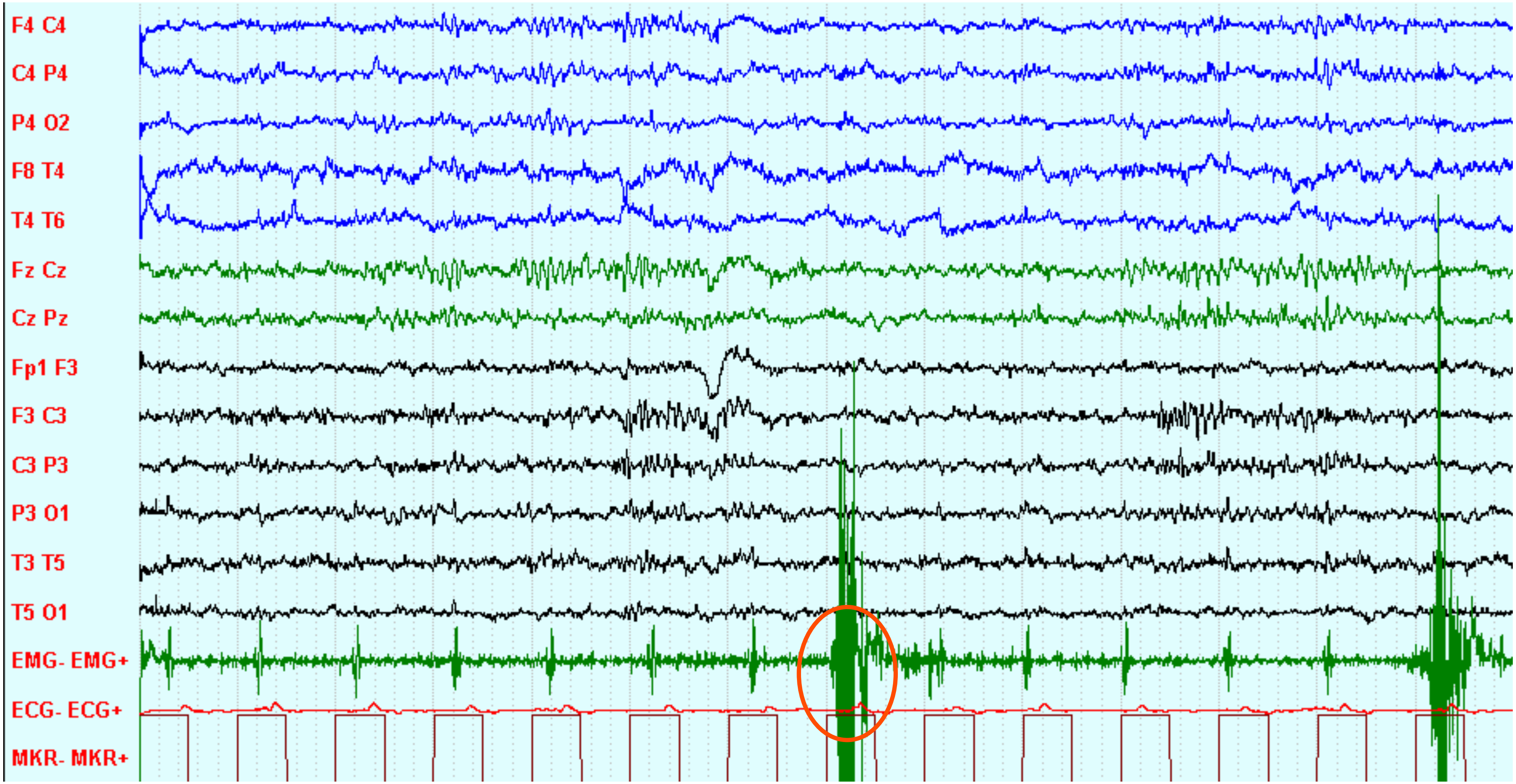
# Alpha rhythm




eyes open

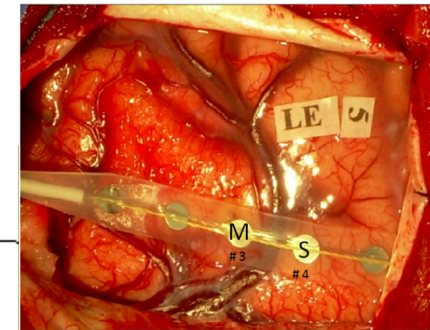
eyes closed

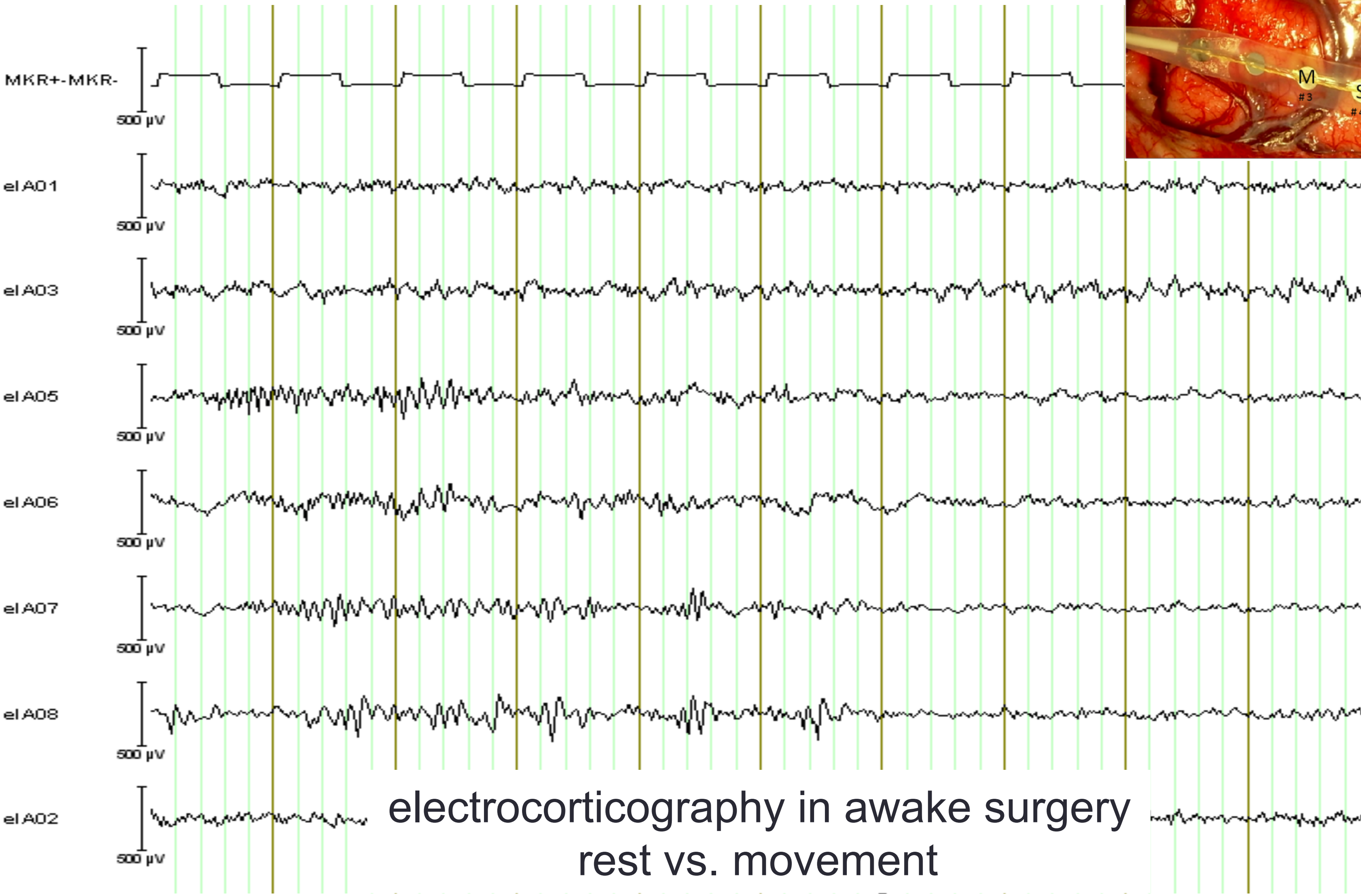
# Alpha rhythm




rest vs movement

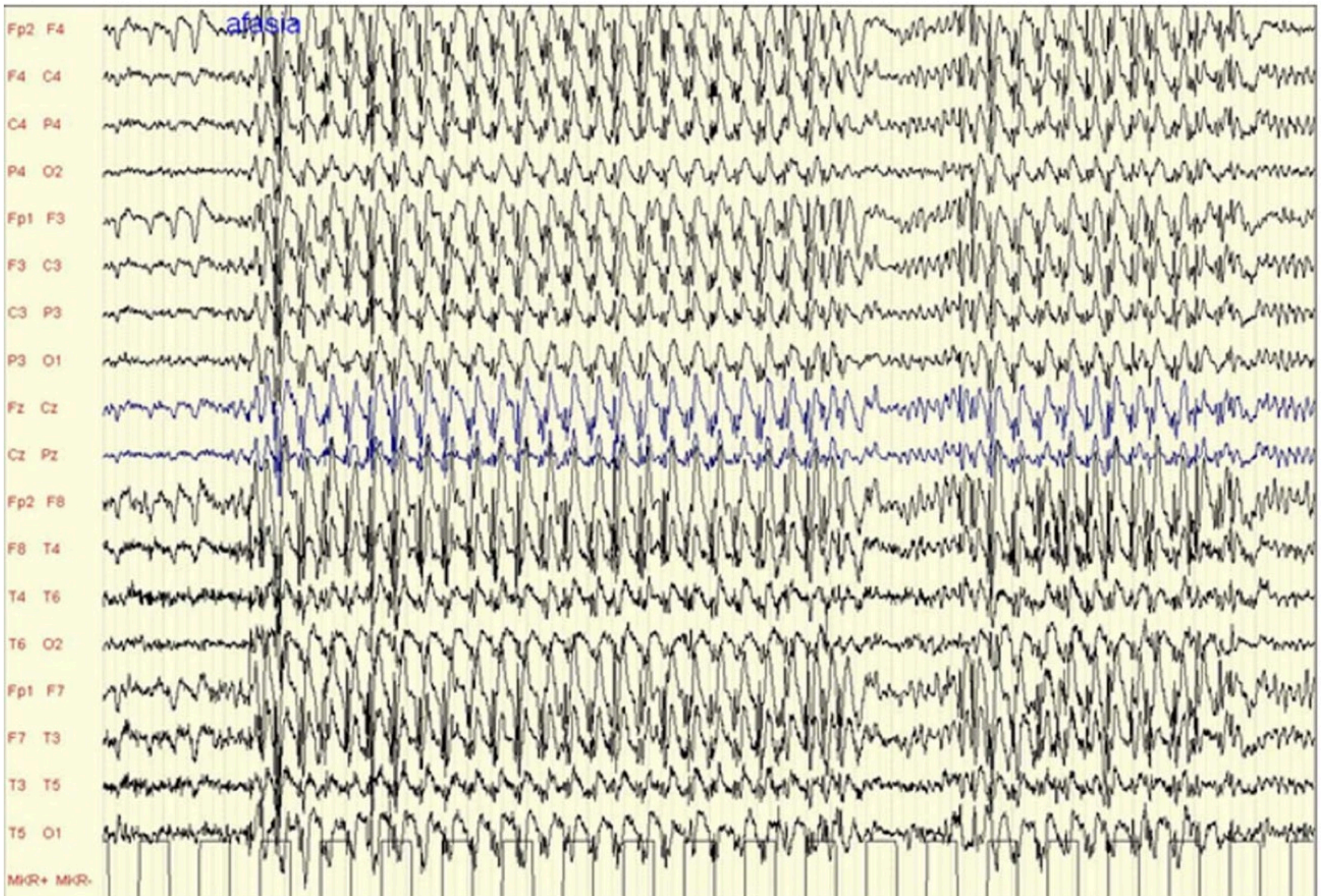
# Alpha rhythm



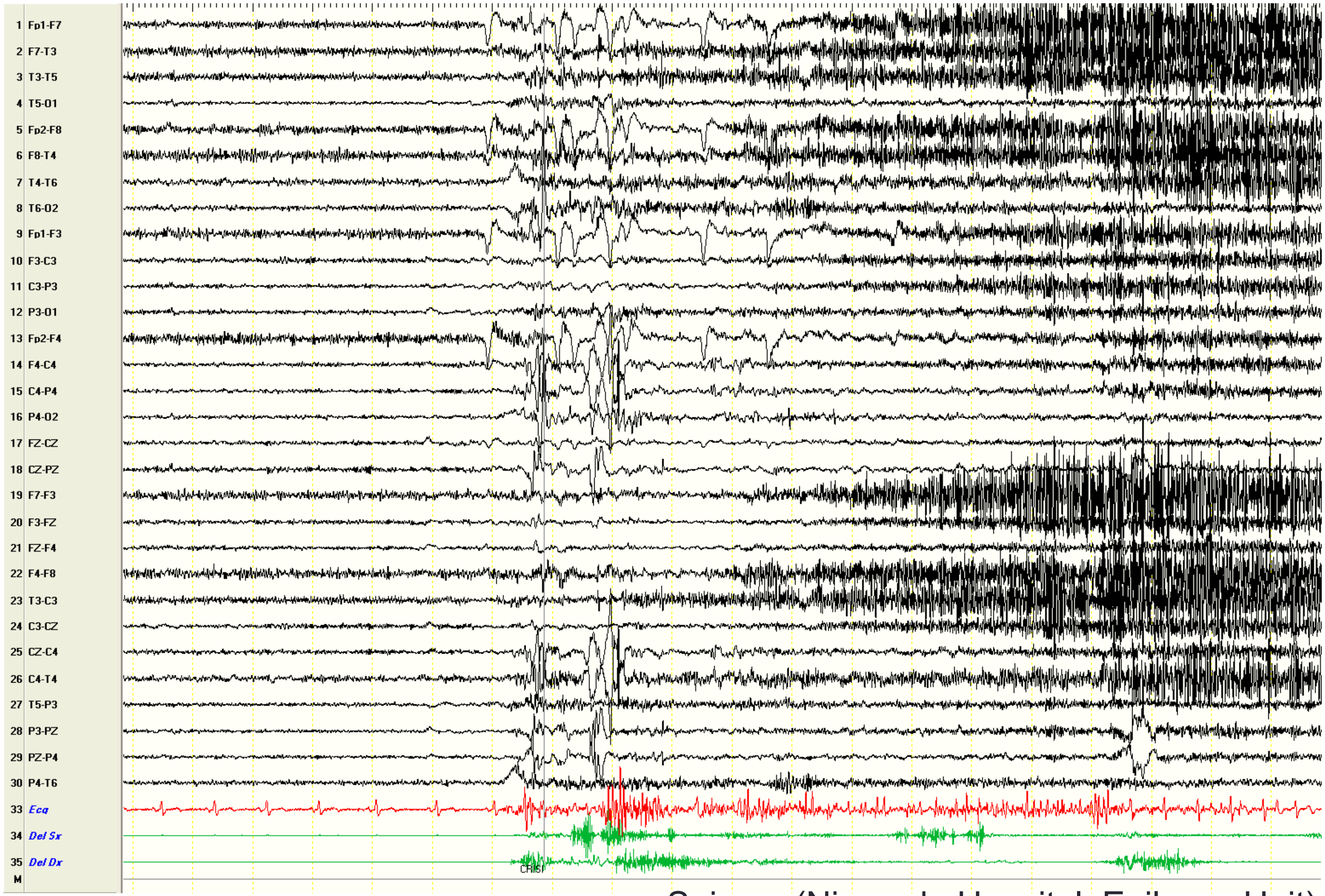

electrocorticography in awake surgery
rest vs. movement

# Pathological EEG



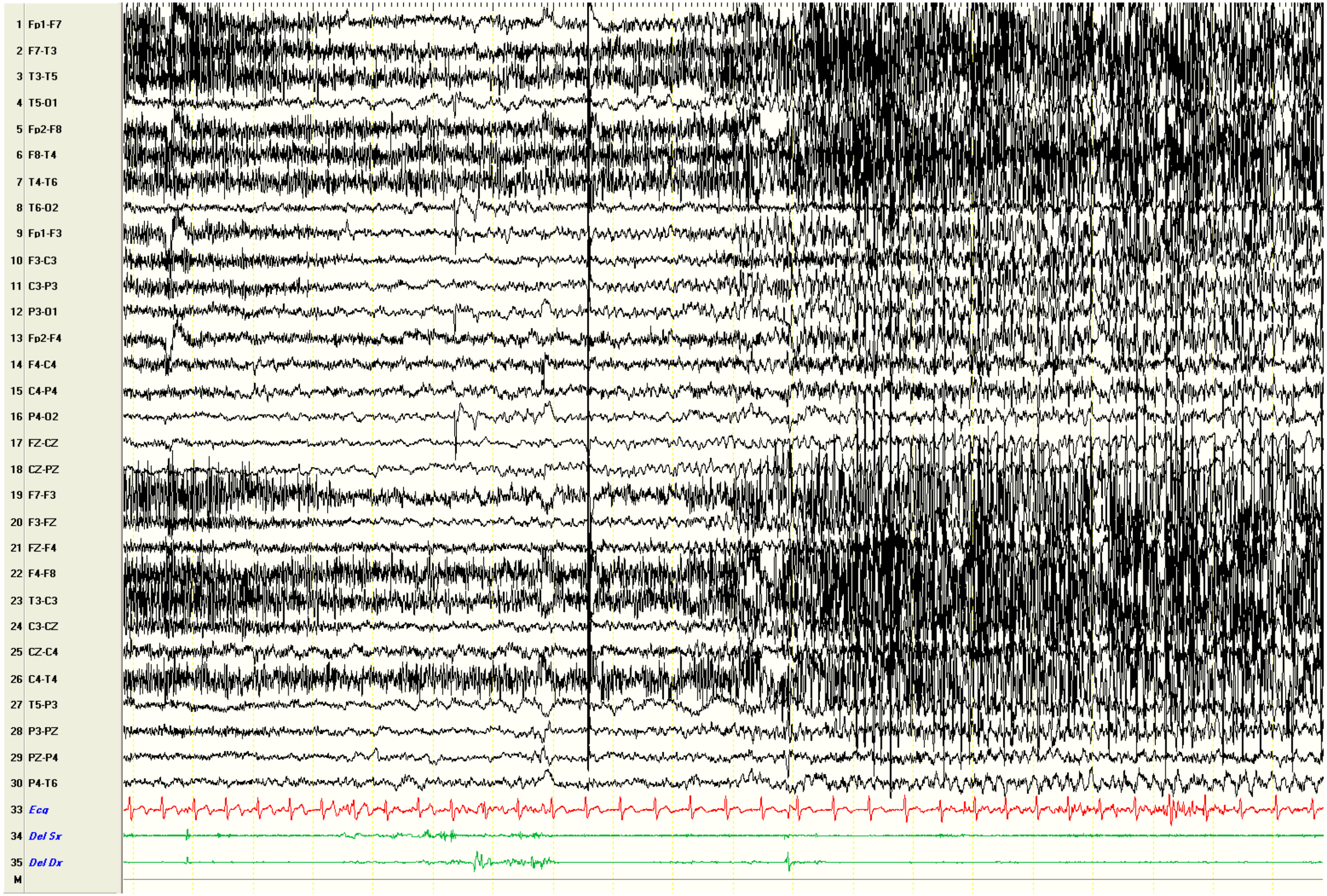

Epilepsy: ictal EEG – speech arrest

# Pathological EEG

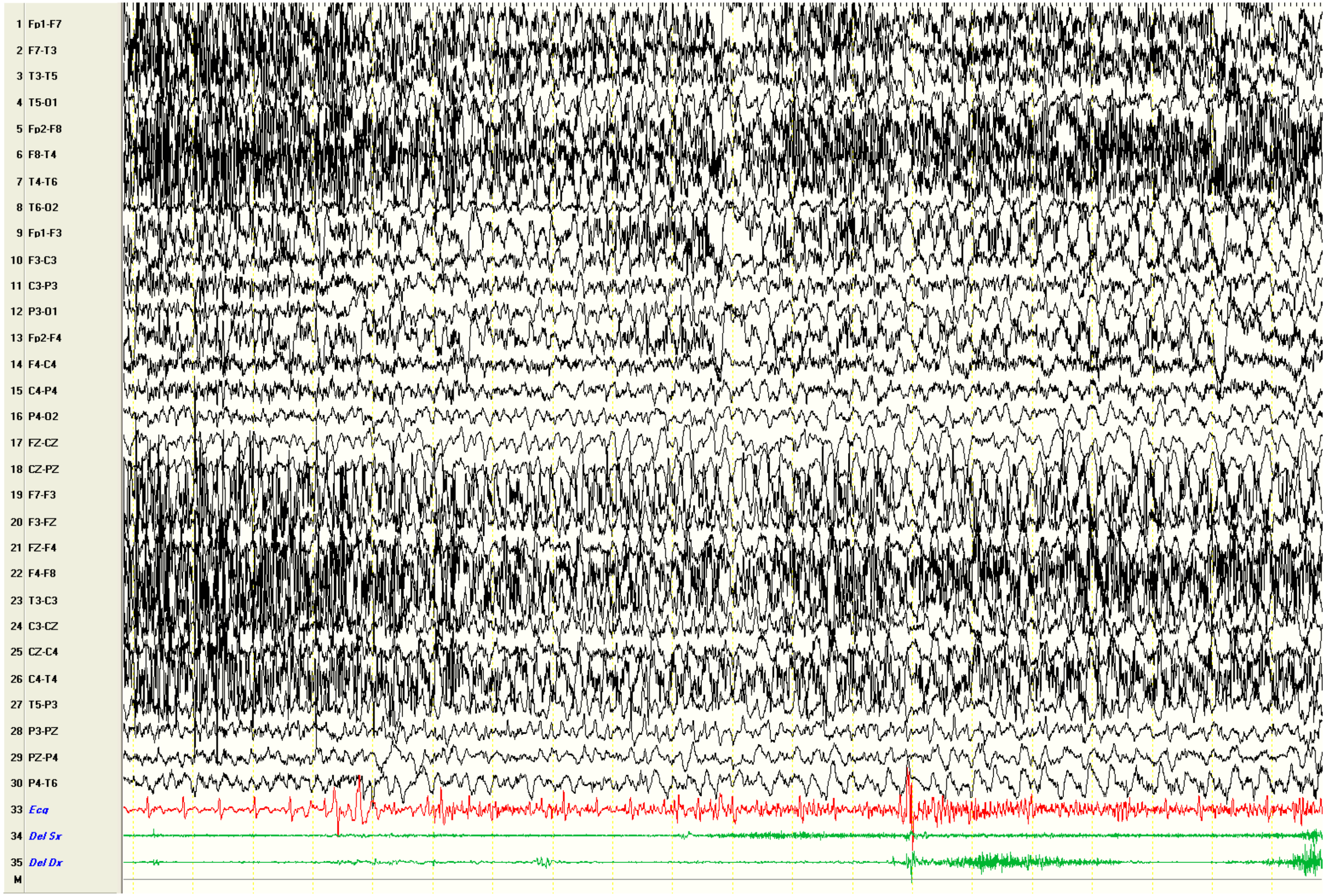



Seizure (Niguarda Hospital, Epilepsy Unit)

# Pathological EEG

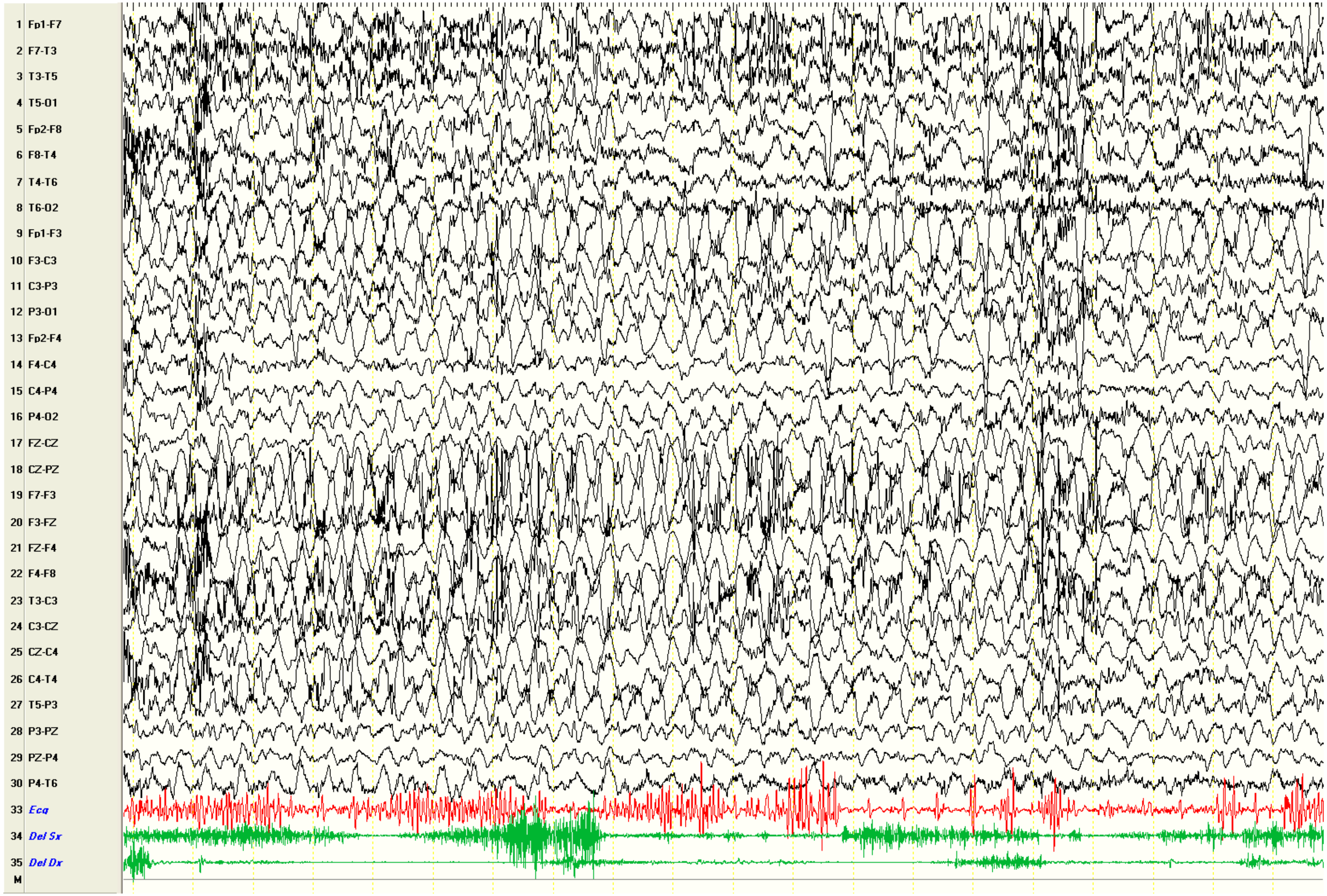


# Pathological EEG



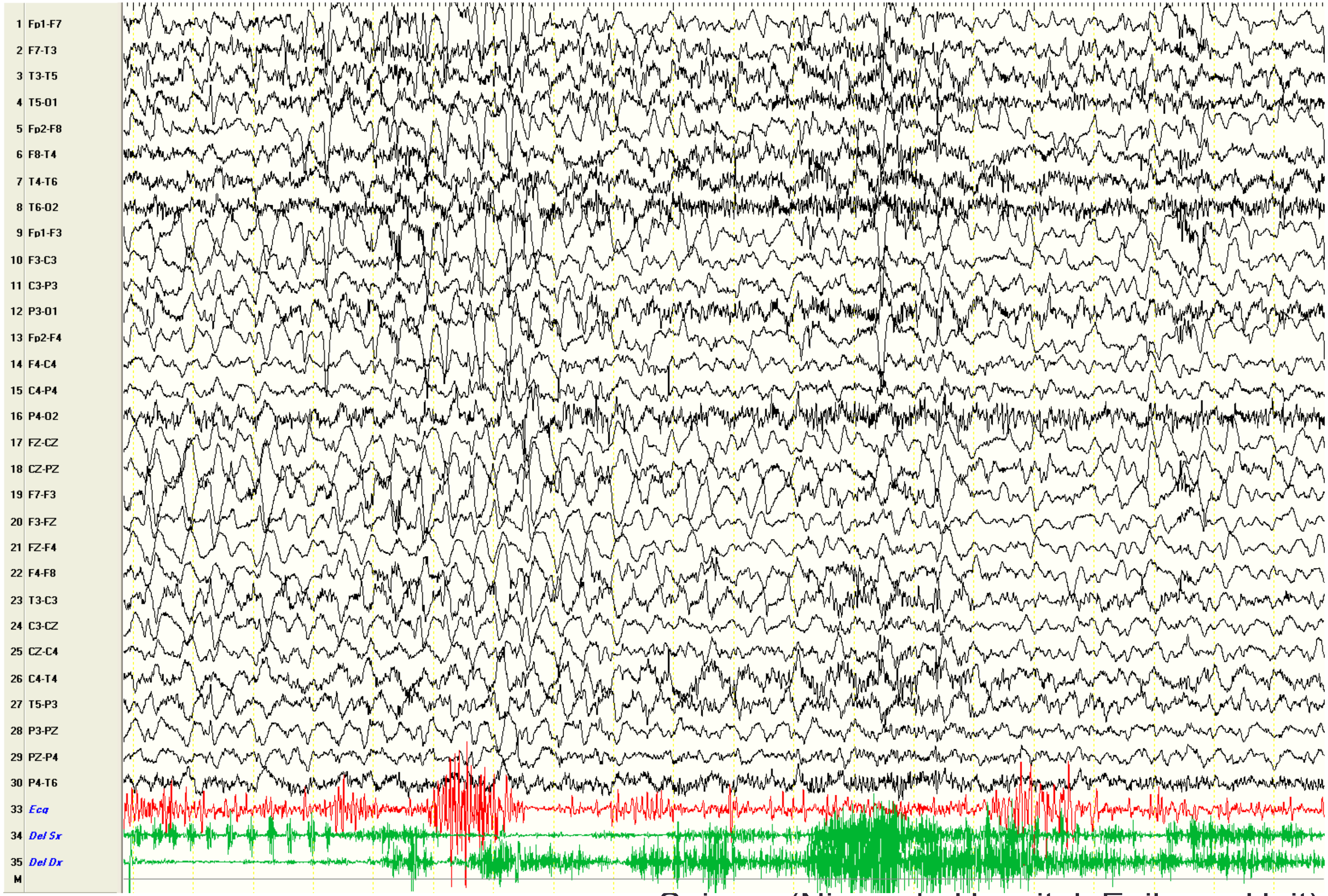

Seizure (Niguarda Hospital, Epilepsy Unit)

# Pathological EEG




Seizure (Niguarda Hospital, Epilepsy Unit)

# Pathological EEG




Seizure (Niguarda Hospital, Epilepsy Unit)

# Artifacts

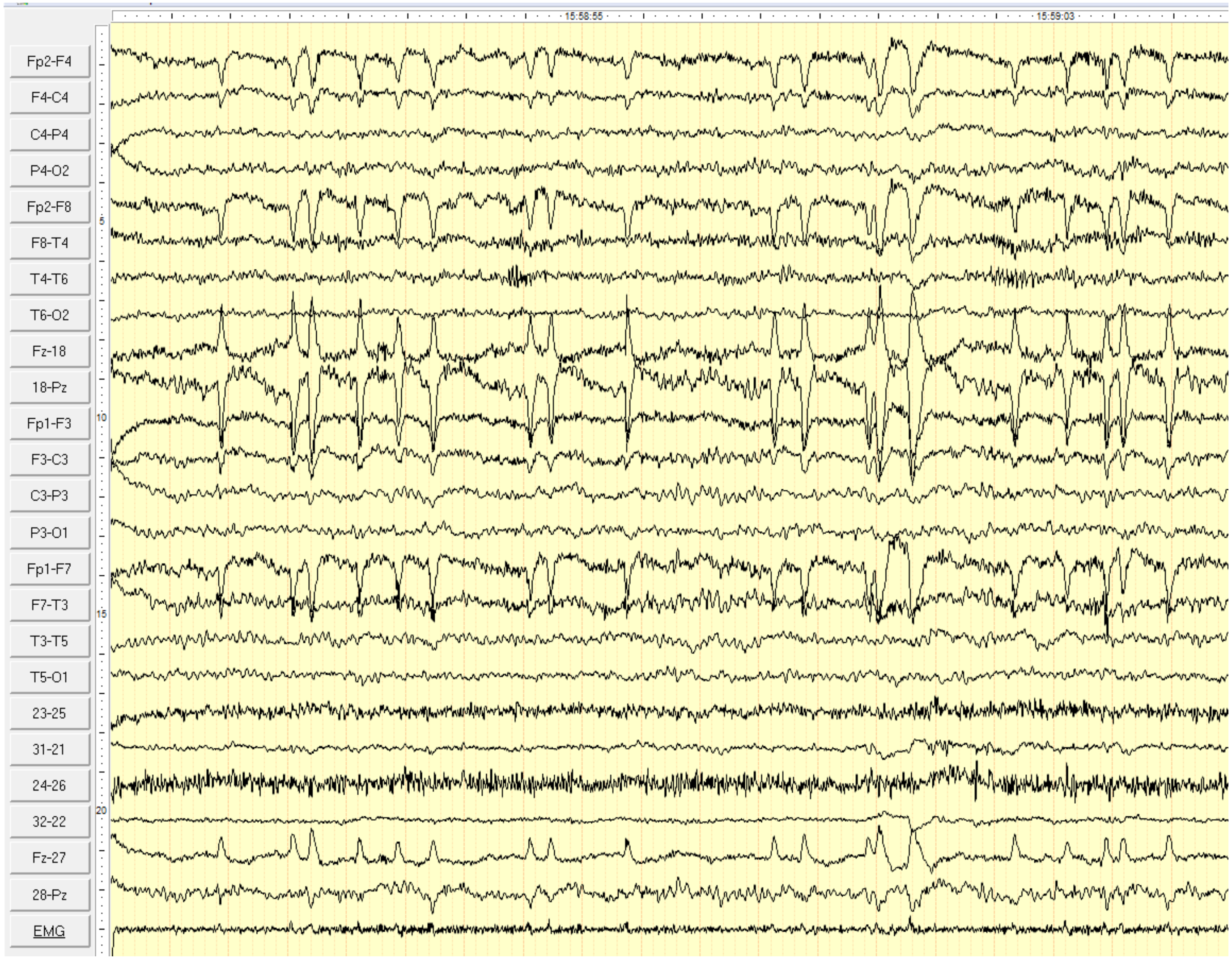
*Physiologic artifacts* are generated from the subject, they arise from sources other than the brain:

- eyes movement
- ECG activity
- legs, arms, head movement
- sweat
- muscle activity

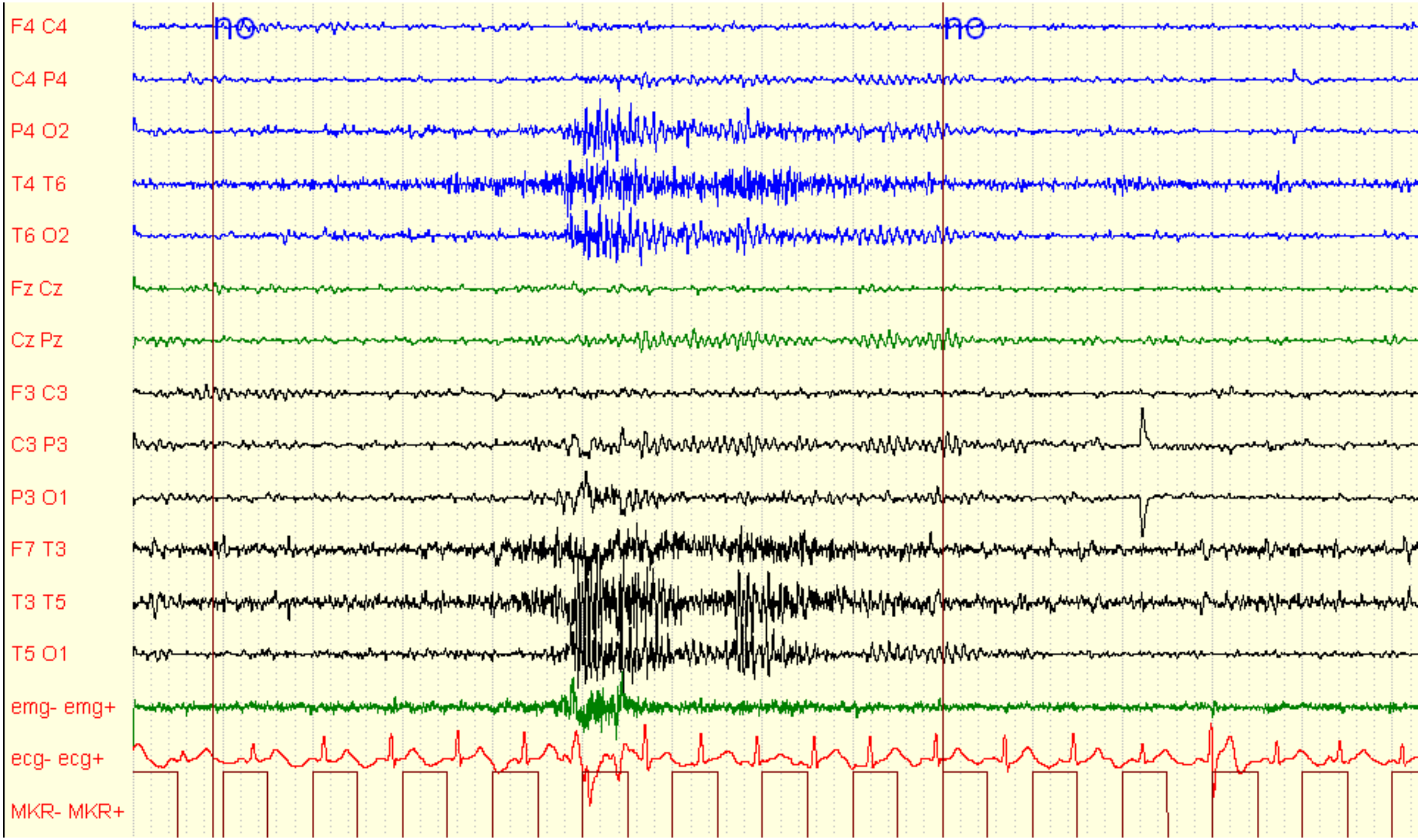
*Extraphysiologic artifacts* arise from outside the body:

- bad contact between skin and electrode
- bad contact between electrode and cable
- electromagnetic interferences
- environment artifacts (50 or 60 Hz)
- artifact due to external manoeuvres
- instrumental artifacts

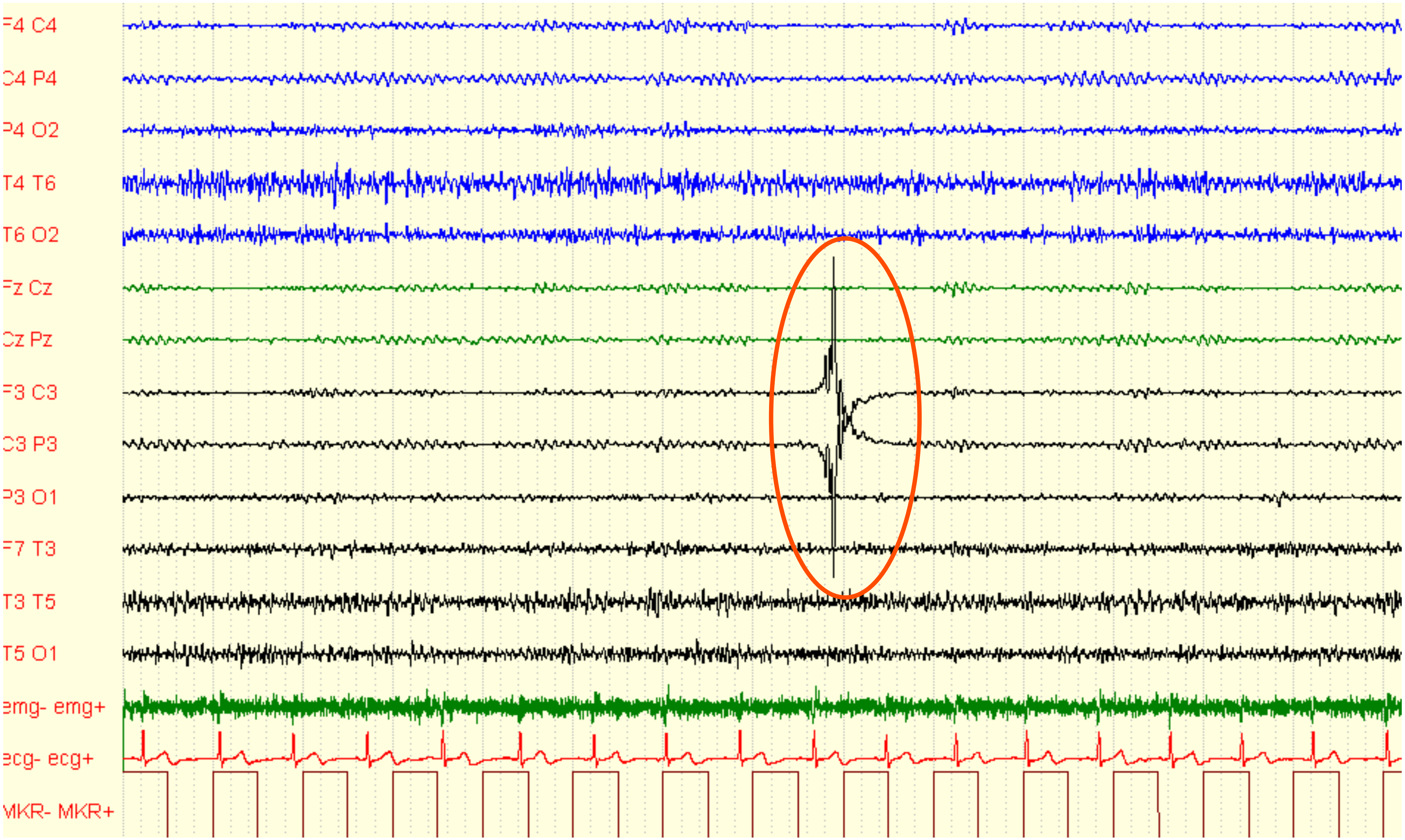
# Eyes blink


15:58:55
15:59:03
Fp2-F4
F4-C4
C4-P4
P4-O2
Fp2-F8
F8-T4
T4-T6
T6-O2
Fz-18
18-Pz
Fp1-F3
F3-C3
C3-P3
P3-O1
Fp1-F7
F7-T3
T3-T5
T5-O1
23-25
31-21
24-26
32-22
Fz-27
28-Pz
EMG

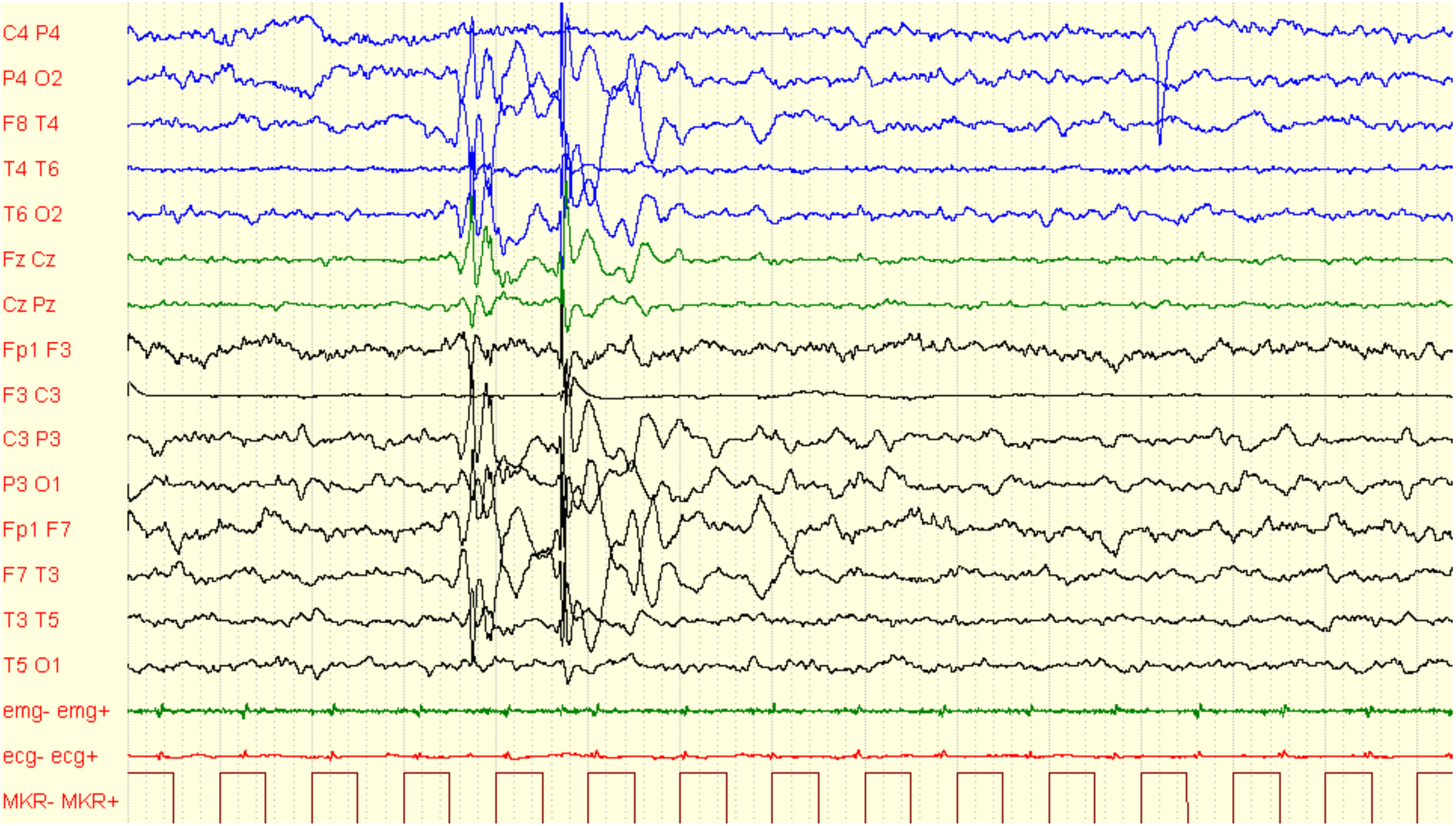
# Movement artifact



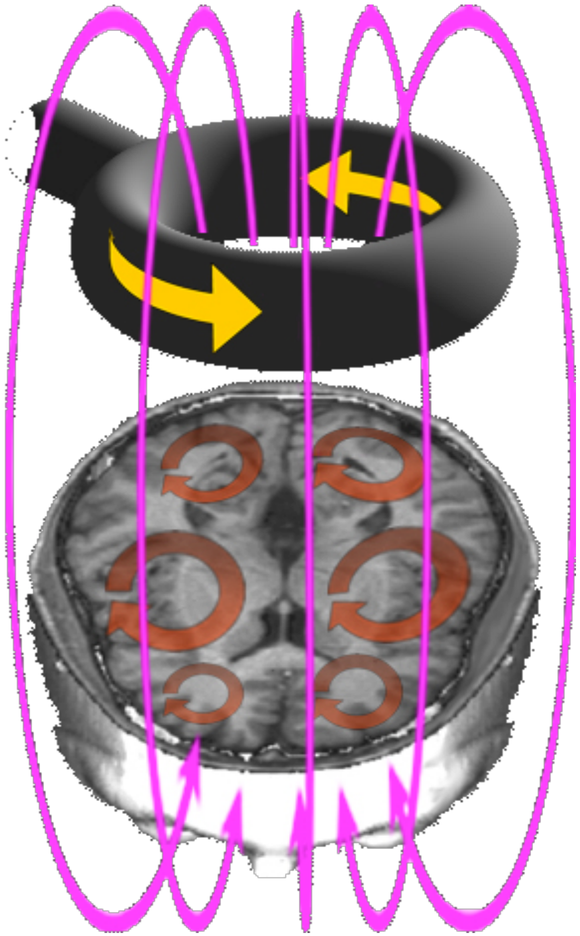
# Artifacts: bad contact between skin and electrode

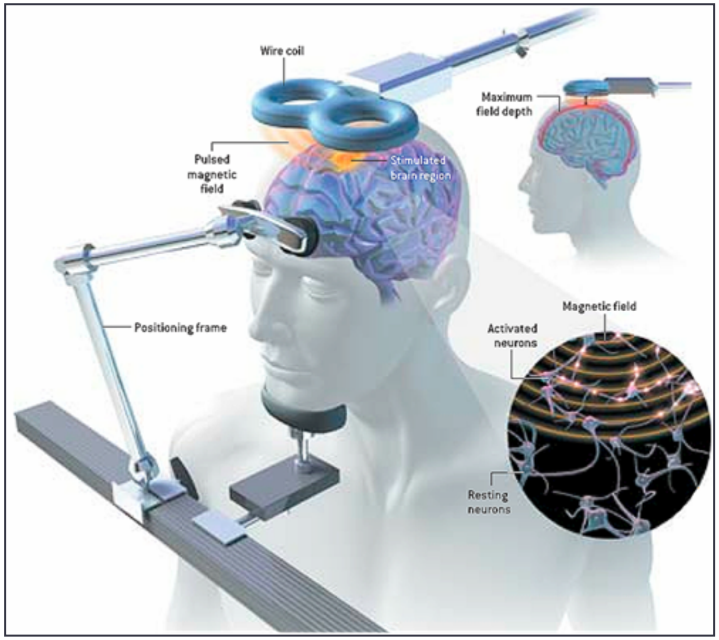


# Artifacts: bad contact between electrode and cable



# Trascranial magnetic stimulation (TMS)






- TMS allows the safe, non-invasive and painless stimulation of the human brain cortex.
- TMS uses a rapidly changing magnetic field to induce brief electric current pulses in the brain that can trigger action potentials in cortical neurons.

# Trascranial magnetic stimulation (TMS)

- the coil is connected to a pulse generator that delivers electric current to the coil
- the coil produces small electric currents in brain regions via electromagnetic induction (Maxwell-Faraday equation)

$$\Delta \times E = -\frac{\partial B}{\partial t}$$

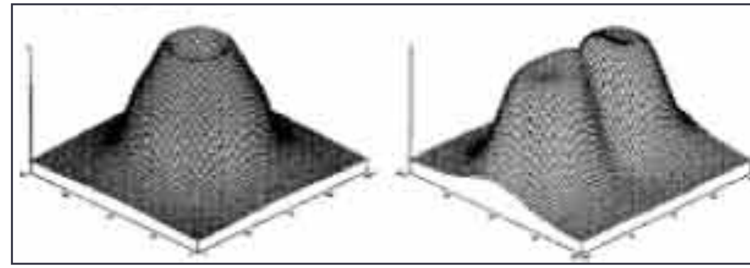
- by directing the magnetic field pulse at a targeted area, one can either depolarize or hyperpolarize neurons

# Coil types

**Round coil:** the original type of TMS coil

**Figure-eight coil** (i.e., butterfly coil): results in a more focal pattern of activation

**"Hotspot" determination**



# Mode of stimulation

**Single or paired pulse TMS**
causes neurons in the neocortex under the site of stimulation to depolarize and discharge an action potential.

- if used in the primary motor cortex, it produces muscle activity referred to as a motor evoked potential (MEP) which can be recorded on electromyography.
- if used on the occipital cortex, 'phosphenes' (flashes of light) might be perceived by the subject.

**Repetitive TMS**
produces longer-lasting effects which persist past the initial period of stimulation.
rTMS can increase or decrease the excitability of the corticospinal tract depending on the intensity of stimulation, coil orientation, and frequency.

# Applications of TMS

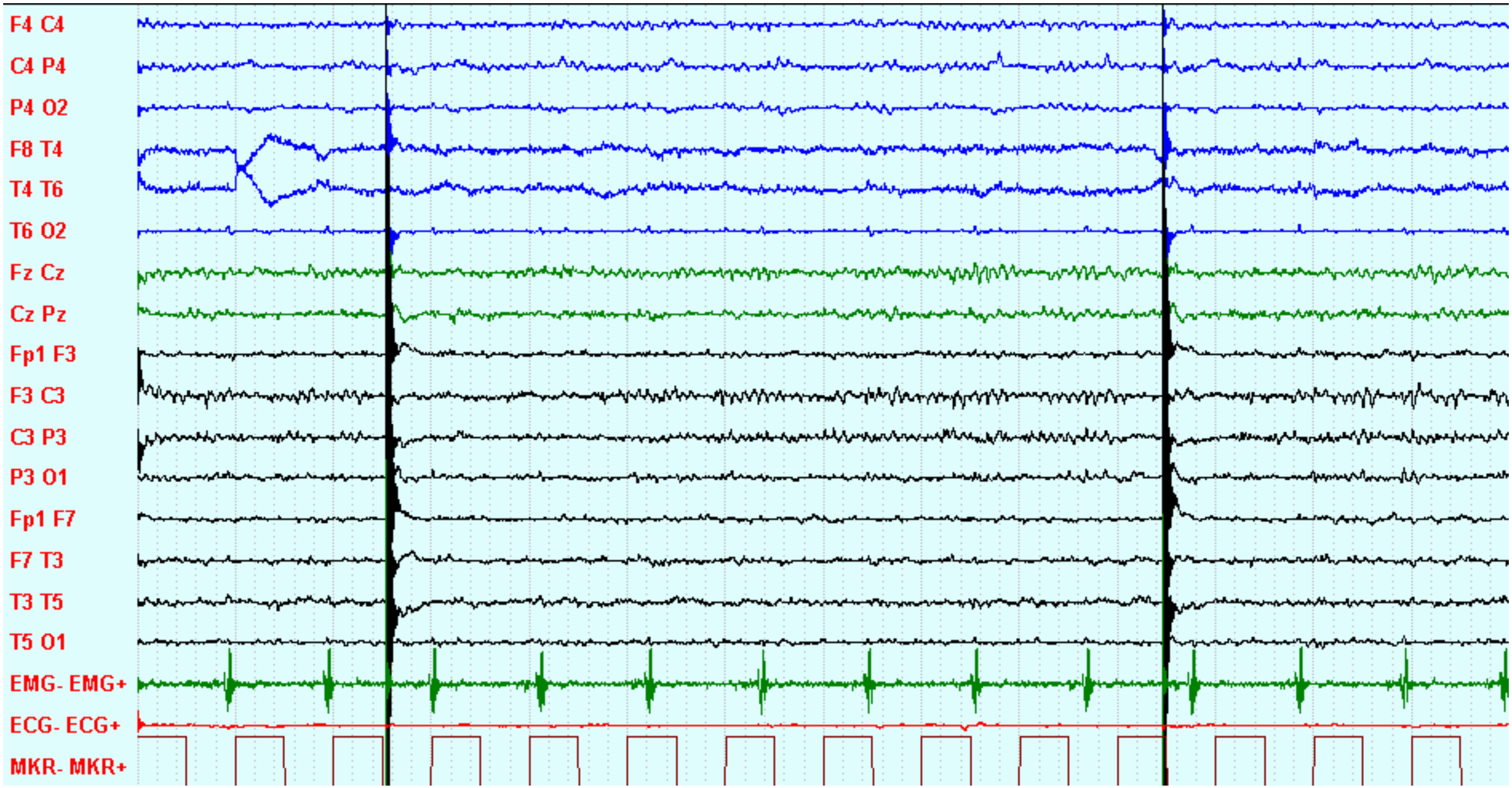
**Clinical**

- functional integrity of the corticospinal motor projections (stroke, MS, ALS, movement disorders, etc.)
- treatment of depression

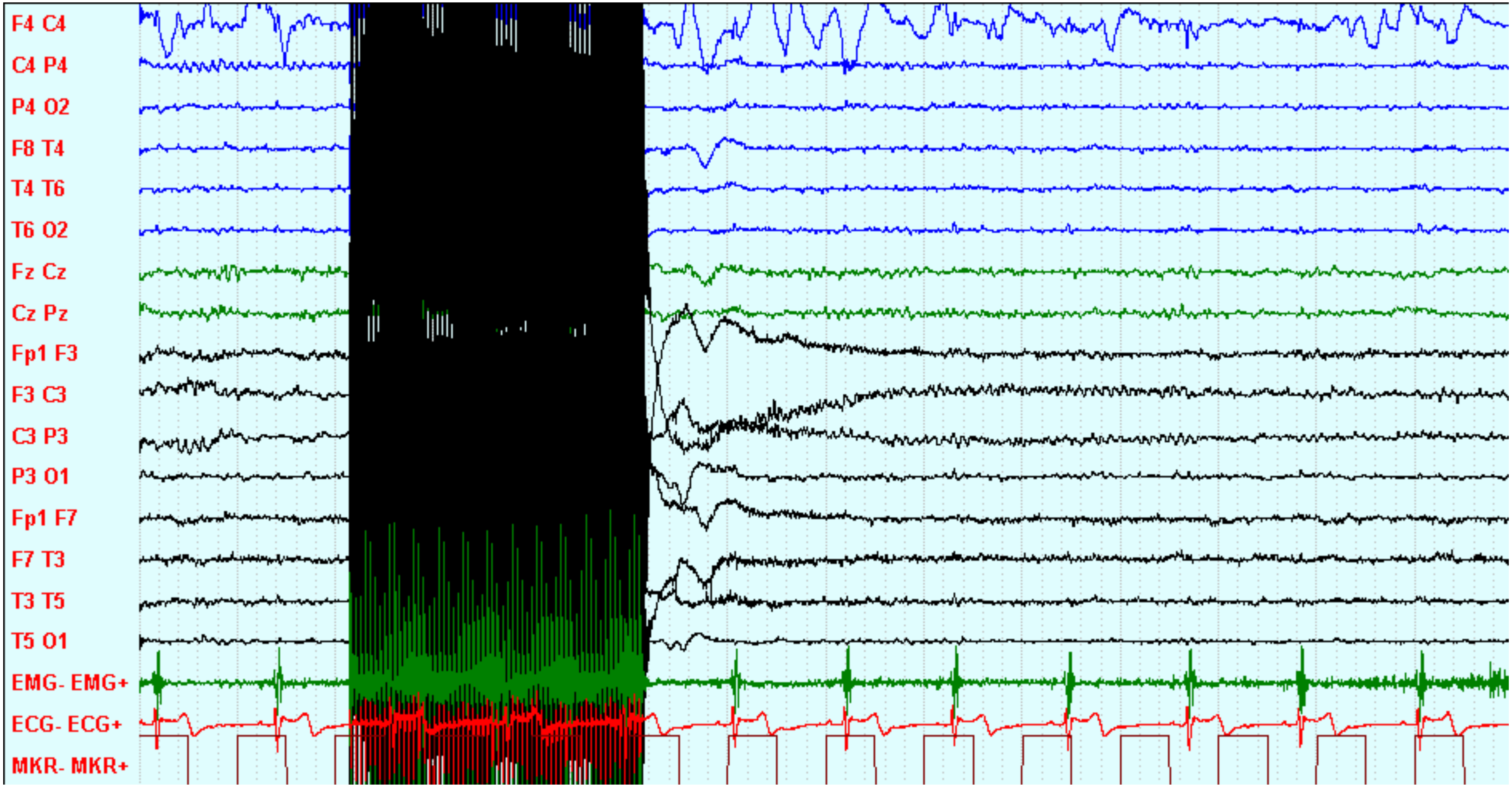
**Experimental**

Single Pulse - motor system probe
Repetitive - working memory disruptions
- sequence learning

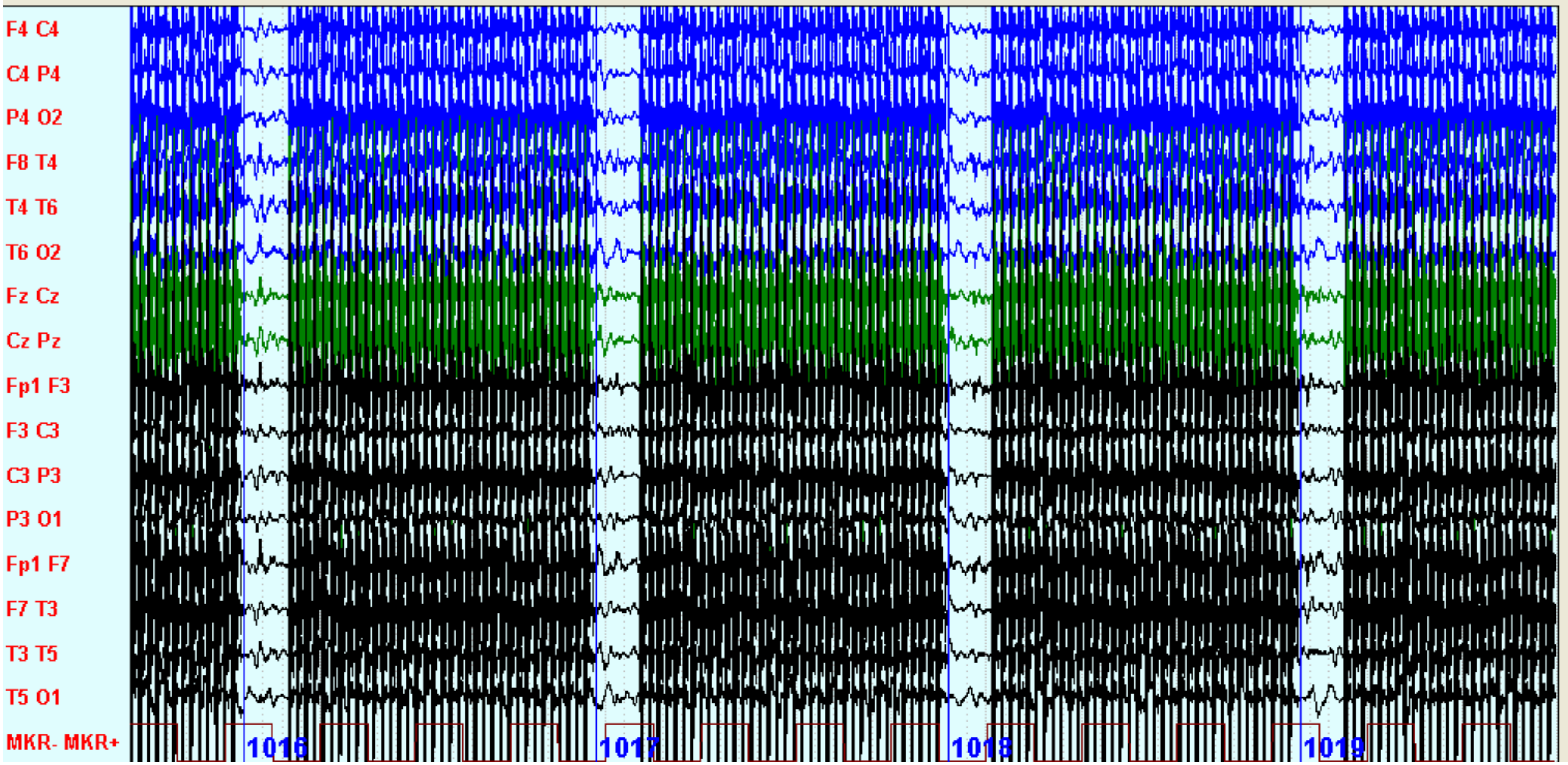
# Artifacts: single-pulse TMS



# Artifacts: repetitive TMS

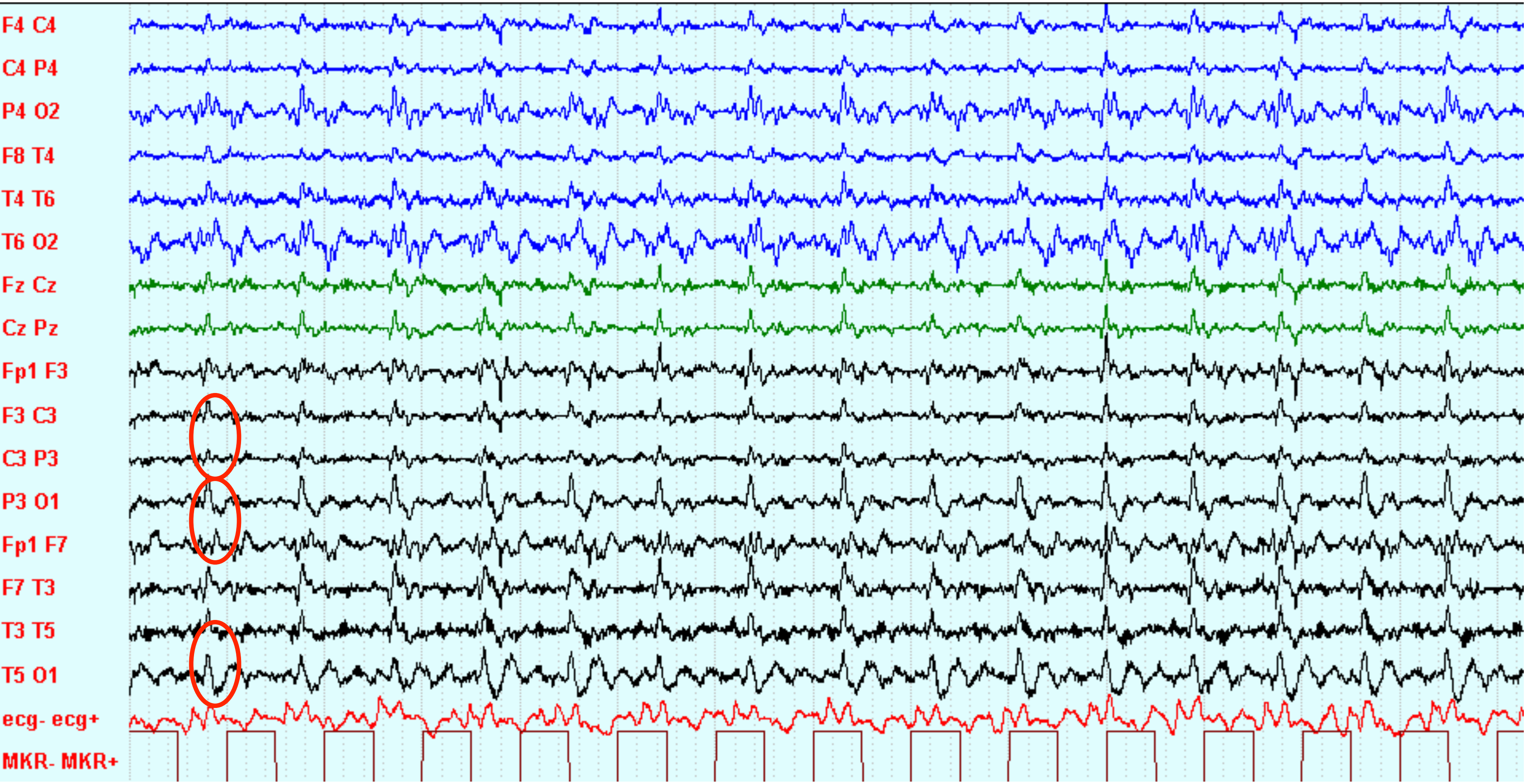


# Artifacts: magnetic field




EEG inside a MR scanner (1.5T)

# Artifacts: ballistocardiograph (BCG)




EEG inside a MR scanner (1.5T)