Elaborazione di Immagini - Laurea in Bioinformatica Prof. G. Menegaz

EEG SIGNAL PROCESSING

1. Recording

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The human brain

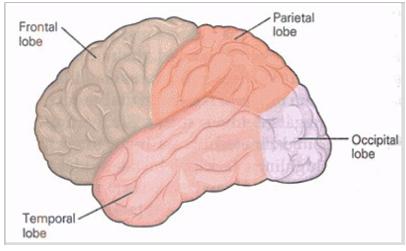
The lobes have specialized functions.

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)

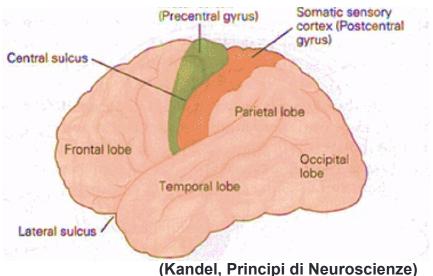
The human brain

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.

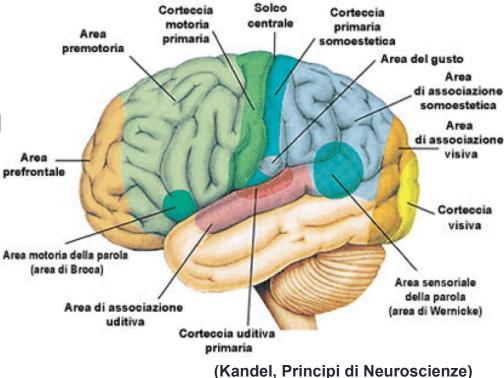
For example, the **central sulcus** separates the precentral gyrus, which is concerned with motor function, from the postcentral gyrus, which is concerned with sensory function.



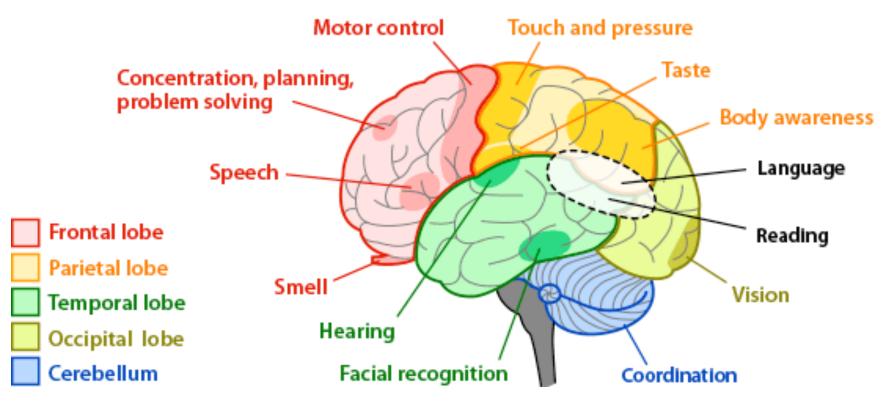
Functional areas of the brain

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



Functional areas of the brain



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

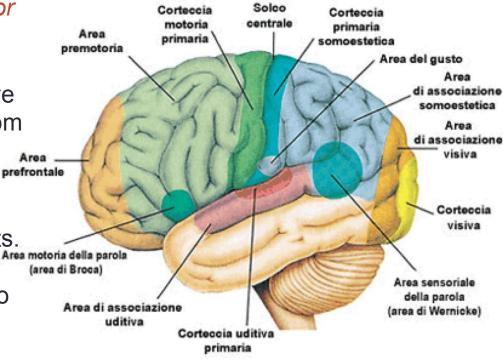
Functional areas of the brain

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.

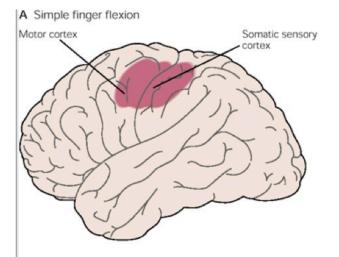
Motor areas generates motor impulses through the pyramid tracts.

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.

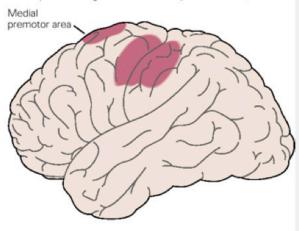


(Kandel, Principi di Neuroscienze)

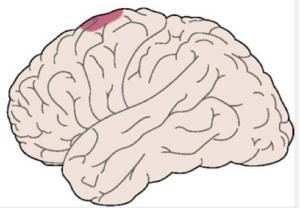
Functional areas: motor regions



B Sequential finger movements (performance)



Different areas of the cortex are activated during the movement or the movement imagination of simple tasks or complex sequences. C Mental rehearsal of finger movements

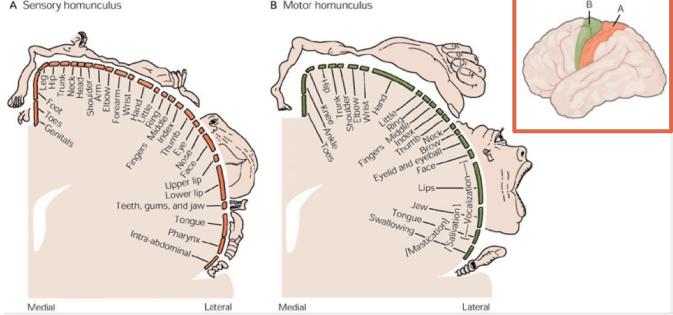


(Kandel, Principi di Neuroscienze)

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.

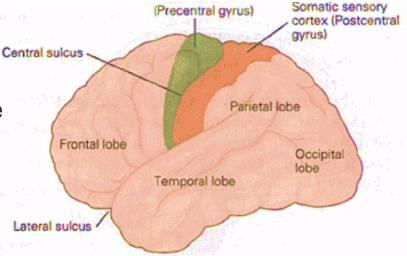
In the sensory (left) and motor (right) cortex, areas related to specific parts of the body are present.

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.

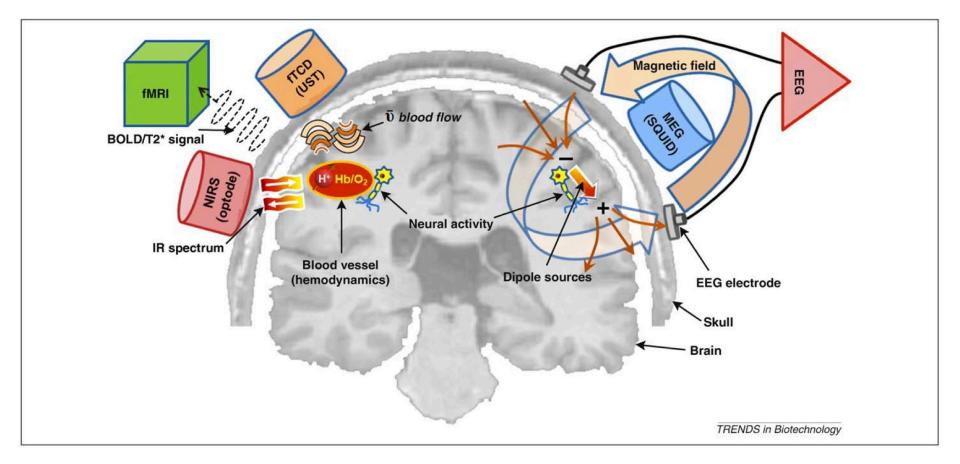
Motor imagery

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



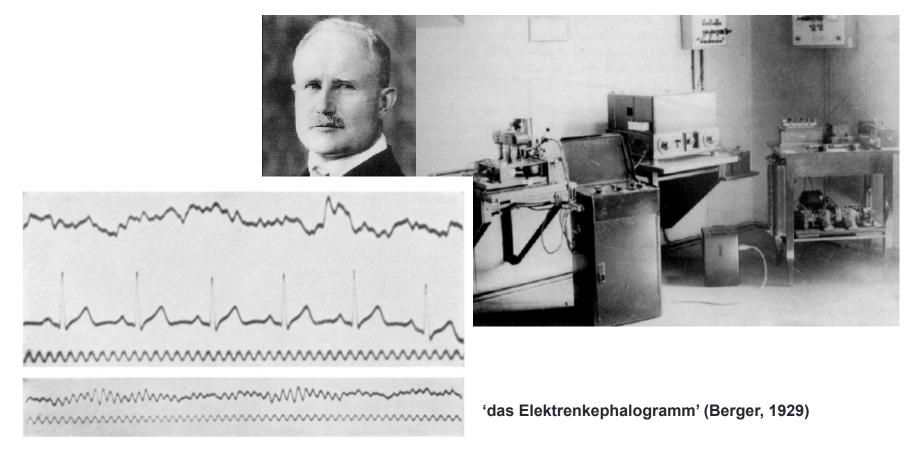
- the motor imagery, defined as a mental simulation of the movement, is an efficient mental strategy to operate the brain computer interface
- the imagination of the movements of the right hand, left hand, foot or tongue results in a characteristic change in the brain signal over the sensorimotor cortex

Methods for measuring brain activity



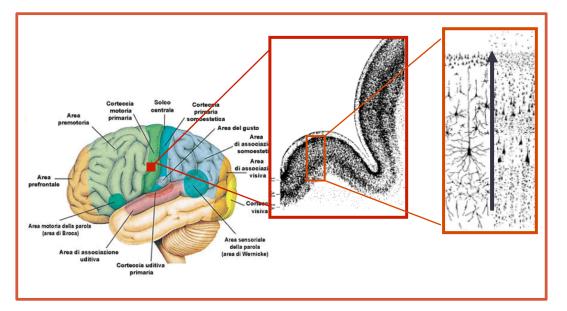


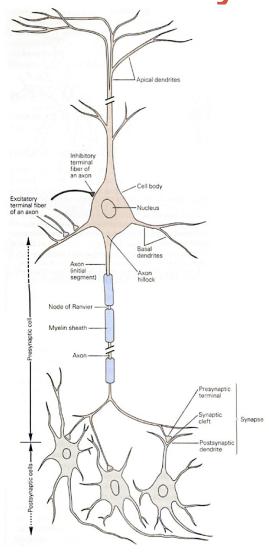
1924: Hans Berger, a German psychiatrist, recorded the brain electrical activity by using an electroencephalography (EEG) (the recording of "brain waves") and discovered the alpha wave rhythm known as "Berger's wave".



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.

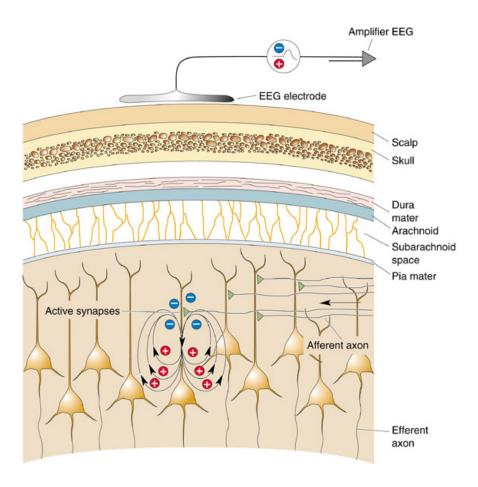




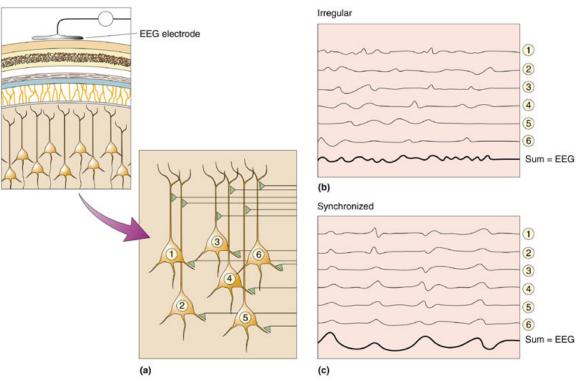
Origin of EEG signal

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

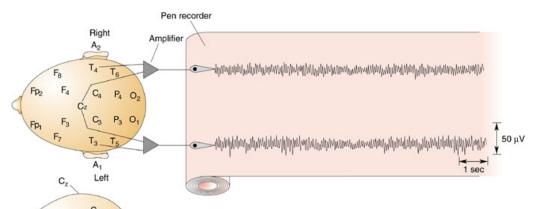


Origin of EEG signal



- 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" \rightarrow monopolar recording

Electrodes measure voltage-differences at the scalp in the microvolt (μ V) range.

Voltage-traces are recorded with millisecond resolution – great advantage over brain imaging (fMRI or PET).

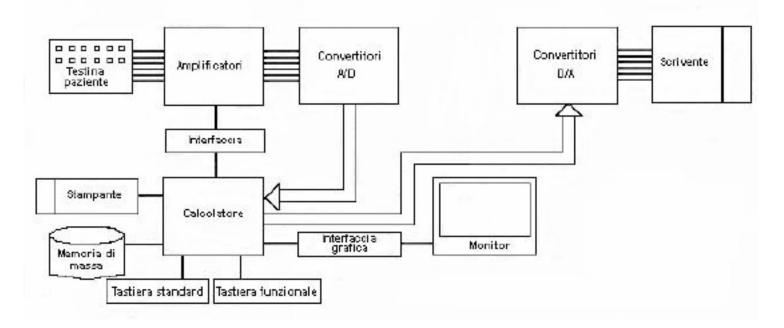
The EEG: general characteristics

- 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 electricallyconductive paste
- economic, reliable, durable but require long preparation times

Electrodes Stickers

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



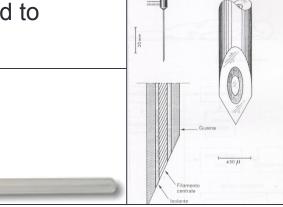
EEG electrodes

- 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



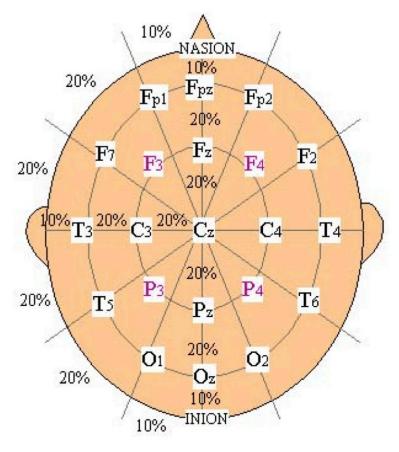


Standard montage

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

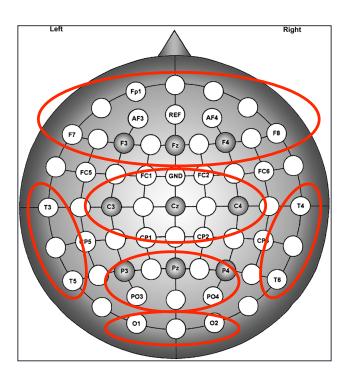
Standard montage

Location: Frontal, Central, Temporal, Parietal, Occipital electrodes Label: even numbers – right hemisphere

odd numbers – left hemisphere

z - central electrodes





International System 10/20

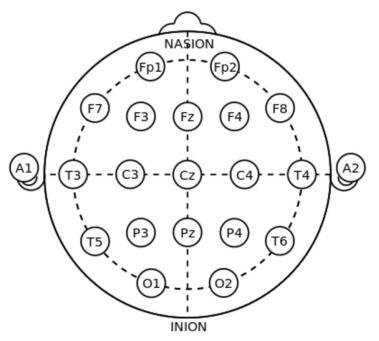
Standard montage

Symmetry:

- antero-posterior
- between hemispheres

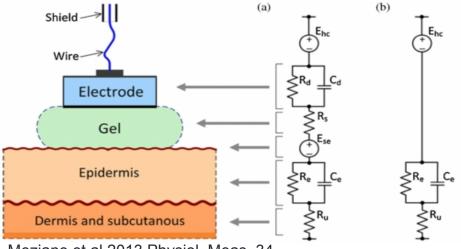
Each site has a letter to identify the lobe and a number to identify the hemisphere location.

- 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 k Ω

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



Video-EEG

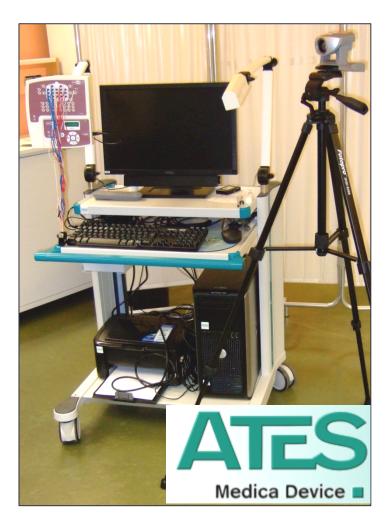
coordinated system of video recording during an EEG

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



EEG-fMRI coregistration system

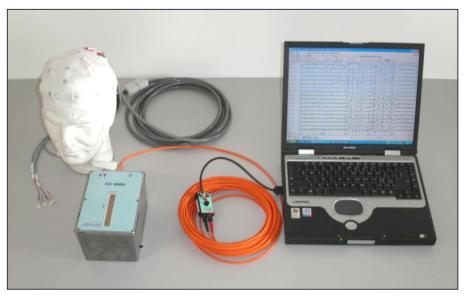
Technical characteristics of cap and amplifier

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**



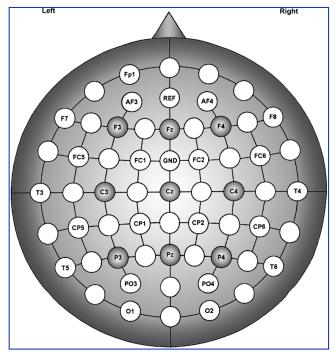
EEG cap with 256 channels (Electrical Geodesics Inc. Eugene, OR, USA)

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



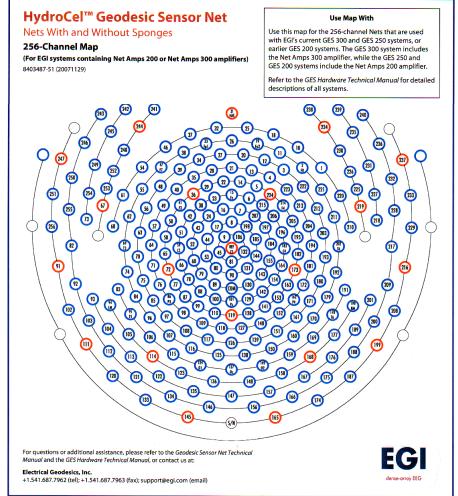
EEG channel configuration

Standard EEG

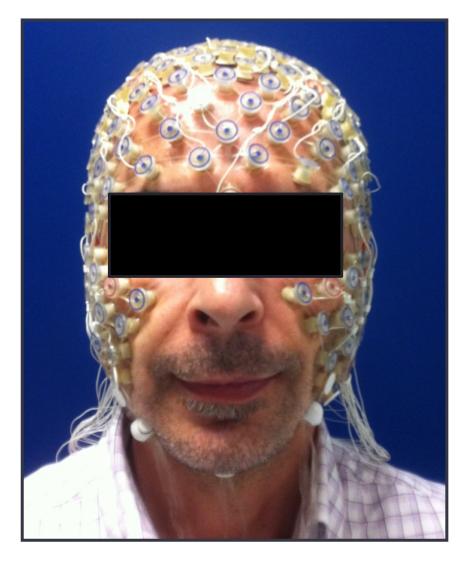


High density EEG technology is developed to enhance the poor spatial information content of the EEG activity.

High-density EEG

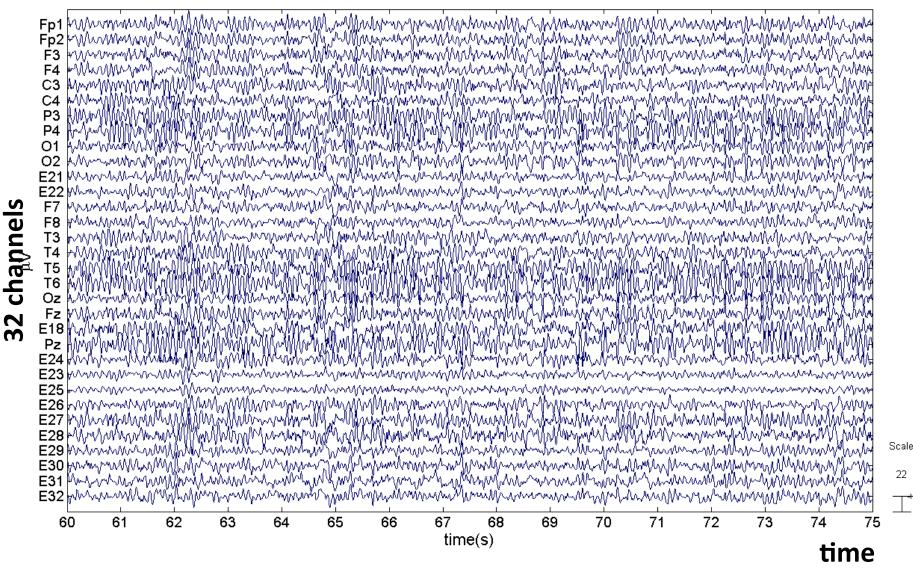


High-density EEG cap: 256 channels



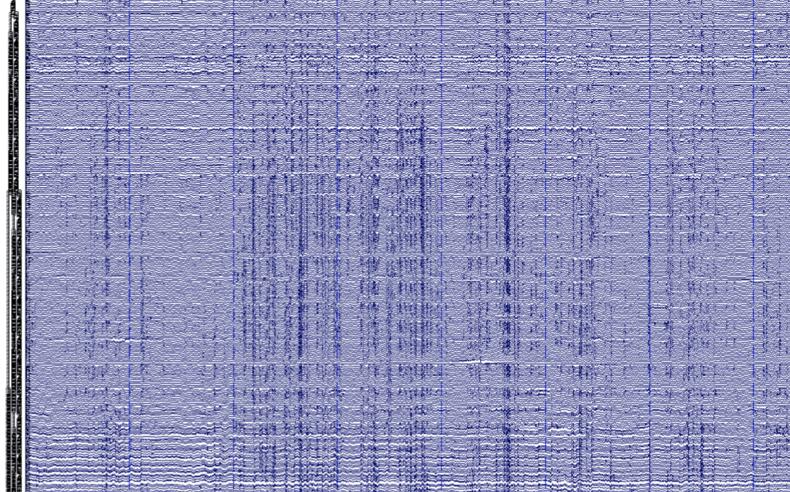


Standard EEG - 32 channels



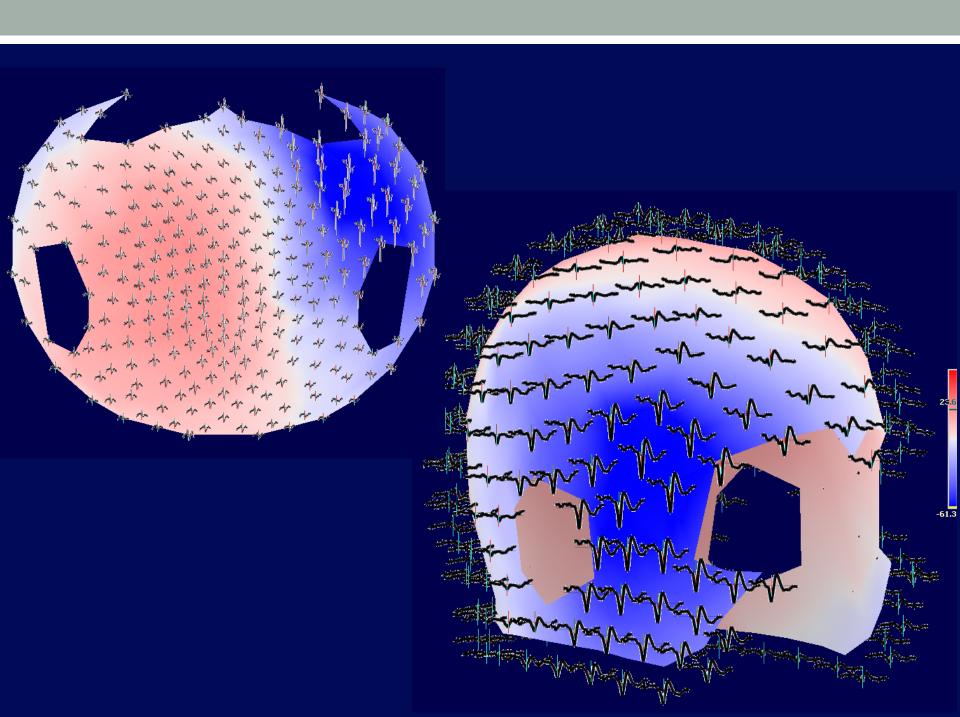
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High-density EEG - 256 channels



Scale 25

time



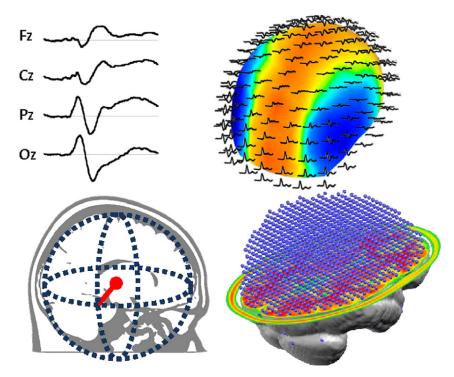
Progression of EEG data acquisition and analyses

From low-density to highdensity 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.

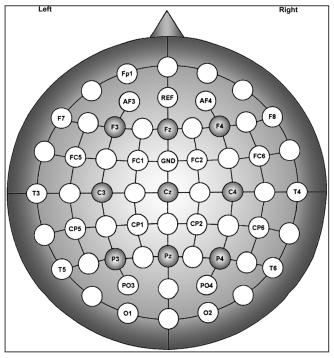
Variations due to:

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

Inter-individual and intra-individual variability

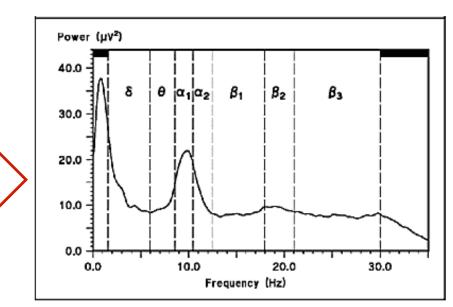
- peak variable 8-13 Hz

- age



The brain rhythms

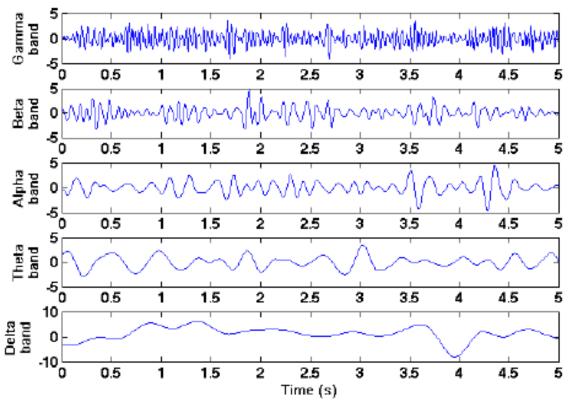
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MKR- MKR+	



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

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Beta	13-30	1-20		frontally, Mental activity	a halla di alla di	475 +P3 +Pz +P +P05 +P04 +76 +91 - 52

The brain rhythms



- 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)

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

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

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Fz Cz	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	Mmy
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P3 O1	warman warman ward and and warman warma	WWW
T5 O1	man when a short when the short when a short when the short when t	www
emg- emg+		
ecg- ecg+		
MKR- MKR		

eyes open

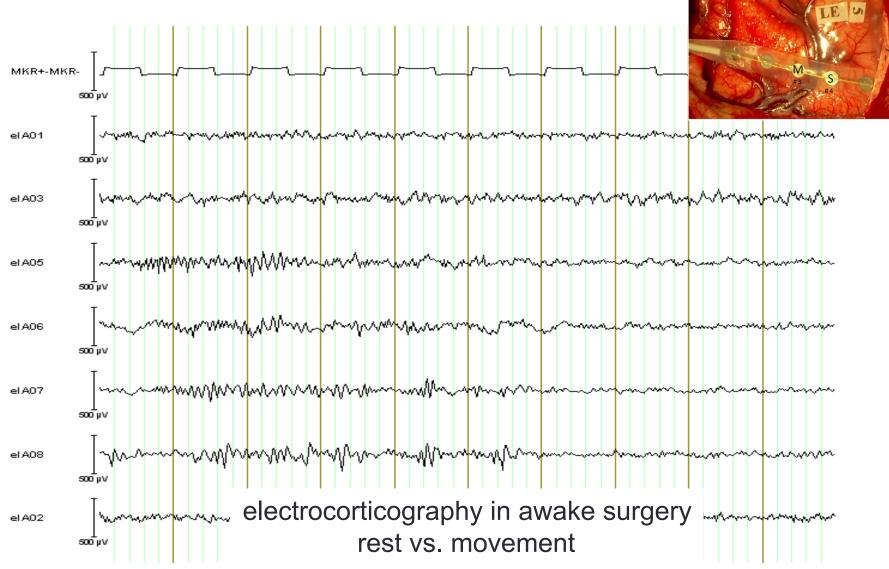
eyes closed

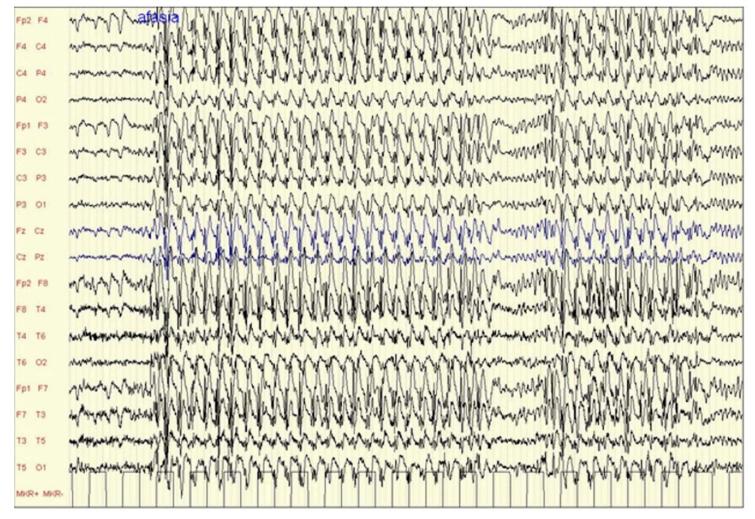
Alpha rhythm

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Cz Pz	man man and the second of the
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F3 C3	www.manageway.www.wayawawayallynhnnyng.
C3 P3	man we we we we have a server the we
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T3 T5	professional and a second way and a second with the second and the
T5 01	marine and a second
EMG- EMG+	
ECG-ECG+	
MKR- MKR+	

rest vs movement

Alpha rhythm



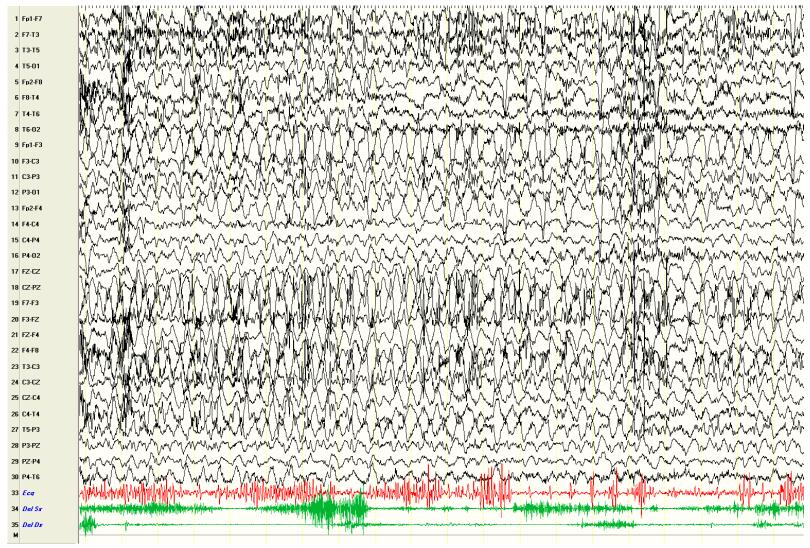


Epilepsy: ictal EEG – speech arrest

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3 T3-T5	
4 T5-01	
5 Fp2-F8	
6 F8-T4	when we
7 T4-T6	man and the second and th
8 T6-02	at a solar residence and a solar re
9 Fp1-F3	
10 F3-C3	
11 C3-P3	
12 P3-01	
13 Fp2-F4	
14 F4-C4	
15 C4-P4	
16 P4-02	
17 FZ-CZ	
18 CZ-PZ	
19 F7-F3	
20 F3-FZ	
21 FZ-F4	
22 F4-F8	
23 T3-C3	
24 C3-CZ	
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1 Fp1-F7 2 F7-T3 3 T3-T5 4 T5-01 5 Fp2-F8 6 F8-T4 7 T4-T6 8 T6-02 9 Fp1-F3 10 F3-C3 11 C3-P3 un Multher 12 P3-01 13 Fp2-F4 14 F4-C4 15 C4-P4 16 P4-02 ᡁᡃᡃᡞ᠕ᡣ $f_{M_{M}}^{M_{M}}$ 17 FZ-CZ 18 CZ-PZ 19 F7-F3 20 F3-FZ 21 FZ-F4 22 F4-F8 23 T3-C3 24 C3-CZ 25 CZ-C4 26 C4-T4 27 T5-P3 28 P3-PZ 29 PZ-P4 30 P4-T6 33 Ecq 34 Del Sx 35 Del Dr м



1 Fp1-F7	Month March
2 F7-T3	Mr. a. Mr. a Million and Million and Million and March and Andrea Million and a second and a march and a second and a march and a
3 T3-T5	በማለከት በሆኑ እስለ ለዲሞት የሚለ እና ለመለከብ እና ለመለከብ እና ለመለከብ እና ለመለከት እና ለመከረለ በ አለት በሆኑ ለመለከት በዚህ እና በሆኑ ለግን ለከተለ እና ለከላከ ለ ለእና እና ለጠናከረ እና ለግን እና
4 T5-01	A Mar & Mar marine March And And march the Mill Me Mill and he marked and and when the second and the march is the march is the marked and the
5 Fp2-F8	A REALING IN MARCHANGE AND A REAL AREA AND A REAL AND A
6 F8-T4	winner and real the land of the production of th
7 T4-T6	Marine
8 T6-02	
9 Fp1-F3	
10 F3-C3	
11 C3-P3	
12 P3-01	A. M. A. A. M.
13 Fp2-F4	
14 F4-C4	and have been and the second and the
15 C4-P4	
16 P4-02	Now have a weather and the second of the stand of the second of
17 FZ-CZ	
18 CZ-PZ	MAN I LIMAN Low MAN WANT WANT WANT WANT WANT WANT A MANY MANY MANY MANY MANY MANY MANY MA
19 F7-F3	
20 F3-FZ	White the way when the
21 FZ-F4	MANNA MANA MANA MANA ANA ANA ANA ANA ANA
22 F4-F8	
23 T3-C3	and the production of the prod
24 C3-CZ	when the second of the second
25 CZ-C4	him of the week of the second of the of the second of the
26 C4-T4	
27 T5-P3	
28 P3-PZ	N when we
29 PZ-P4	and the second way was a second way and the second way and the second way and the second way was a second way w
30 P4-T6	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
33 <i>Ecq</i>	MANA WAR WAR WAR WAR WAR WAR WAR WAR WAR WA
34 <i>Del Sx</i>	
35 <i>Del Dx</i>	
	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

Fp2-F4	1 marsher and have been been and and and and and and and and and an
F4-C4	I marine the way and a second a secon
C4-P4	- warmen where a second warmen and the second warmen we warmen warmen warmen and the second warmen warme
P4-02	and and a second and the second and
Fp2-F8	I merer many how and have had many a provide the second of more and the many of the second have the second have the second of the second have the second of
F8-T4	and more and the providence of the provided of the pro
T4-T6	www.www.www.www.www.www.www.www.www.ww
T6-O2	1 - mar make why we have a second when a second when we have the second when the second we have the second w
Fz-18	To an annound for the prove with the formal have been and the formation of
18-Pz	The answer and a second with the first find and a second with a second and and a second of the first and the second and the se
Fp1-F3	10 marshare from the second of
F3-C3	- Kanan man and and and and and and and and and a
C3-P3	- mountain mountain mountain and and and and and and and and and an
P3-01	
Fp1-F7	I amounter the second have been and the second of the second we have been the the second back of the second s
F7-T3	1 monor the for the for the for the second of the second o
Т3-Т5	I wannerstand wanter and a second wanter and a second water and a seco
T5-01	I ware ware ware and the second ware and the second ware ware and the second ware and
23-25	warmer and a second a
31-21	I marrow Mary Mary Mary Mary Mary Mary Mary Mary
24-26	when the second and t
32-22	1 ²⁰
Fz-27	I manunal work of the hard and the second and the s
28-Pz	- many many many many many many many many
EMG	1 - presences and a second strand and and and and and and and and and

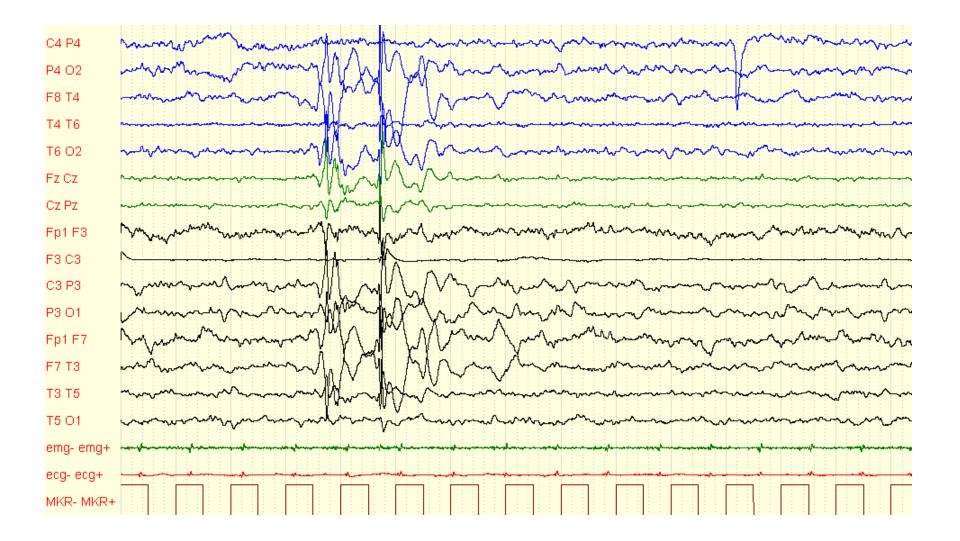
Movement artifact

E4.04	han a porta and a second and a second a
F4 C4	
C4 P4	him
P4 O2	Marine marine war war and war war war war war and the proper war and the property of the prope
т4 т6	
T6 O2	have a server and a server and a server a
Fz Cz	
Cz Pz	man man and a second water a second water a second water a second and a second and a second
F3 C3	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
C3 P3	have a second and the
P3 O1	
F7 T3	many and a second and the second and a second a second and a second a se
тз т5	here have been and the second and th
T5 O1	how
emg- emg+	
ecg- ecg+	
MKR- MKR+	

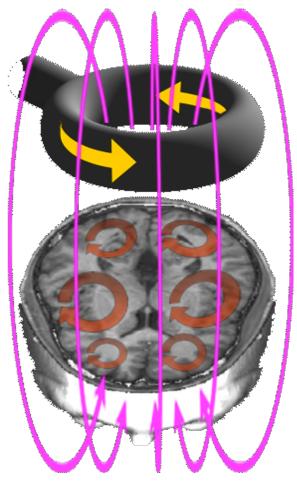
Artifacts: bad contact between skin and electrode

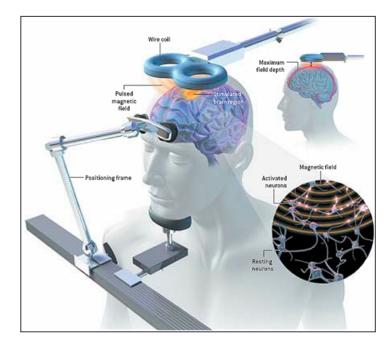
=4 C4	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
04 P4	man management was a second was a
P4 O2	$\cdots + \cdots +$
т4 т6	miline-milipetilisespecturespecturespectures and a second
T6 O2	was were wither the stand of the second of the
=z Cz	man and a second and
Oz Pz	www
=3 C3	
C3 P3	www
P3 O1	
=7 T3	nd-and-and-and-and-and-and-and-and-and-a
тз тб	htteres of the second and a second se
T5 O1	~1942-f=laf24lag-elaf94df1ag4f=h=R=ala=afa7fa-f=h=f=a-active=h=a-afa2+blaf1+ba2+bf1=4bfaf1+ba2+bf1=f=aaaaaafa6ag1+bd1+ba2+bf1=f=aaaaaafa6ag1+bd1+ba2+bf1=f=aaaaaafa6ag1+bd1+ba2+bf1=f=aaaaafafaag1+bd1+bd2+bf2=bf1=f=aaaaafafaag1+bd1+bd2+bf2=bf1=f=aaaaafafaag1+bd1+bd2+bf2=bf1=f=aaaaafafaag1+bd1+bd2+bf2=bf1=f=aaaaafafaag1+bd1+bd2+bf2=bf1=f=aaaaafafaag1+bd1+bd2+bf2=bf1=f=aaaaafafaag1+bd1+bd2+bf2=bf1=f=aaaaafafaag1+bd1+bd2+bf2=bf1=f=aaaaafafaag1+bd1+bd2+bf2=bf1=f=aaaaafafaag1+bd1+bd2+bf2=bf1=f=aaaaafafaag1+bd2+bf2=bf1=f=aaaaafafaag1+bd2+bf2=bf1=f=aaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaaafafaag1+bd2+bf2=bf1=f=aaaaafafaag1+bd2+bf2=bf1=f=aaaaafafafaafafaag1+bd2+bf2=bf1=f=aaaaafafafaafafaafafaafafaafafaaf
emg- emg+	
ecg- ecg+	
MKR- MKR+	

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

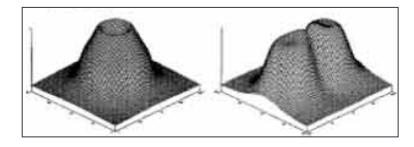


Coil types

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

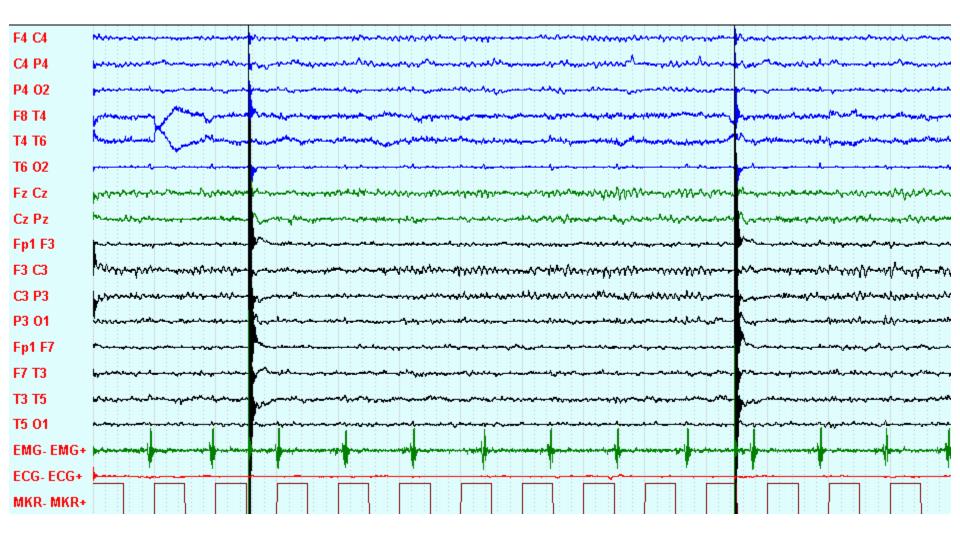
- functional integrity of the corticospinal motor projections (stroke, MS, ALS, movement disorders, etc.)
- treatment of depression

Experimental

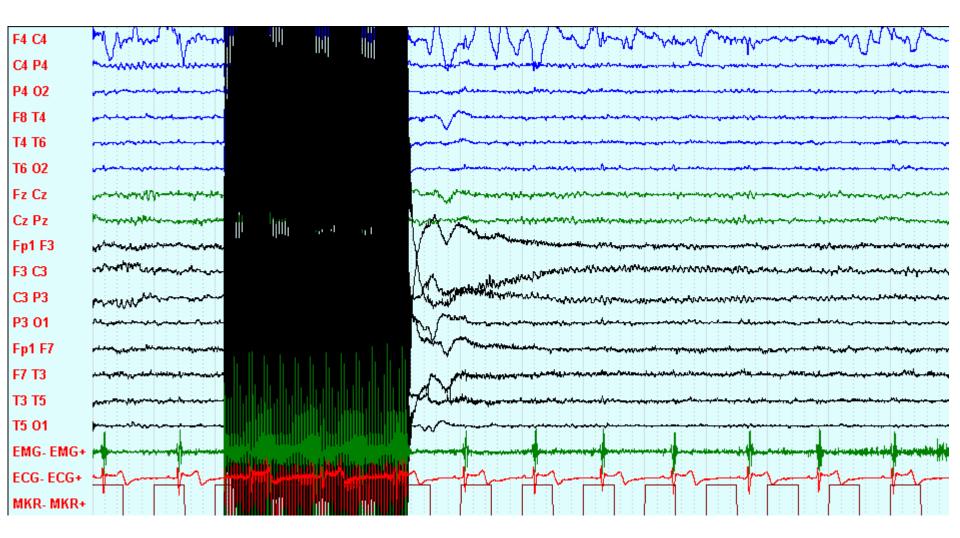
Single Pulse- motor system probeRepetitive- working memory disruptions

- sequence learning

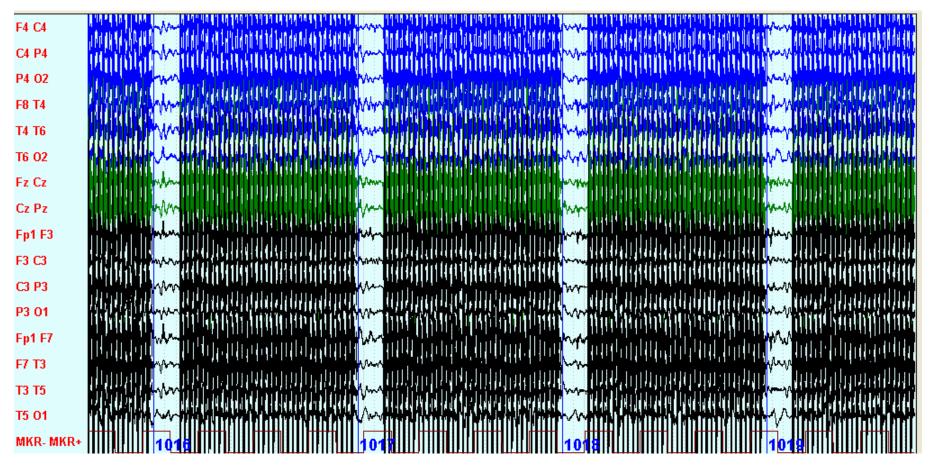
Artifacts: single-pulse TMS



Artifacts: repetitive TMS

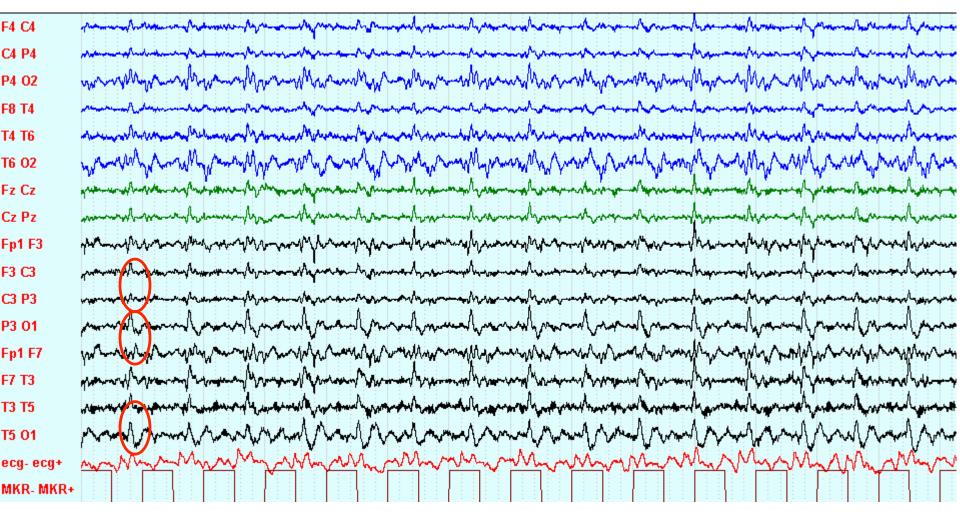


Artifacts: magnetic field



EEG inside a MR scanner (1.5T)

Artifacts: ballistocardiograph (BCG)



EEG inside a MR scanner (1.5T)