The word come from the greek(electro=electrical potential), (encefalo=brain), (gram=graph). This word consist of graphical representation of the elctrical activities of the brain. There are several ways to recover info. some of these are invasive like put the electro in the brain but we don't talk about this, we will talk about non invasive techniques.

The electroencephalogram (1)

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Veronica

Topics

How old this tecniques is? It's quite close 200.

- Overview
- EEG instrumentation We will talk about to collect signals.
- Practicalities of data collection
- Artifacts

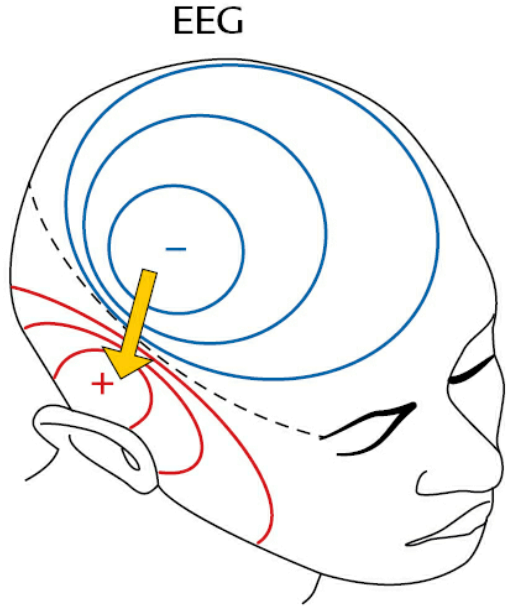
Reference: Hari and Puce. *MEG-EEG Primer*. Oxford University Press. 2017

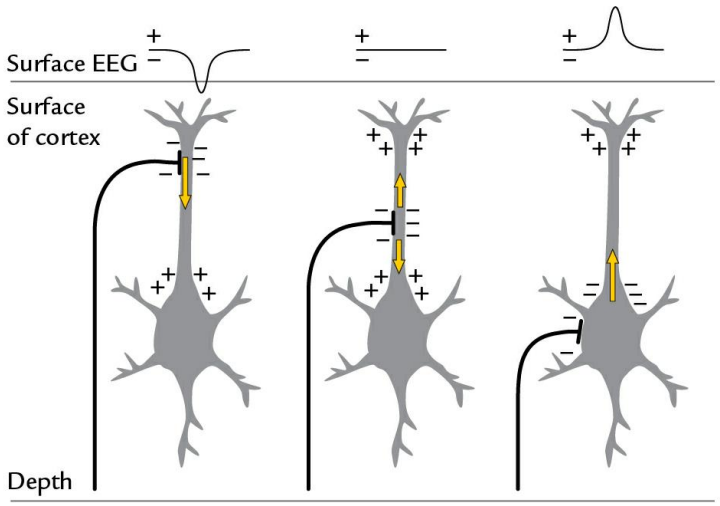
Not topics (today)

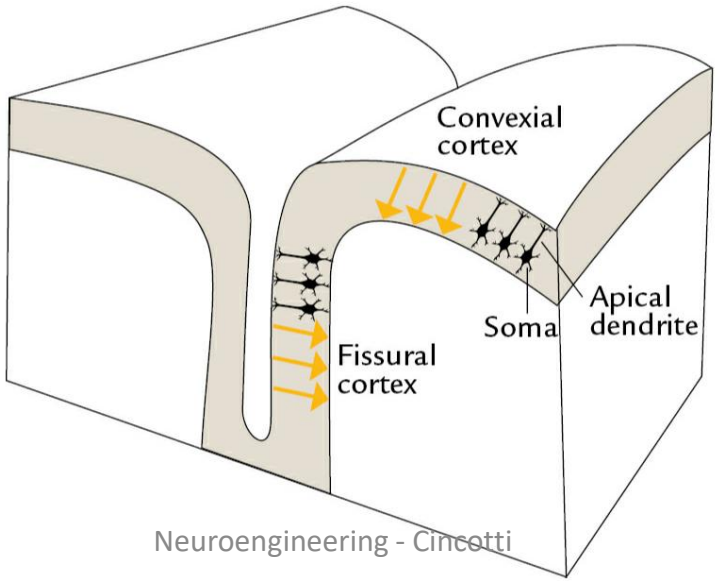
We will not cover this topic today. How the membrane of neurons generates electrical signals.

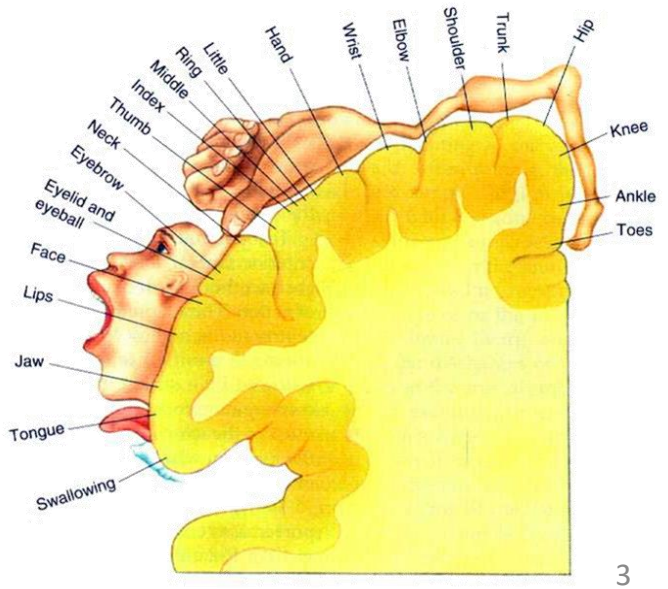
- The biophysics of EEG generation
  - Anatomy and physiology of the neural cell
  - Generation of neural electrical correlates
  - Synchronization of neural populations at different scales
  - Principles of brain organization

We will assume that there are sources in the brain, when the brain is active. The brain generates the current and we can record potential from the surface.









An Overview

Early EEG Recordings

Richard Caton was the first to record electrical activity from the brain. He made invasive recordings directly from the cortex of rabbits, cats and monkeys (Caton, 1875)

First non invasive experiment.

- Noninvasive human EEG began to progress significantly in the 1920s and 1930s following the reports published by Hans Berger, a psychiatrist in Jena, Germany

He's considered the father of EEG.

  - He was able to demonstrate a large and persistent 10-Hz rhythm that he named “alpha.”

- Lord Adrian, a British neuroscientist became interested in EEG activity in the early 1930s.

it means that a system that is not working is "kept warm" so that it can quickly attain full capacity whenever needed

  - Adrian and Matthews observed that alpha oscillations appeared when the cortex had little to do, and they hence proposed, for the first time, an idling ozio hypothesis for brain rhythms

It changes its amplitude when you open and close your eyes. As soon as a person open his eyes the rythm decreases(disappears). This phenomena is called ALFA BLOCKING so the alfa rithm is blocked when open your eyes.

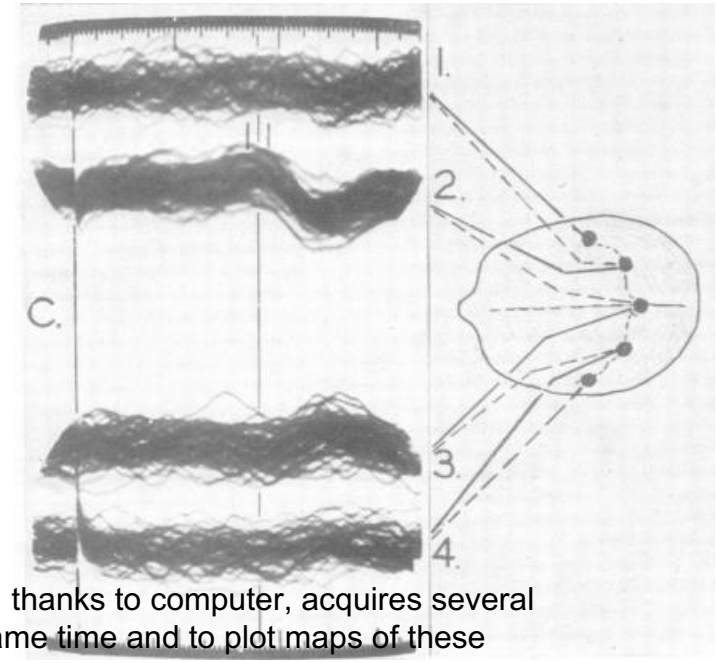
This is a trace of 1 channel electroencephalogram.

The amplitude of this brain is a few tens of microvolt so 20-50.

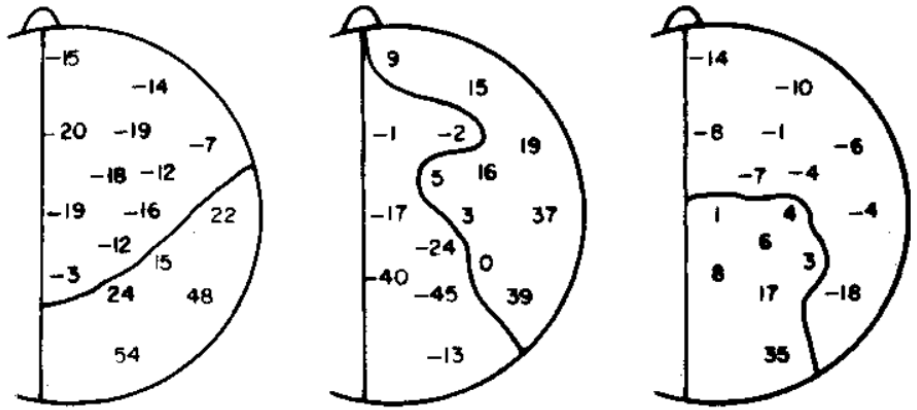
Early ERP recordings

- A real leap in EEG applications occurred in the 1960s and 1970s when the first computers became routinely available and made it possible to average EEG signals time-locked to various sensory stimuli, thereby significantly increasing the signal-to-noise ratio.
  - Event related potentials
- Another important technical advance was the attempt to plot the EEG topographies as a function of time

In the previous case there isn't stimula because the subject decides if open your eyes or not.



It's also possible, thanks to computer, acquires several channel at the same time and to plot maps of these activities



Lets go back to spontaneous activities. So you put electrodes on the head of your subject and record the EEG.

Brain Rhythms – alpha and mu

at the back of the head and in the Rolandic areas

This is a high resolution EEG(high resolution then we have collected the signal from a lot of elechtrodes). Here you can see 6 traces and these traces are collected from the 2-2-2 channel in the figure.

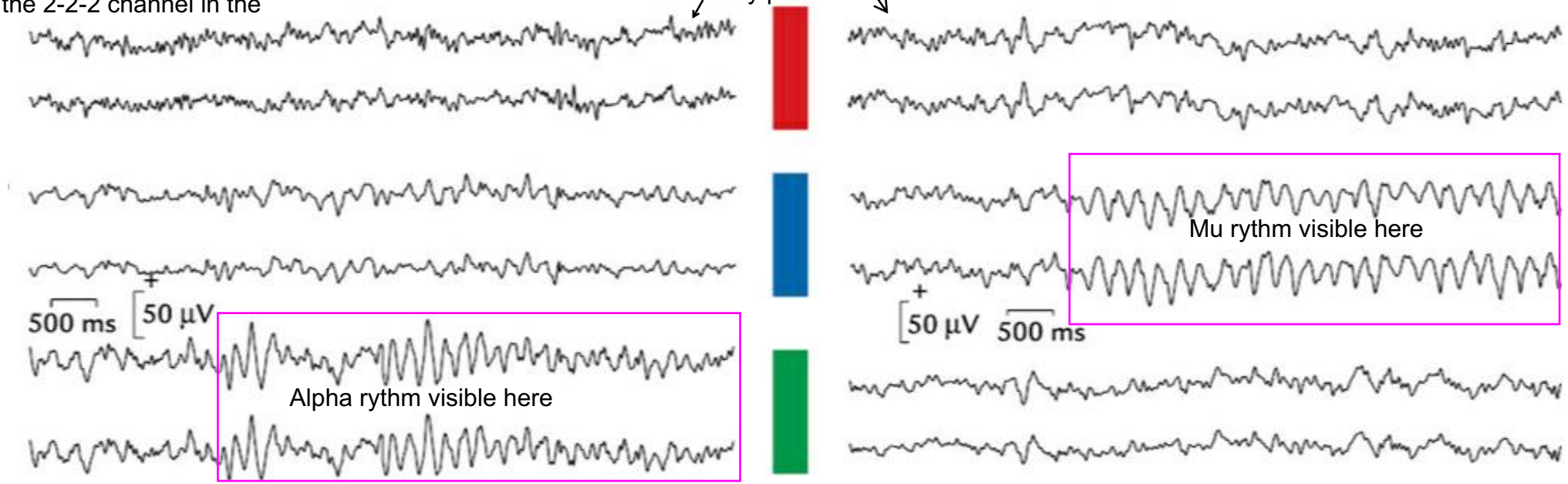
Alpha and Mu are measured in different parts of the brain, Alpha from the back channel and Mu from the central channel. They also differ in shape and frequency.

Alpha

when the brain is inactive

they are both EEG recordings of a healty patient

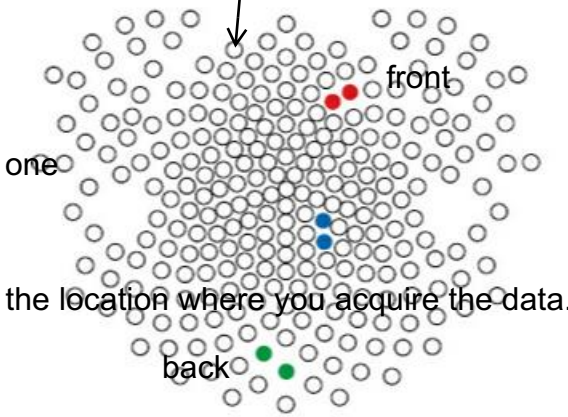
Mu (Gastaut, 1952)



We can see that the front signal is more regular than the back one. This is what Hans Berger discoverd.

Alpha is strongest when the eyes are closed and mu is strongest when the subjects are totally relaxed and not making any movements

This is an head that shows where the channel are taken.



- Location of electrodes (central or occipital)
- Frequency of oscillations (around 10 Hz)
- Waveform shape (sine or «arcs»)
- «Waxing and waning»

mu has at least 2 frequency components, one around 10 Hz and another around 20 Hz

The EEG is different depending on the location where you acquire the data.

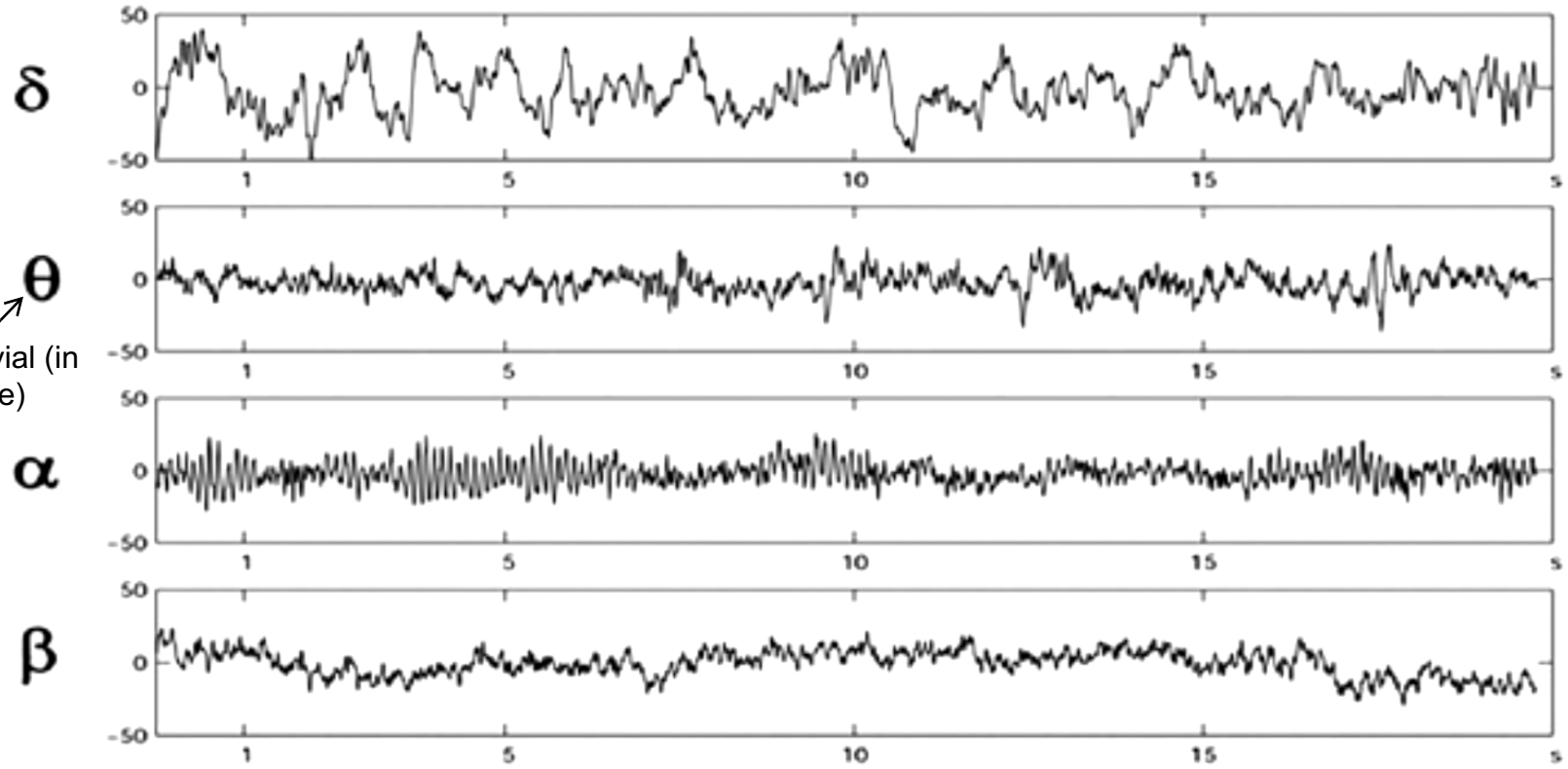
EEG increases and decreases in amplitude and this tecnique is called WAXING AND WANING.

Brain rhythms – delta, theta, gamma

These rithms change a lot depending on location and condition of the subject...

- Frequency bands of EEG rhythms
  - Delta: < 3.5 Hz
  - Theta: 4–7.5 Hz
  - Alpha: 8–13 Hz
  - Beta: 14–30
  - Gamma: > 30 Hz

during memory retrivial (in the ippocampus zone)



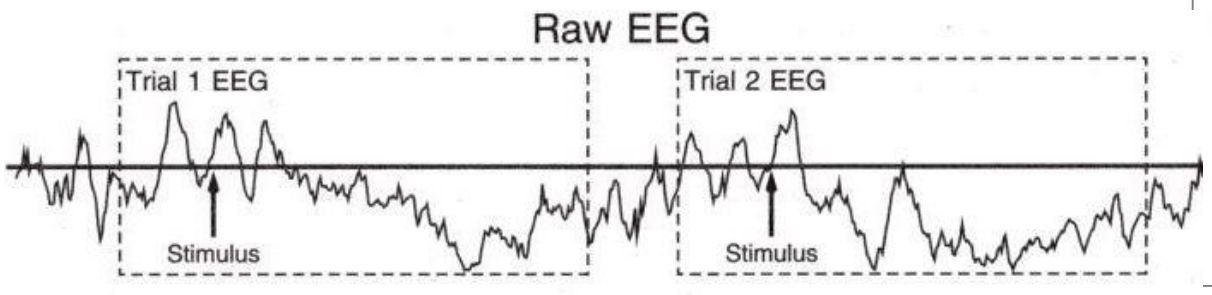
Note that the mu rhythm is in the alpha band (yes, it's confusing)

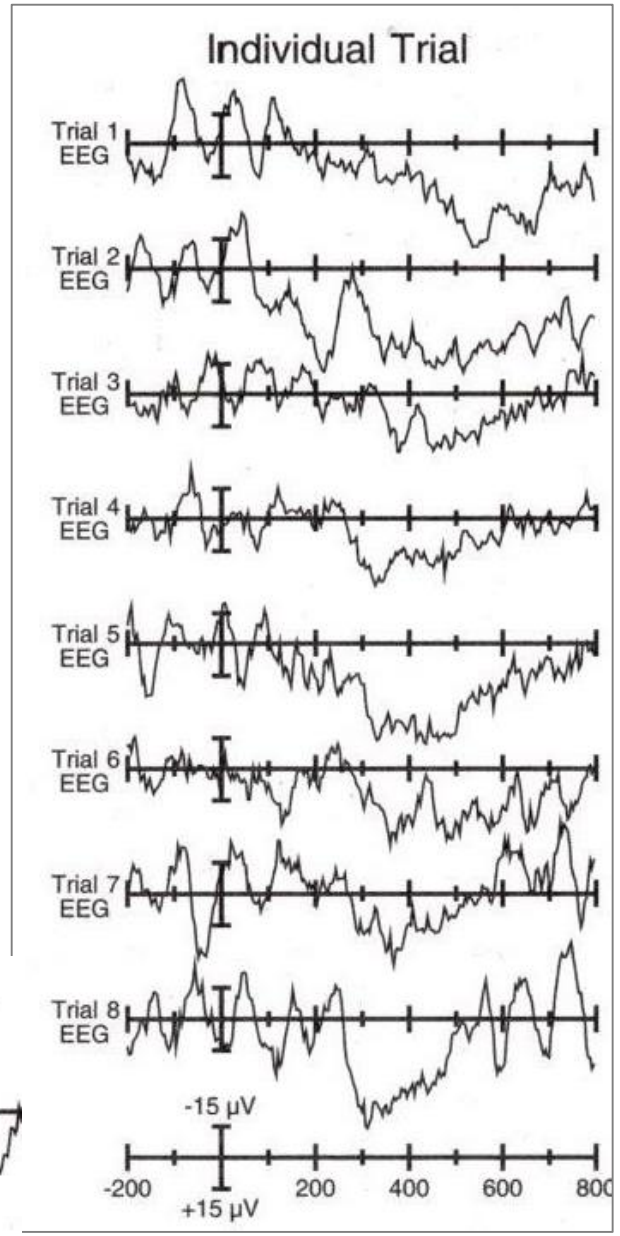
Rhythms are better investigated using spectral analysis or narrow-band filtered signals

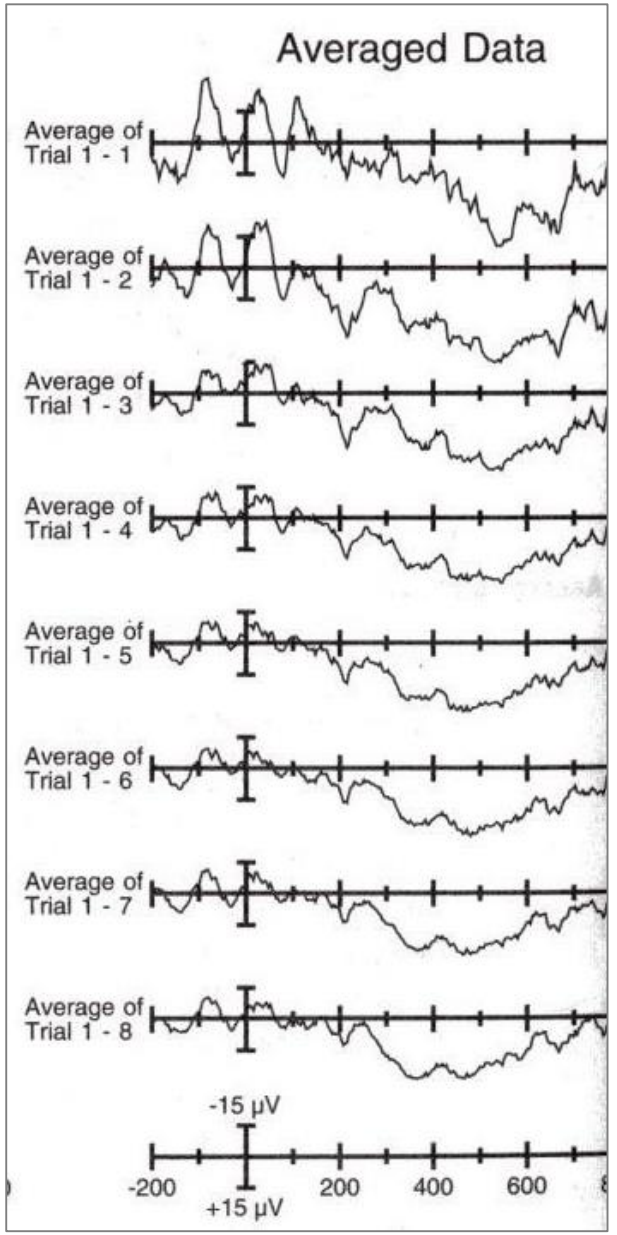
A characteristic feature of brain rhythms is their frequency of oscillation. Here are summarized the conventional range of frequencies that each rhythm covers. Nevertheless, its is not all about frequencies, because rhythms are associated with functions. Oscillations in the "alpha band" (i.e. between 8 and 13 Hz) will be called alpha, mu, or tau rhythms depending on whether they are generated by the visual, motor or auditory cortical systems. And the presence of "harmonic components" (i.e. oscillations at multiple of the fundamental frequency) will change the shape of the waveform (from almost sinusoidal in case of the alpha rhythm, to arc-shaped in case of the mu rhythm).

Evoked and Event-Related Responses

- Besides spontaneous brain activity, EEG can show time-locked (evoked) responses to various sensory stimuli.
  we extract a part of EEG sinchronized with the stimulus.
- The latency after the stimulus can range from a few milliseconds to several hundreds of milliseconds
- Event related potentials can be recorded during tasks involving aspects of motor planning and other cognitive operations.







EEG Instrumentation

Can I acquire signals by just putting two wires on the skin of the person? yes, in principle because you're teoretically just measuring a potential difference. There are two problems: first is the amplitude, so we need to amplify the signal.

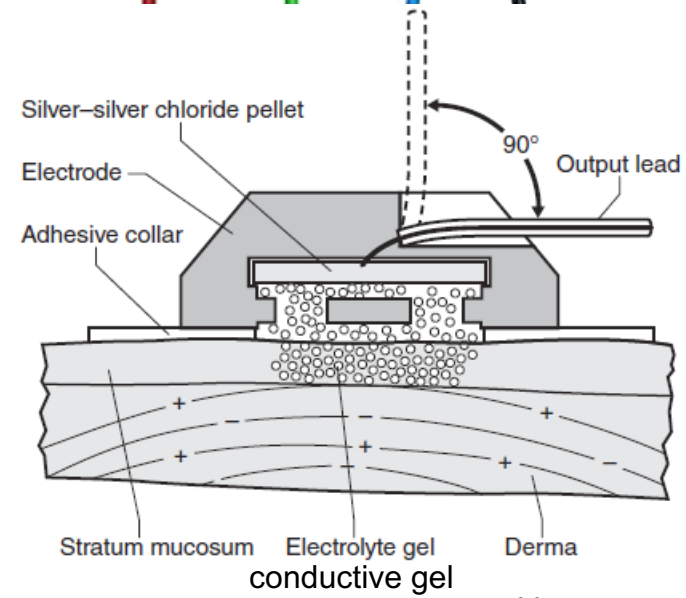
Electrodes

- The most commonly used EEG electrodes are made of silver and silver chloride (Ag/AgCl).
  - nonreactivity with biological tissue
  - accurate reproduction of extremely slowly changing potentials
  - low polarization potentials, drift, and noise.
  - *(see figures in the following slide)*

Silver is very conductive, and silver chloride has the ability to avoid polarization

We have to choose how electrodes to use.

deviazione

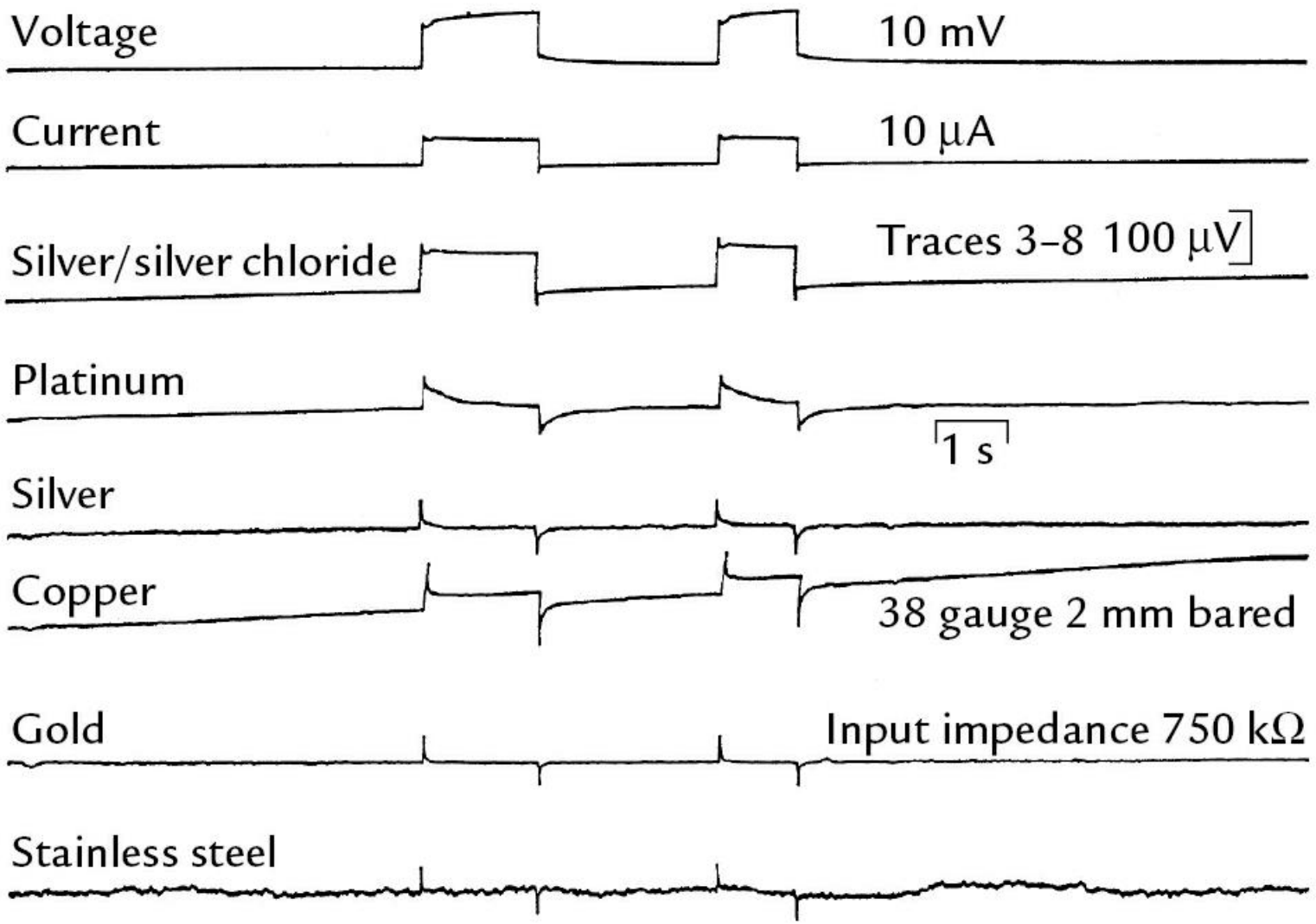


- Impedance is a measure of the quality of the contact between the scalp, electrode, and conducting medium
  - must be measured with alternating current.

Electromaiography: electrical activities of the muscles.

a two square-wave pulses have been passed through electrodes made from different metals.

all the electrodes used in a recording should be made from the same material



EEG Amplifiers - CMRR

COMMON-MODE REJECTION RATIO

we will use differencial amplifiers.

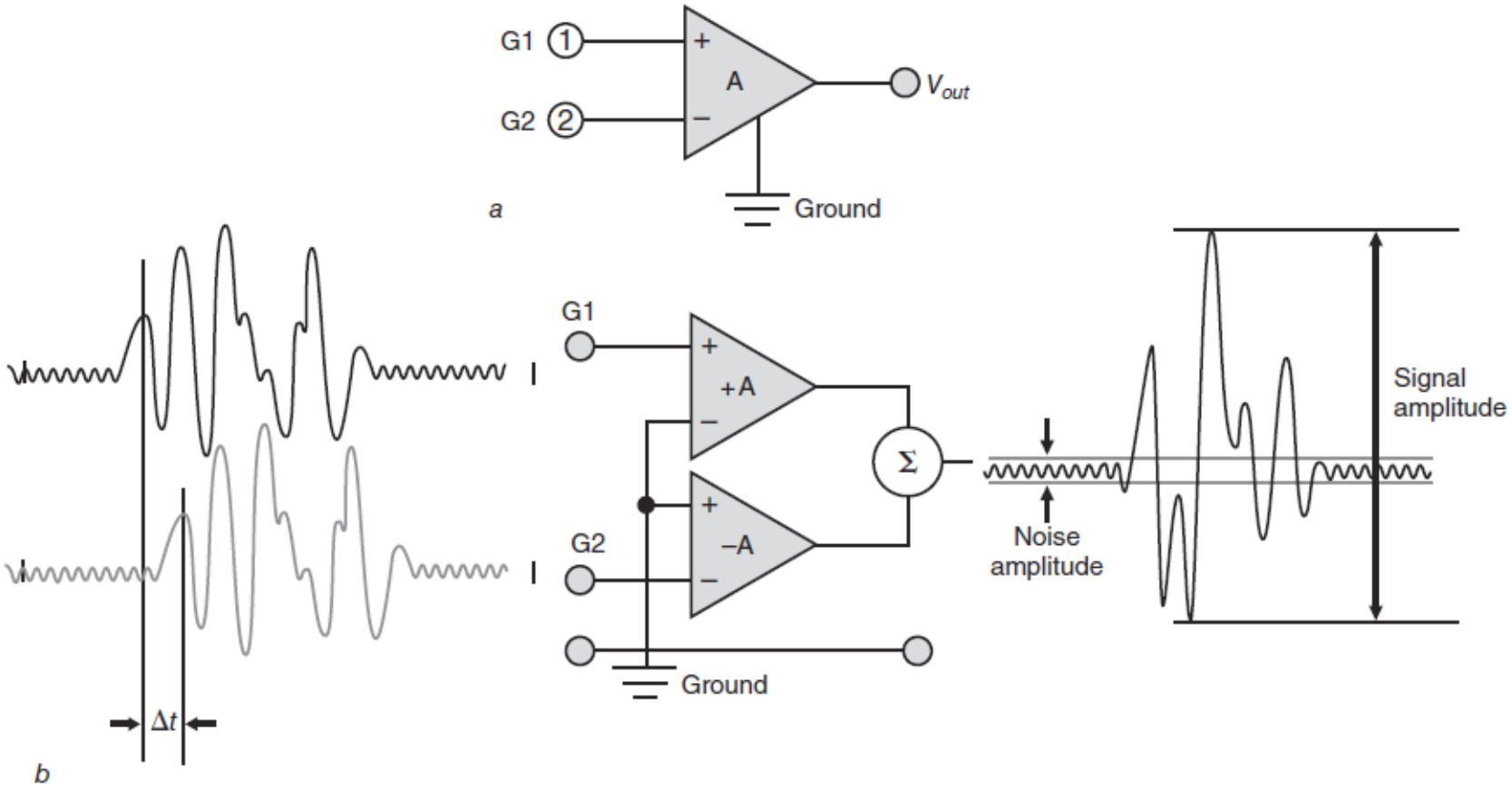
- the requirements for a good EEG amplifier are
  - low noise / high gain,
  - high input impedance (hundreds of MΩ),
  - and high (~100 dB) CMRR.

How do you choose the amplifier?

- Examples of unwanted common-mode signals could be power-line noise or noise arising from a cardiac or nerve stimulator in another part of the body.
  - A good amplifier should reject, or strongly suppress, all common-mode signals and amplify only the signals of interest.
- A measure of interest is the amplifier's **common-mode rejection ratio** (CMRR), which is the ratio between the differential gain (how much the difference between the inputs is amplified) and the common-mode gain (how much the common signal in both inputs is amplified).
  - CMRR is expressed in decibels as follows:

$$CMRR = 20\log_{10}\left(\frac{gain\ for\ difference\ signal}{gain\ for\ common\text{-}mode\ signal}\right)$$

Differential Amplifiers

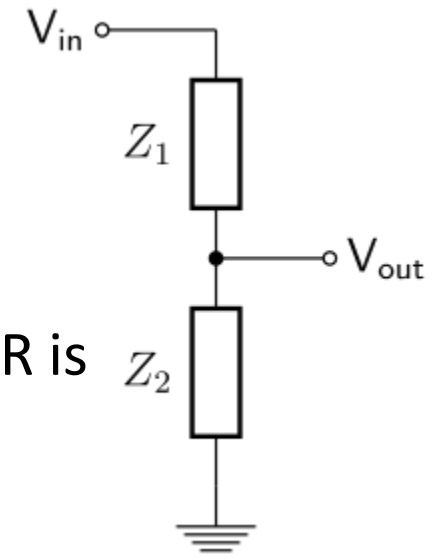


A ground electrode, also fixed to the subject, is required to feed the two halves of the differential amplifier. The ground electrode location can be freely chosen, as far as it does not introduce a high common mode signal.

Input Impedances

The first reason why you need a high impedance is that what are doing is just a simple elctronics device where we have two resistances, a potencial generator and you are measuring the partition which is produced by the resistance.

- An important feature of the amplifier is its input impedance, which should be many orders of magnitude higher than the electrode impedances so that the amplifier remains as insensitive as possible to small changes in electrode impedances.
  - Impedances should be low so that the biological potential is not dampened (voltage divider).
  - impedances should be comparable across electrodes, because CMRR is reduced by any asymmetry in the measuring circuit

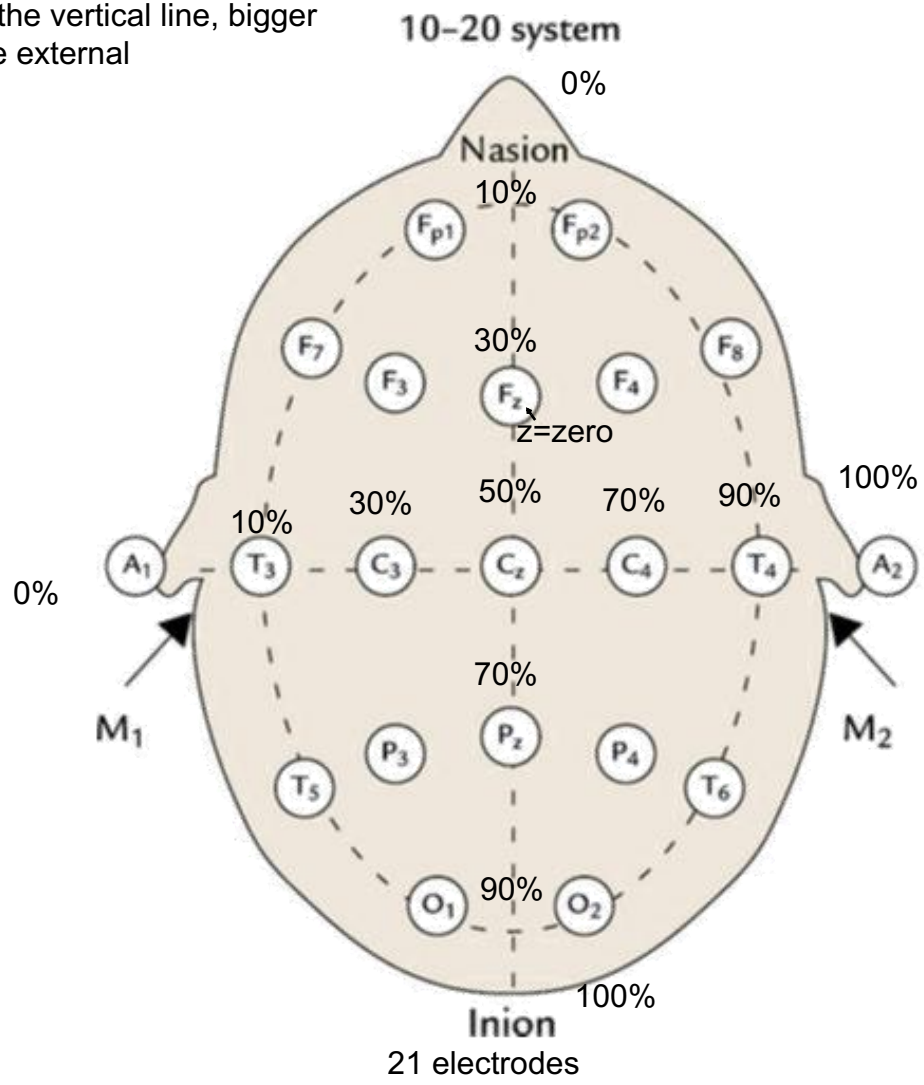


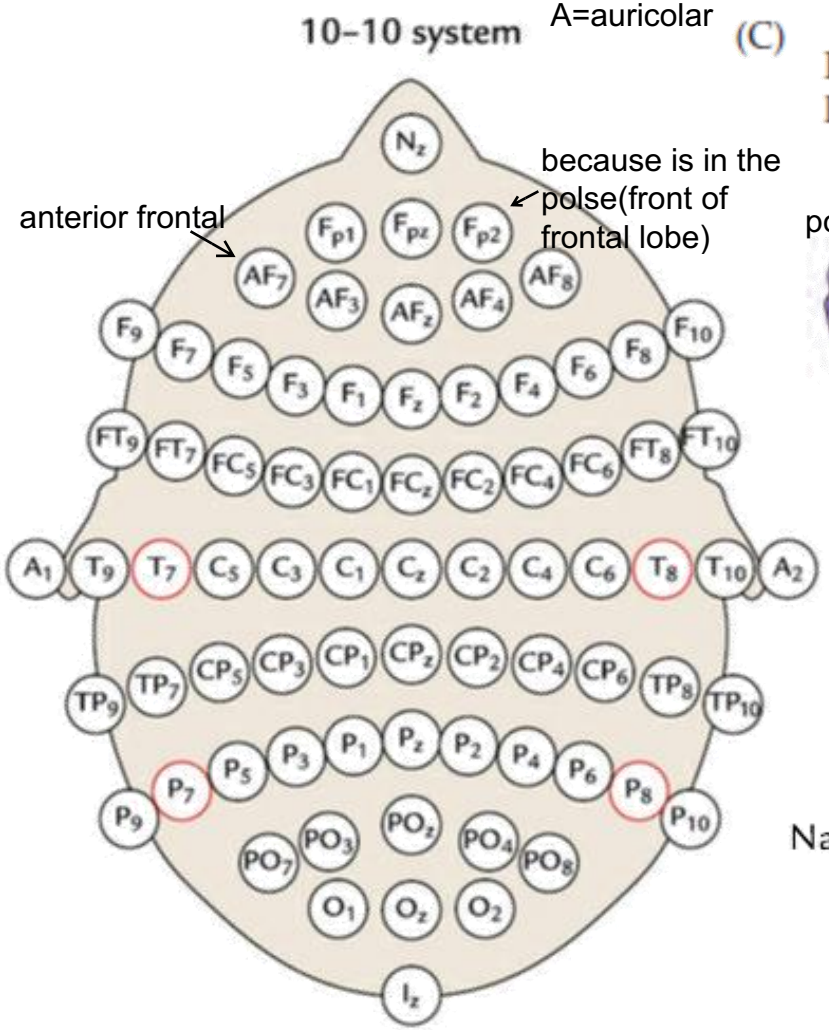
- EEG guidelines suggest to keep impedance below 5 kΩ.
- Modern amplifiers with input impedances (hundreds of MΩ) allow to relax this requirement.

Standard Electrode Positions

F=frontal
T=temporal
P=parietal
O=occipital
A=auricolar

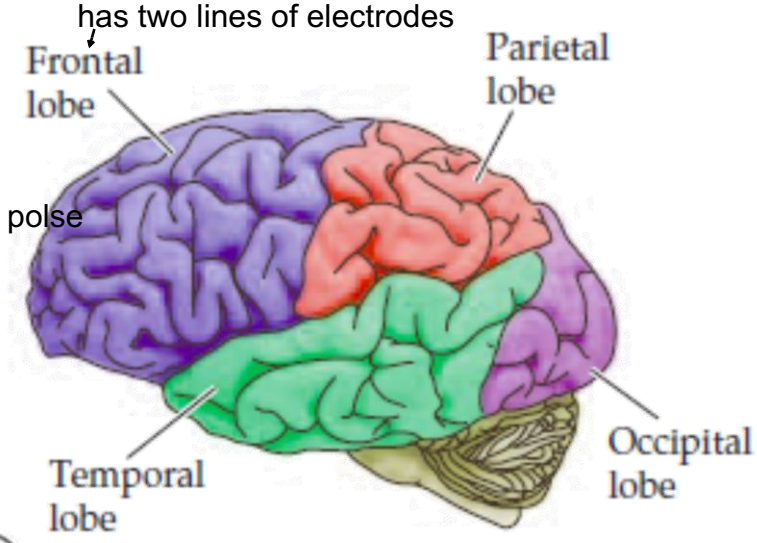
Smaller numbers are closer to the vertical line, bigger are external

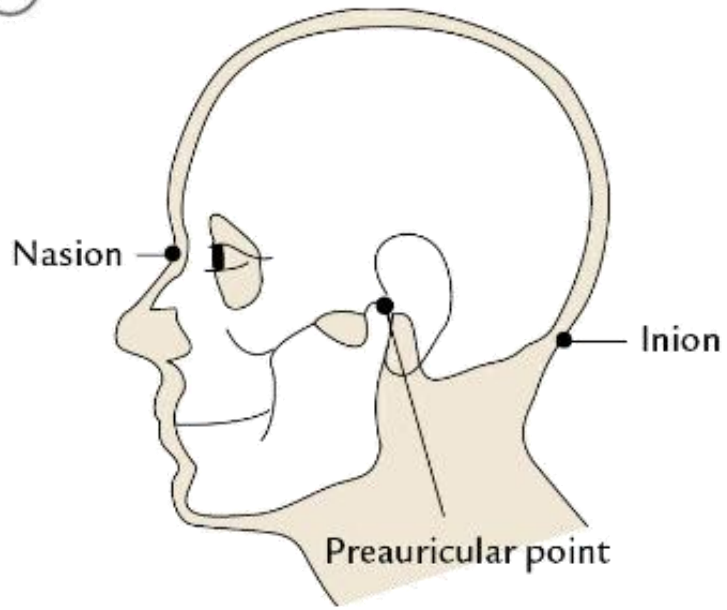




because is in the polse(front of frontal lobe)

It's the biggest lobe, in fact he has two lines of electrodes





International 10–20 system of EEG electrode placement and labeling

Effects of Reference Electrode on Potential Distribution

We acquire potential and physics data.

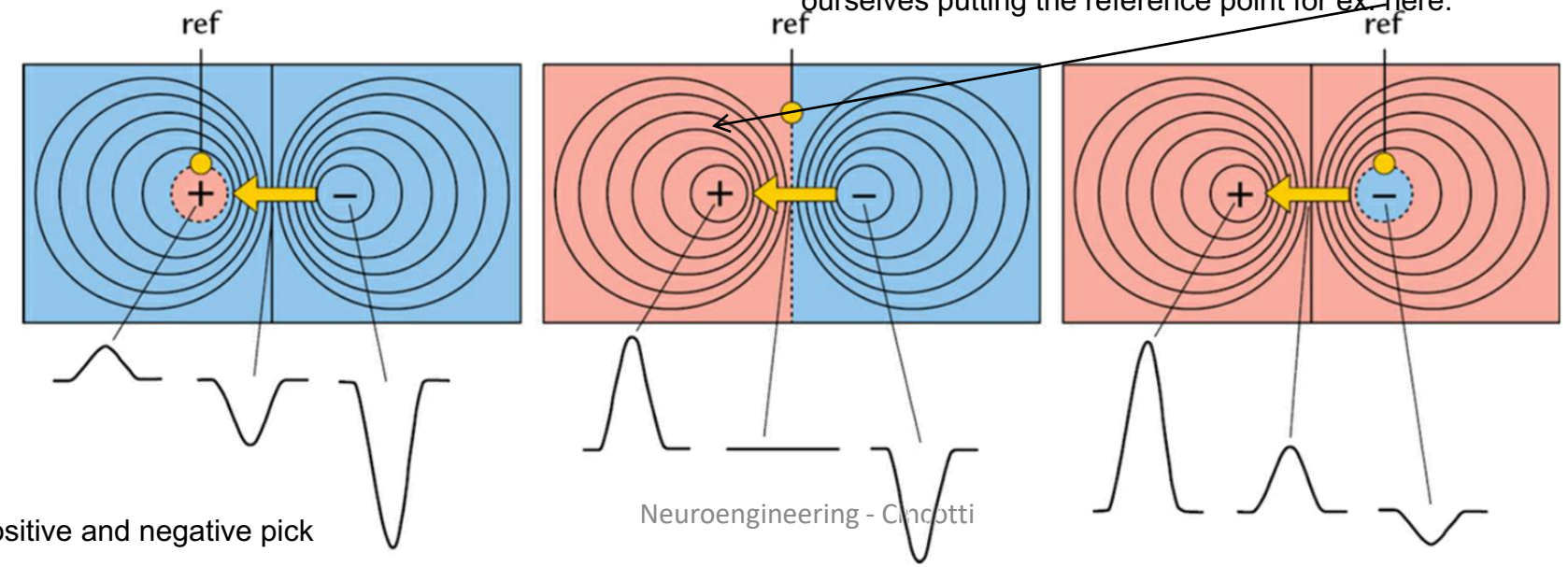
it should be totally neutral and not contribute neural activity to the measurement

- Reference electrodes are typically sited in places that are assumed to be far from the putative activity of interest, and traditionally popular places for reference electrodes have been earlobes, mastoids, and the nose.
- Notably, these electrodes are not inactive,

What changes when we change the reference? Assume you have a brain (neural) source which we module like a double, so this error is a current source which generate some positive potential and a negative potential. What you likely see on the scope is a very neural positive pick on the left. All the curves are equipotential.

- that the shape of the EEG waveforms may change depending on where the reference electrode is located, whereas the corresponding spatial scalp voltage topographies are not altered

In this case the trick is to choose the reference on the line with zero potential.If we don't know priorly where the potential is genereted and what is the orientation, we may find it ourselves putting the reference point for ex. here.

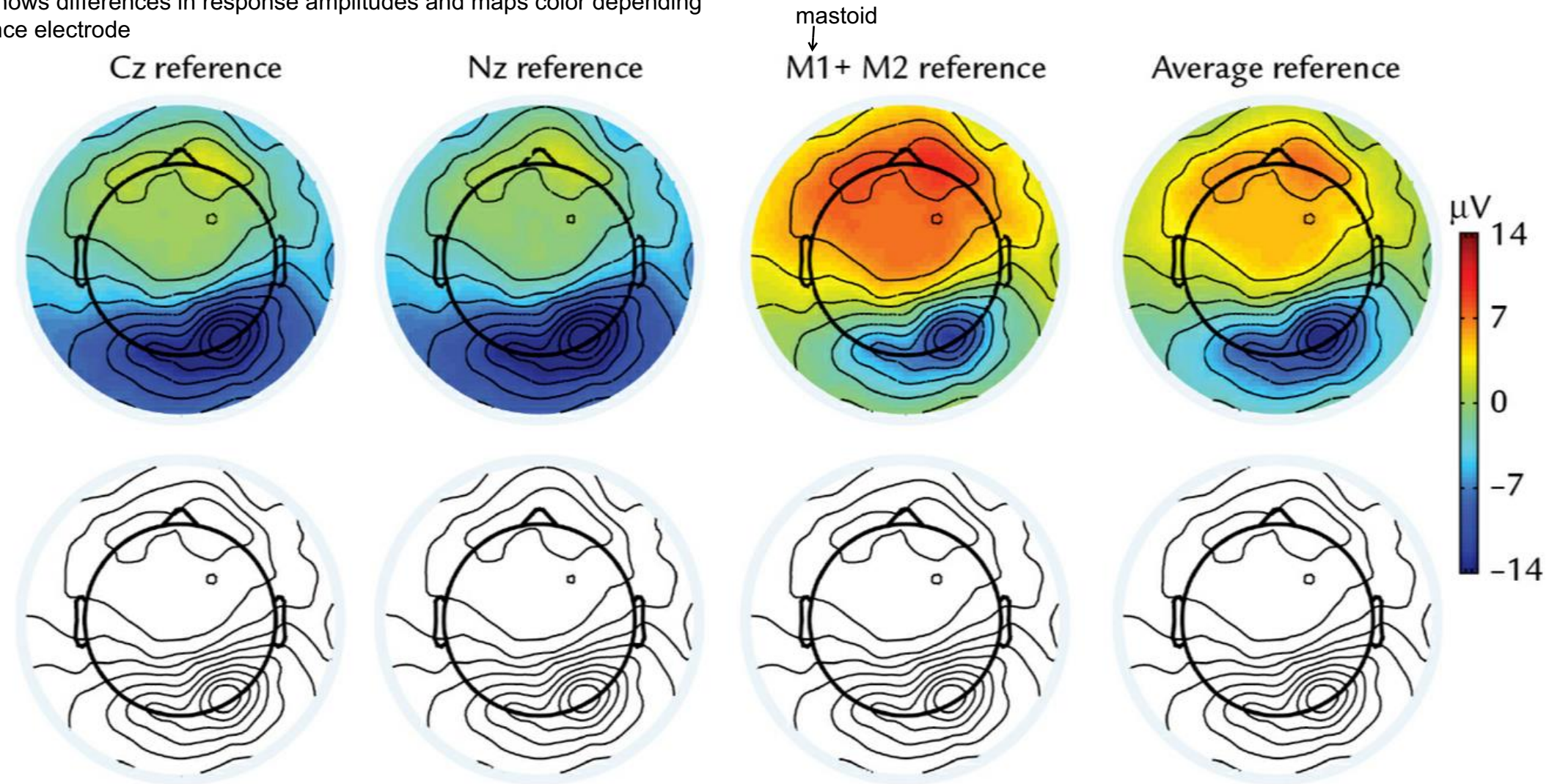


What change? for ex. we have different potential here and in the reference point.(6 and 5 microV). So the potential is 6-5=1 microV

maximum positive and negative pick

You can express the map of potential using this color scheme, using different references.

the first line shows differences in response amplitudes and maps color depending on the reference electrode



in this line there aren't color, to show that the topography remains unaltered independently of the reference electrode

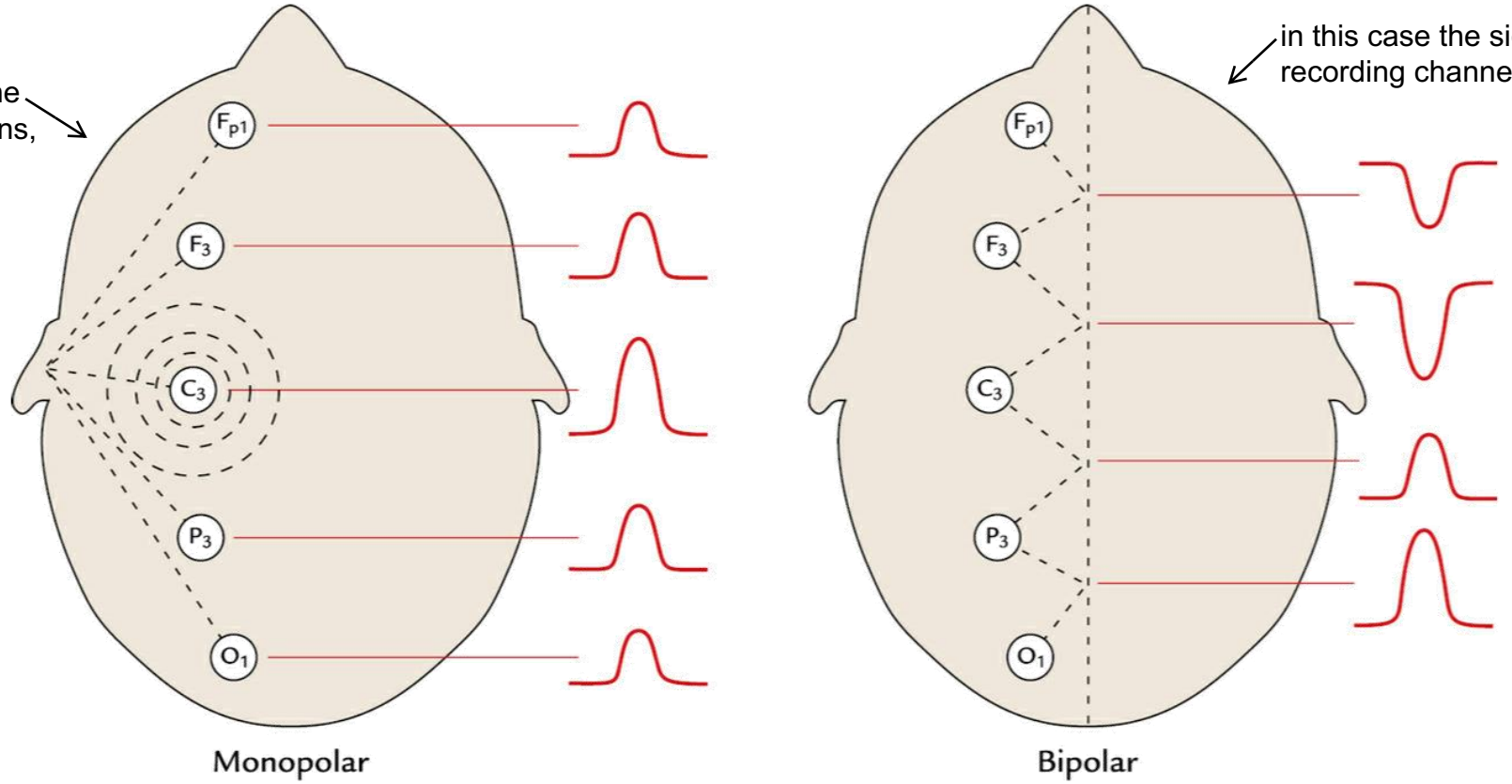
What we usually do is to take a specific electrod and refer every other electrod to this. In gergo this is called MONOPOLAR RECORDING because you compute the difference of potential always with reference to a specific electrod. While BIPOLAR RECORDING is more specific. If you take neighboring electrodes what you record is the difference between 2 neighboring electtrods.

when the single-reference electrode is used for all derivations

- In clinical bipolar recordings, potentials are measured between neighboring electrodes in different standardized pairs of configurations.

in this case the signal has the same polarity in all derivations, but it is largest at C3

in this case the signal polarity reverses in the recording channels containing electrodes



Re-Referencing Relative to an Average Reference

- The integral of the potential over the surface of a sphere that contains only concentric inhomogeneities is zero,
- The summed potentials of evenly spaced electrodes across the entire surface would be null as well
- In practice these conditions are never exactly met

In phisics if you have all sources included in a close surface, for the gauss theorem, the integral of the flat line is zero and from this you can tell that also the surface integral of the potential is zero.

There are positive and negative aspects by using this reference. If you have some artifacts which produced a strong potencial which affect the electrod, in theory if you use mastoid reference ~~or average reference~~ the influence of the artifact is no more local.