Electroencephalogram (EEG)

- EEG first recorded in 1924 by a German psychiatrist, Hans Berger.
- EEG one of the first ways of non-invasively observing human brain activity.
- The measured EEG activity is the sum of all the synchronous activity of all the neurons in the area below the electrode that they have the same approximate vertical orientation to the scalp.
- EEG detects thousands of pyramidal neurons beneath each electrode.

1 Continuous graph of changing voltage fields at scalp surface resulting from ongoing synaptic activity in underlying cortex.

Electroencephalogram (EEG)

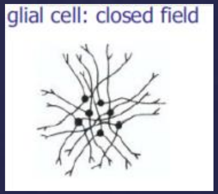
What is measured?

Electrical changes in groups of neurons.

Mostly captures the synaptic activity at the surface of the cortex.

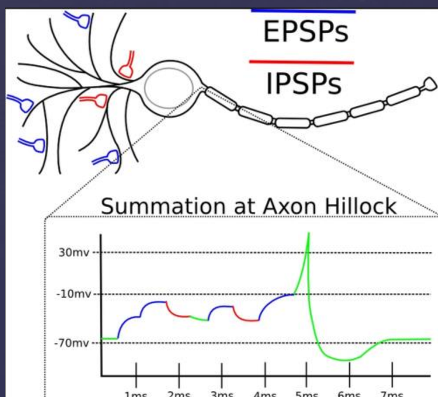
What EEG does not measure:

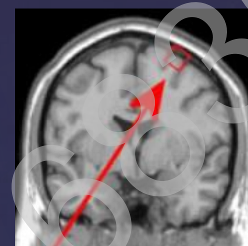
- Single neurons
- Asynchronous activity
- Glial cells
- Subcortical structures

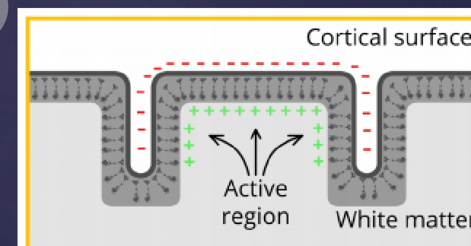


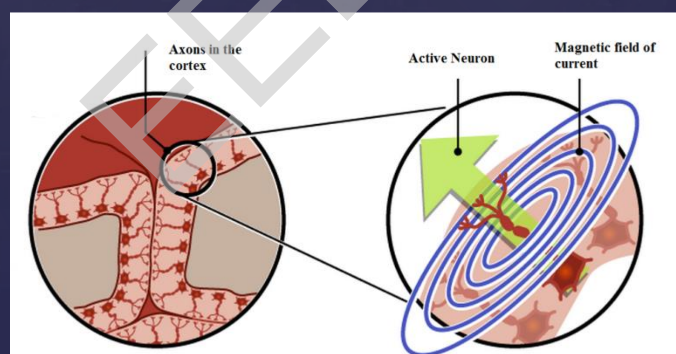
Electroencephalogram (EEG)

Scalp-recorded EEG oscillations are hypothesized to be generated by the summation of excitatory and inhibitory post-synaptic potentials in cortical pyramidal neurons.









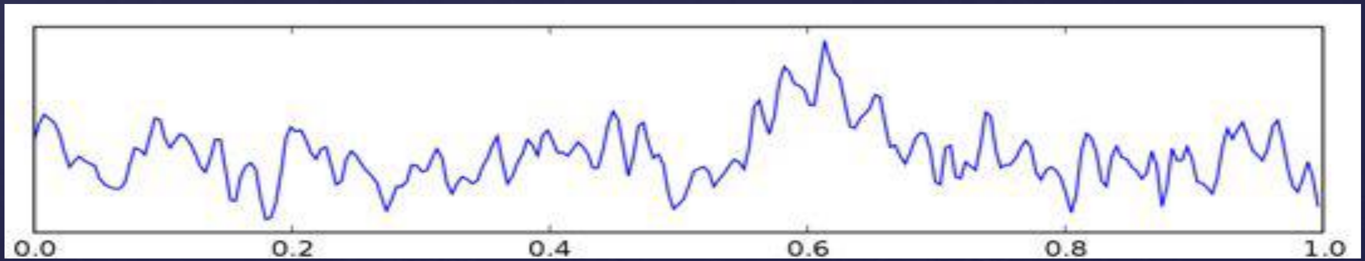
EPSP + IPSP generated by synchronous activity of neurons. Interplay between excitatory pyramidal neurons and inhibitory interneurons.

Electroencephalogram (EEG)

- **How is it measured?**
  Difference between two electrodes

- **How are these changes measured?**
  Frequency, Amplitude, Specific Wave-Types

- **What types of changes can be measured?**
  Certain neurological disorders, tasks, etc.



EEG

Functional meaning of EEG oscillations

↓

"Not Fully Understood"

The amplitude and frequency of EEG oscillations may vary between the mental states of sleep, resting, wakefulness, sensory processing or active engagement in higher order cognitive processing.

EEG ⟷ Behavior Correlation

Electroencephalogram (EEG)

EEG was initially plotted directly on paper-rolls (analog), but nowadays, EEG recordings are digitally recorded and displayed using computers, usually in a referential montage, and stored for subsequent processing and analysis.

EEG showing Epileptiform activity (Interictal Spikes) in some channels

Electroencephalogram (EEG)

The millisecond temporal resolution of EEG allows to investigate fluctuations of EEG activity (i.e., increases/decreases) as a function of task demand or subject samples:

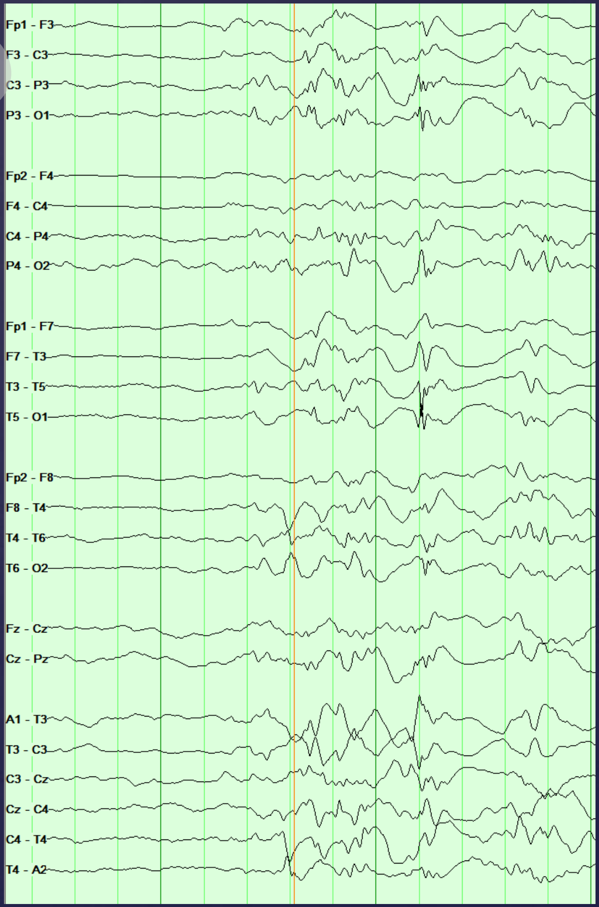
(1/TR = SR)
(1/TR=500)--- (TR=2ms)
If SR=2000Hz----TR=0.5ms

A typical adult human EEG signal is

about 10µV to 100 µV in amplitude when measured from the scalp

and

about 10–20 mV when measured from subdural electrodes.



Brain Waves: State of the Brain

- Patterns of neuronal electrical activity recorded are called **brain waves.**

- Normal brain function involves continuous electrical activity.

- Brain waves change with age, sensory stimuli, brain disease, and the chemical state of the body.

- A flat EEG (no electrical activity) is clinical evidence of death.

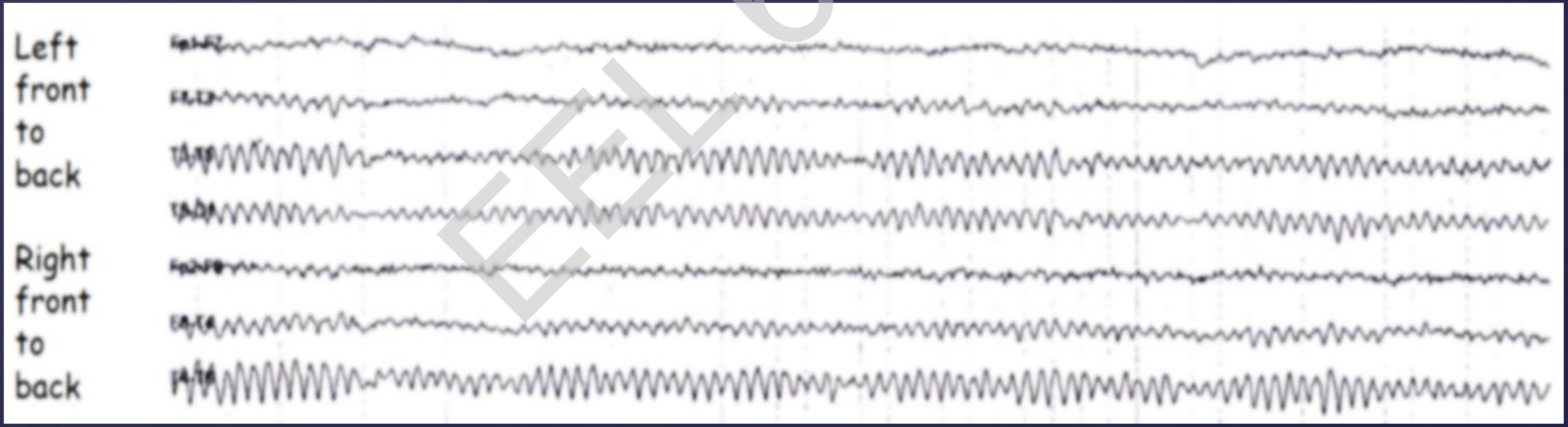
EEG

Continuous Recording (No Event)

- **Anesthesia**
- **Sleep**
- **Resting (eyes open/closed)**

Relative to an Event/Stimulation

- **Sensory**
- **motor**
- **cognitive processing**
- **Electrical/Magnetic Stimulation**

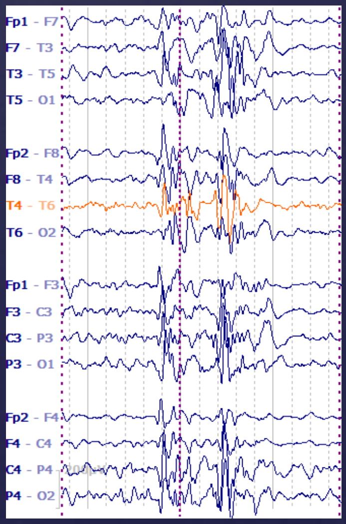


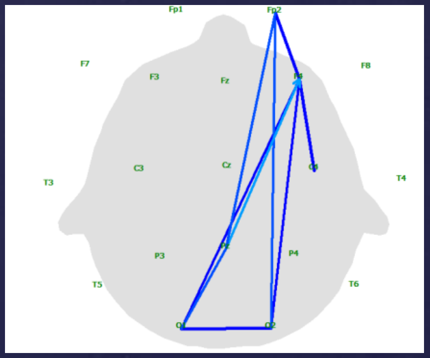
Spontaneous electrical activity with eyes closed. Alpha rhythm present in the posterior region of the brain.

EEG Proposed Function

- **Different oscillations, produced by stimulus at a given location may favor different types of direction of attentional control, or level of connectivity.**

- **Interactions between cortical oscillations within and between brain regions may mediate <u>optimal information processing.</u>**



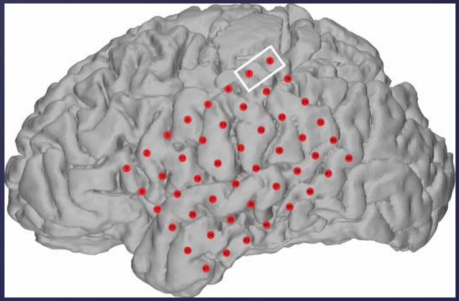


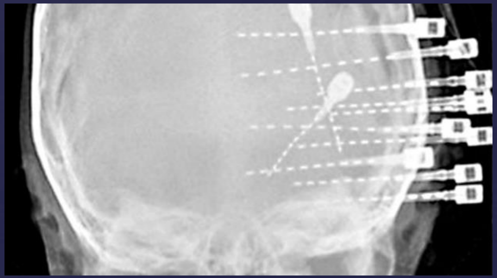
EEG

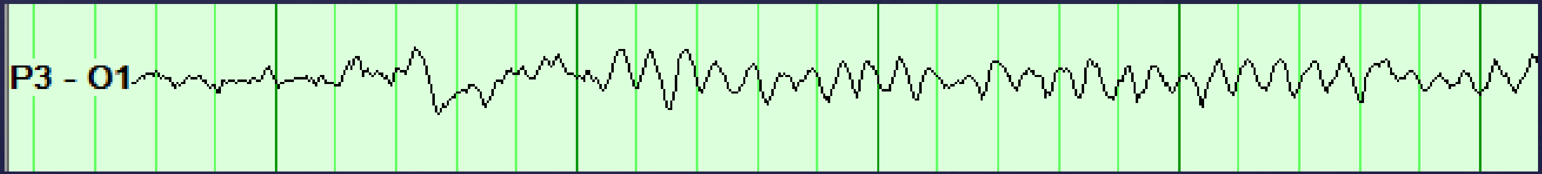
- Electroencephalography is generally defined as the neurophysiologic measurement of the electrical activity of the brain recorded from electrodes placed at sites of interest on the head.
- These EEG recordings can be obtained either at the **scalp level (external)** level or at the intracranial or subdural **(internal) level.**
- The resulting traces of brain activities are known as electroencephalograms **(EEG) and represent electrical signals from a large number of neurons**.
- **EEG remains one of the most reliable recording modality.**

External

Internal (iEEG/SEEG)



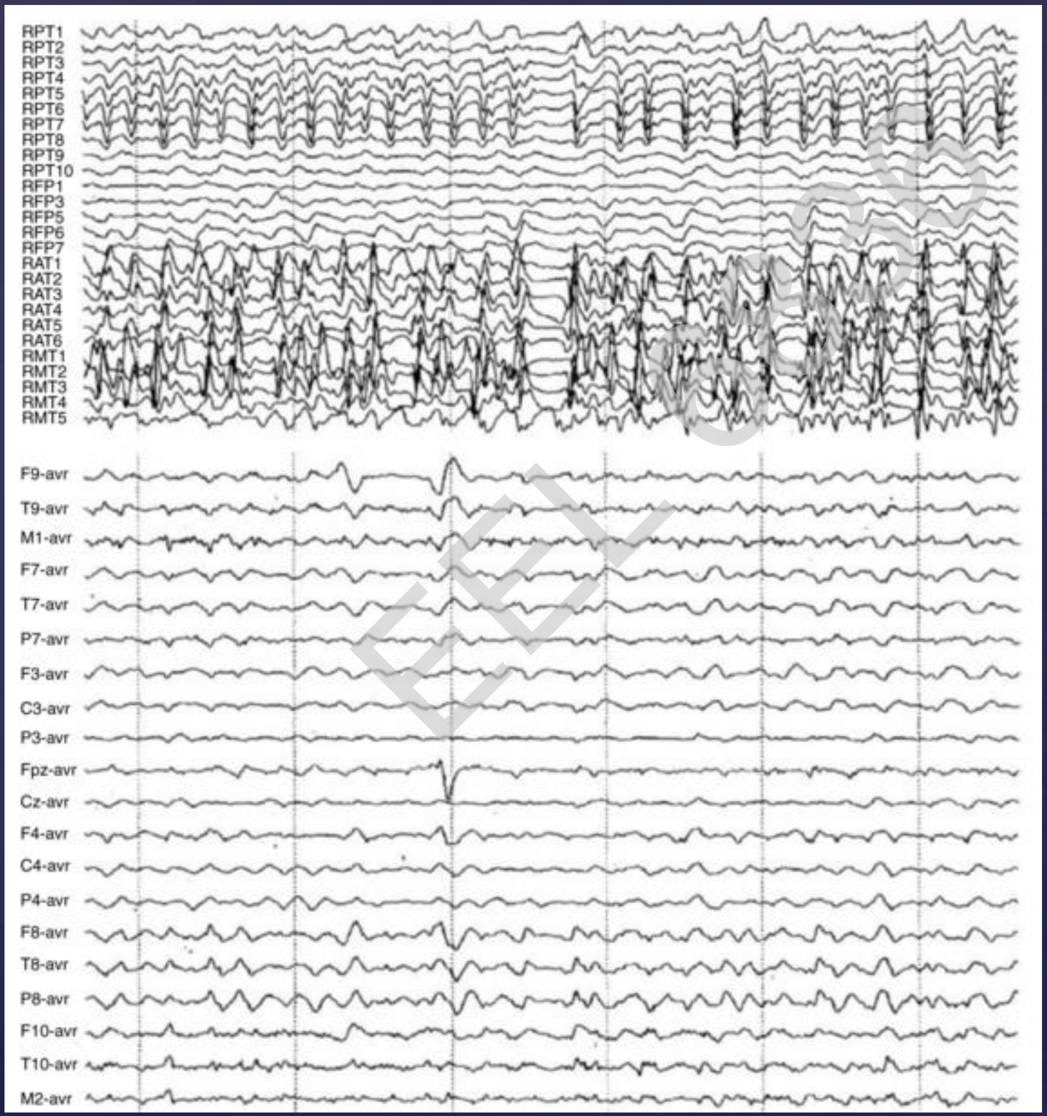




Scalp Vs. Subdural EEG

Subdural

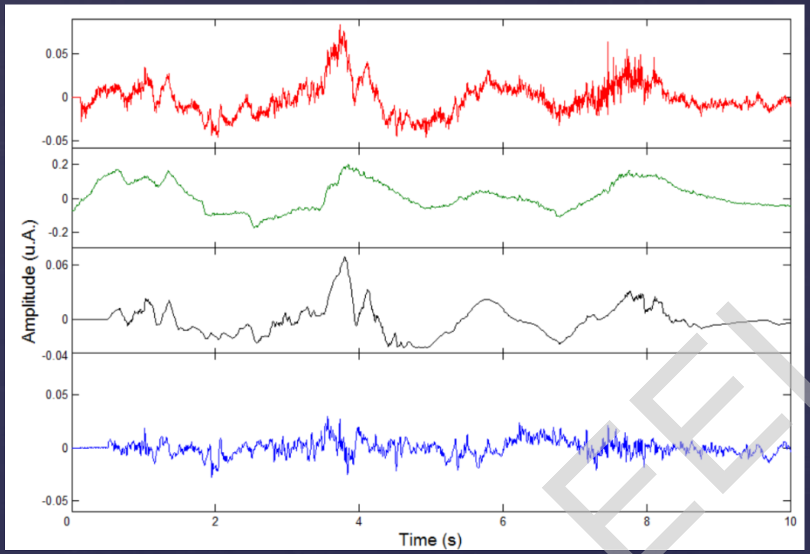
Scalp

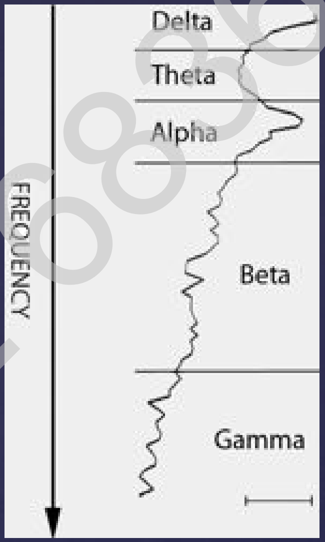


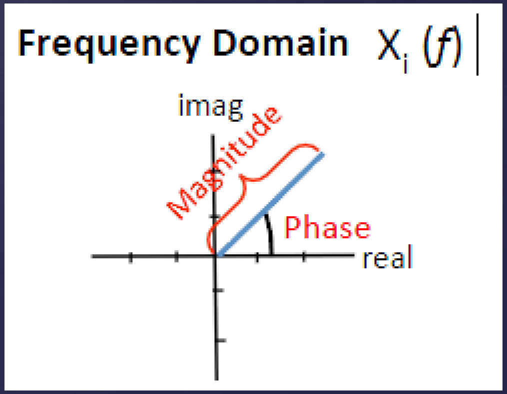
Note: The intracranial recordings appear to have a higher amplitude than the scalp one, which appears to be attenuated.

Ho to Analyze EEG?

TIME vs. FREQUENCY DOMAIN







Local Response:

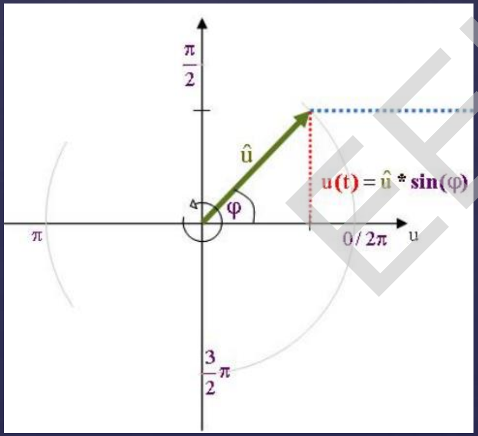
- Amplitude
- Frequency (Power)
- Phase

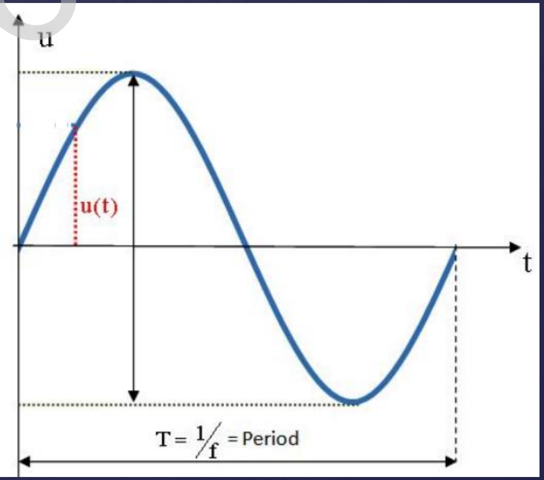
Parameters of waves

Frequency = 1/ wavelength (T) — the speed of change.

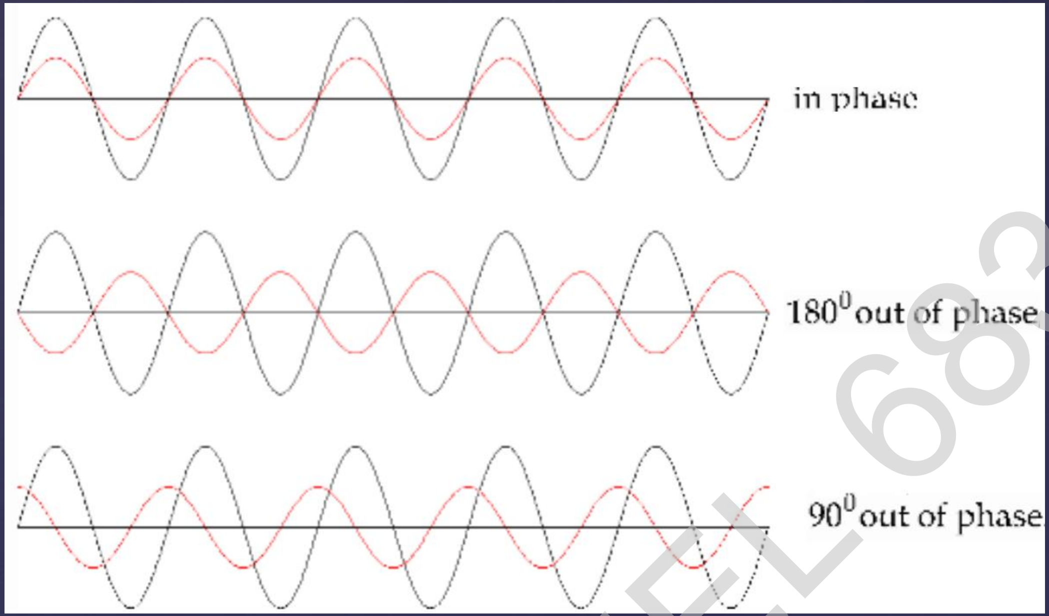
Phase: current state of the oscillation — angle on the unit circle. It runs from 0◦ (-π) — 360◦ (π)

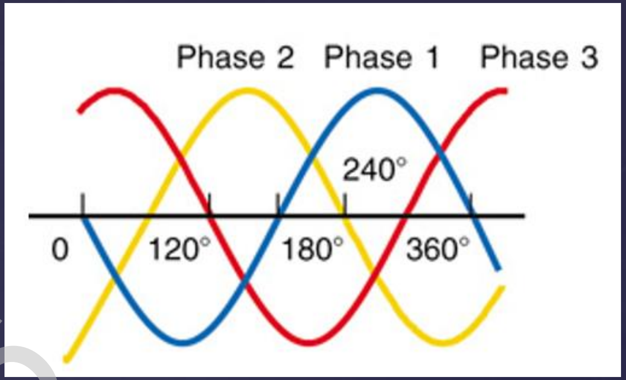
Magnitude: strength of the oscillation.

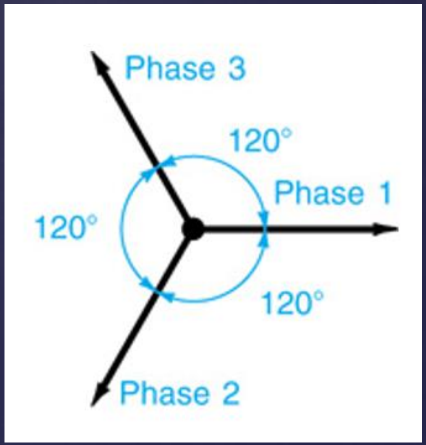




Parameters of waves





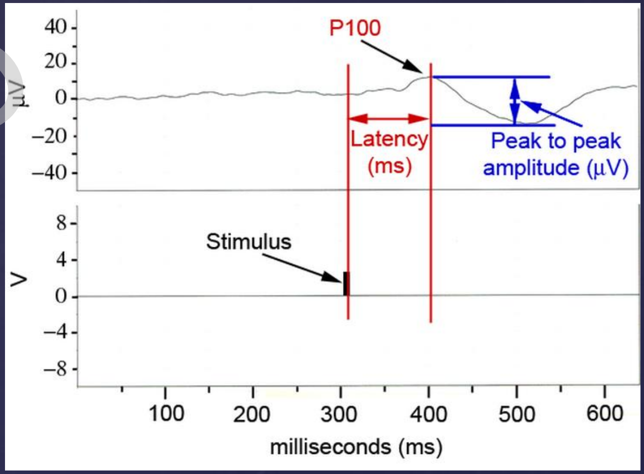


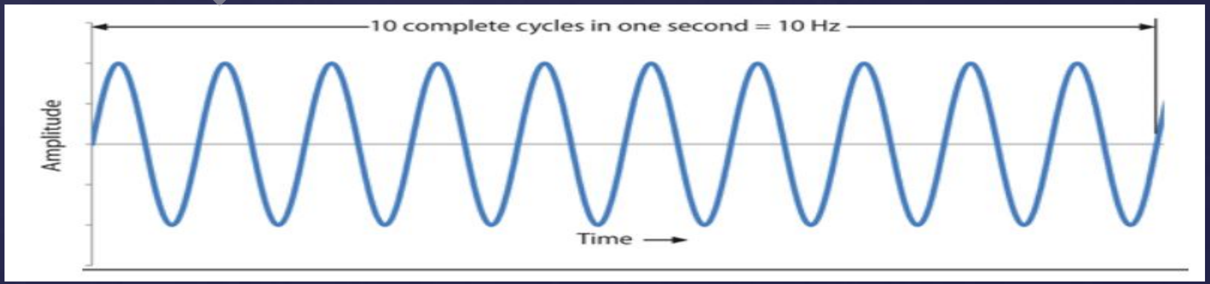
Through time-frequency analyses, we can assess changes in power and synchronization of EEG on a higher order, within or between spatial locations across trials with respect to the onset of task events.

EEG Variables

- EEG- Voltages varying as a function(time) – It is always there, in (on) your brain .

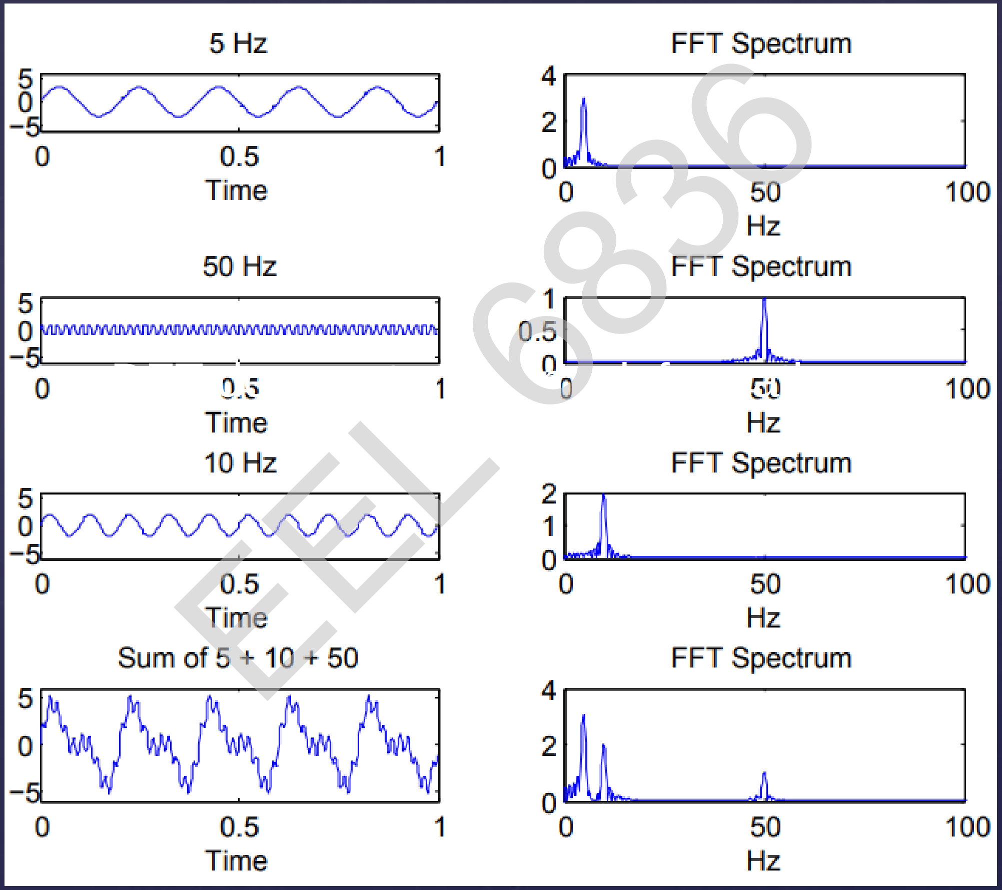
- The 2 major variables describing EEG are: (1) amplitude (height/magnitude) and (2) frequency or how many times per second the signal crosses 0 microvolts (uV) and goes from plus to minus.





How to transforms the signal from time domain into the frequency domain

Discrete Fourier Transform (DFT)

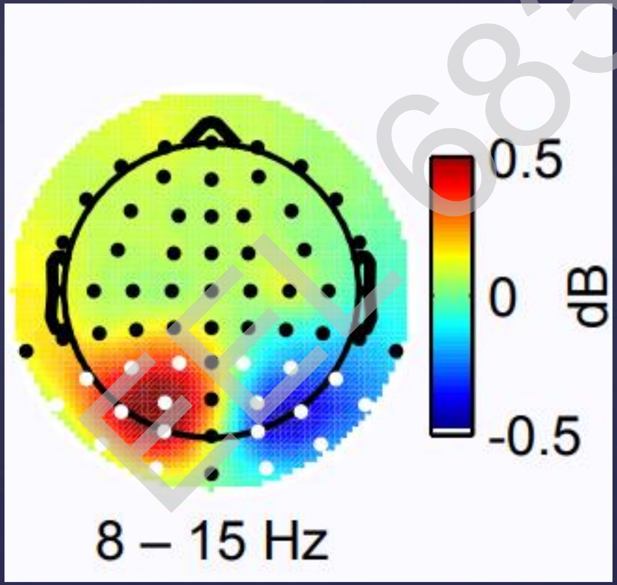


DFT does not give time information.

EEG Power

Example: Spatial attention to left or right.

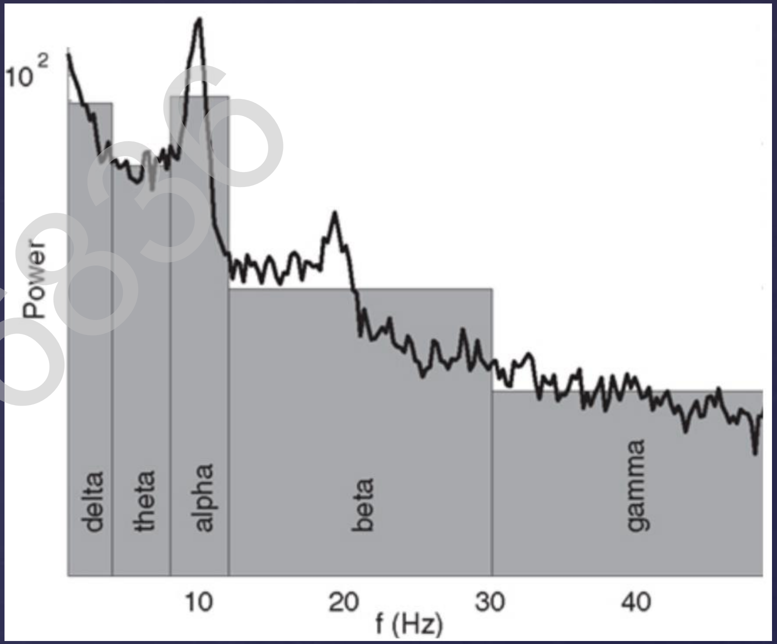
- Stronger Frequency power over ipsilateral or contra-lateral hemisphere



Reference: Busch & VanRullen (2010): Spontaneous EEG oscillations reveal periodic sampling of visual attention. PNAS.

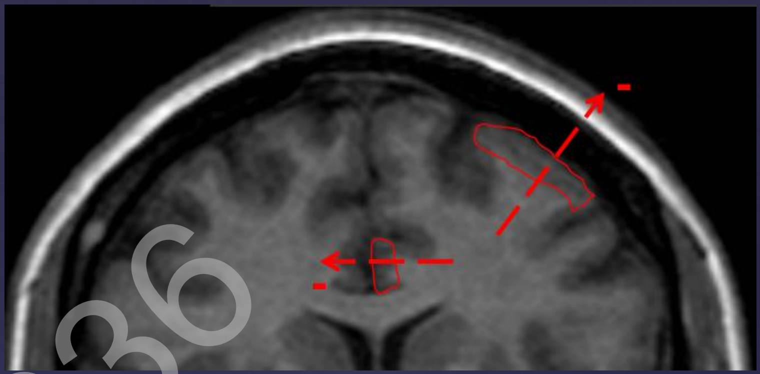
The power on each EEG band is computed as the area under the spectrum for the corresponding frequency band. The power Pb of the frequency spectrum for these bands can be computed as:

$$P_b = \int_{b_{start}}^{b_{end}} F^2(w)\,dw$$



Pb is the power on the frequency band b, b represents the specified frequency band ;and bstart and bend its starting and ending frequencies on each band.

EEG Variables



Amplitude depends on:

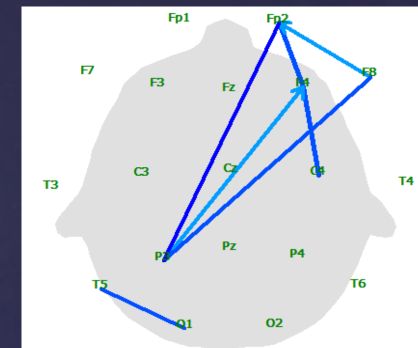
- intensity of electrical potential
- distance of potential
- spatial orientation of dipole
- resistance and capacitance of structures between source and electrodes
- Degree of synchronization – Synchronous discharge over 10 cm2 cortex surface area needed for spikes to show on scalp

Amplitude may decrease with:

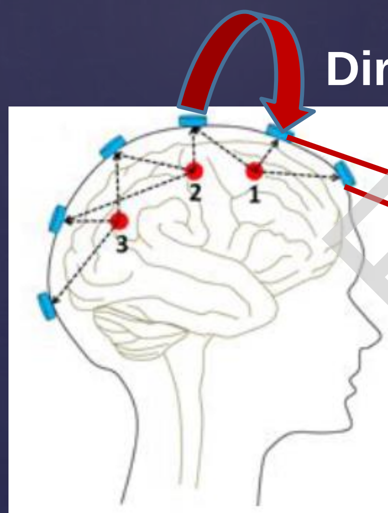
- increased impedance
- decreased impedance resulting in current shunt

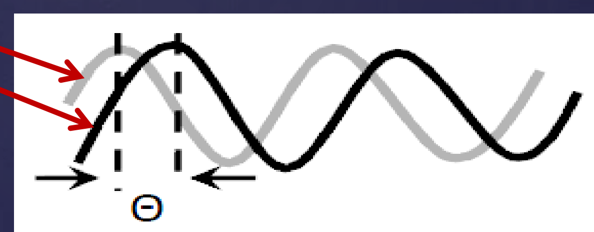
EEG Functional Connectivity

- Correlation (time)
- Coherence(frequency)
- Synchrony(phase-locking)



Directed Partial Coherence

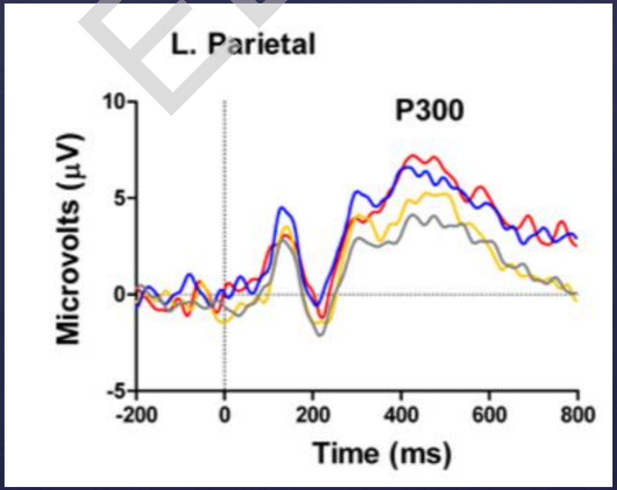




EEG Derivatives

EEG + Event:
Event-Related Potentials(ERPs):

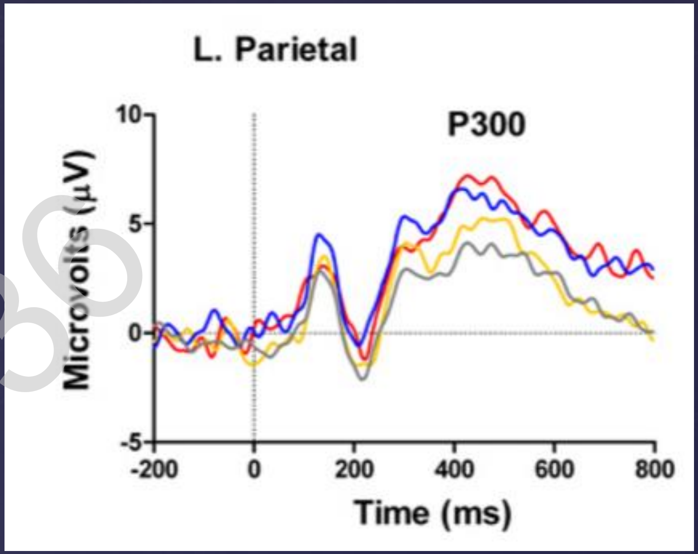
- Event-related potentials (ERPs) are very small voltages generated in the brain structures in response to specific events or stimuli.
- Event-related potentials can be elicited by a wide variety of sensory, cognitive or motor events.
- ERPs in humans can be divided into 2 categories: The early waves, within the first 100 milliseconds after stimulus, are termed 'sensory' and ERPs generated in later parts reflect the manner in which the subject evaluates the stimulus and are termed 'cognitive' ERPs as they examine information processing.



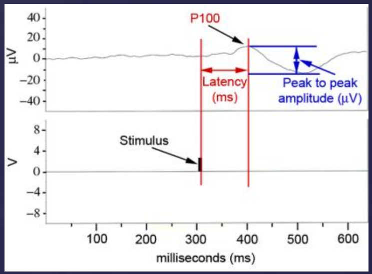
Event-Related Potentials

From EEG to ERP…

- Time-locked average of EEG from many trials involving the same 'event'



- **EEG =20 - 50µv / ERP=1-10 µv**

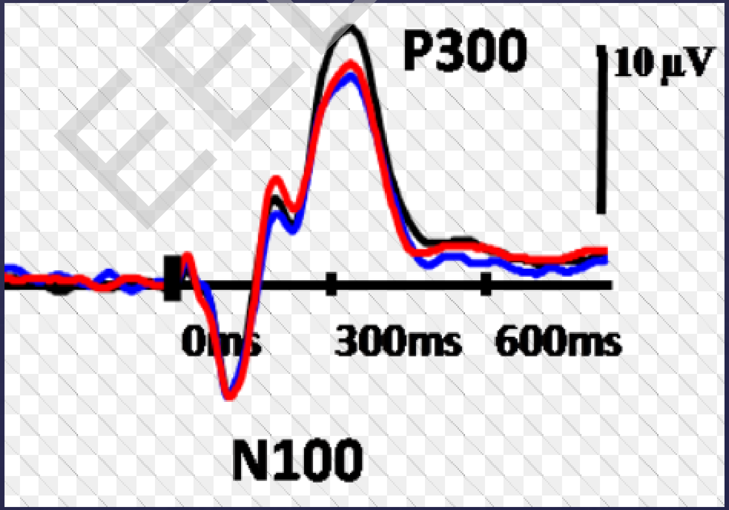


The waveforms are described according to latency (speed of stimulus) and amplitude (greater or less attention).

EEG Derivatives

- Subtle changes in cognitive or emotional states have very subtle EEG effects, which you just can't eyeball.

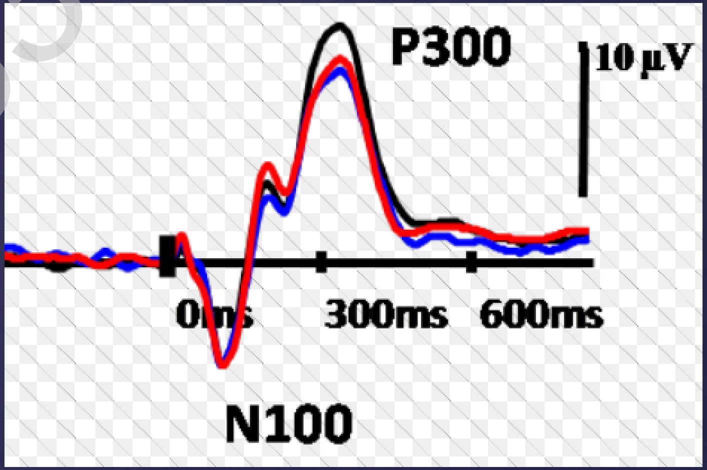
- You can average ERPs because the stimulus generates a series of synaptic events always time-locked and phase locked to the evoking event. But it's impossible to predict what the spontaneous EEG is doing when stimulus is presented.

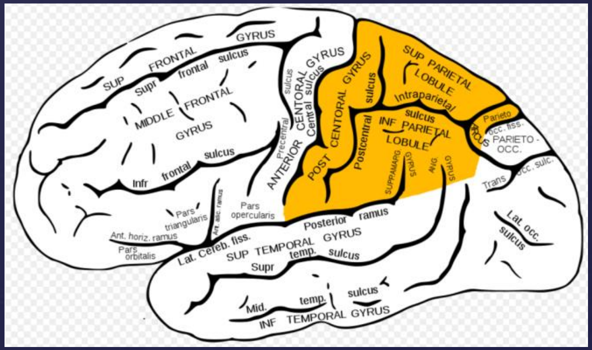


EEG Derivatives

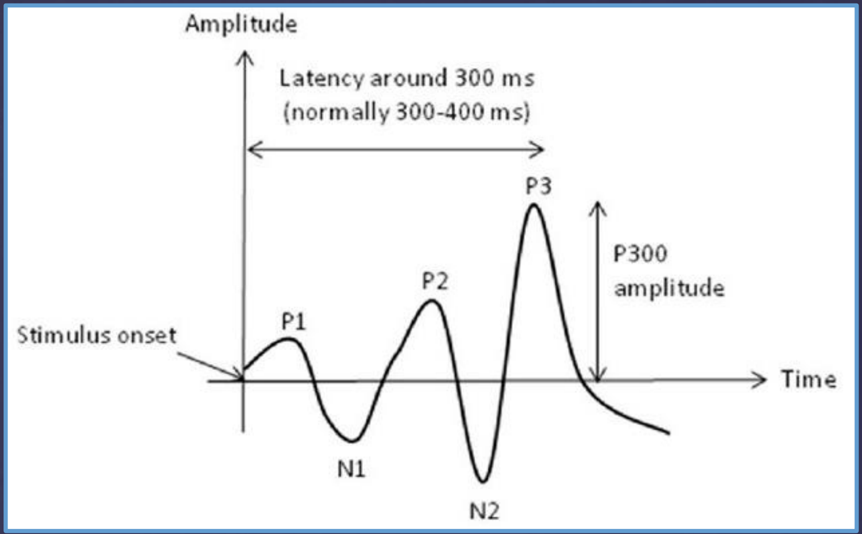
P300 wave is the major component of research in the field of ERP. For auditory stimuli, the latency range is 250-400 msec for most adult subjects between 20 and 70 years of age. Reduced P300 amplitude is an indicator of some disorders (alcohol dependence, drug dependence, nicotine dependence, conduct disorder and adult antisocial behavior).

- The signal is typically measured most strongly by the electrodes covering the parietal lobe.
- Magnitude and timing of this signal are often used as metrics of cognitive function in decision making processes.





EEG Derivatives

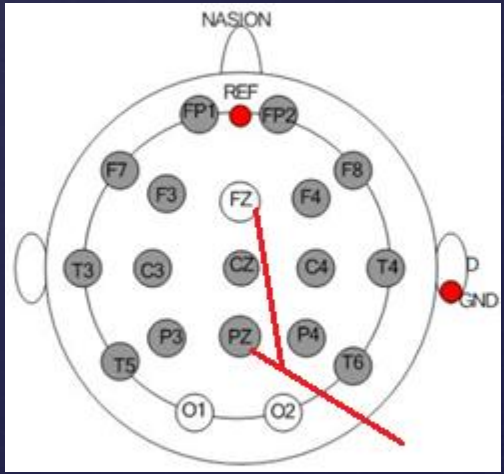


Long Latency Auditory Potentials or Cognitive Potentials are bioelectric responses of the cortex activity.

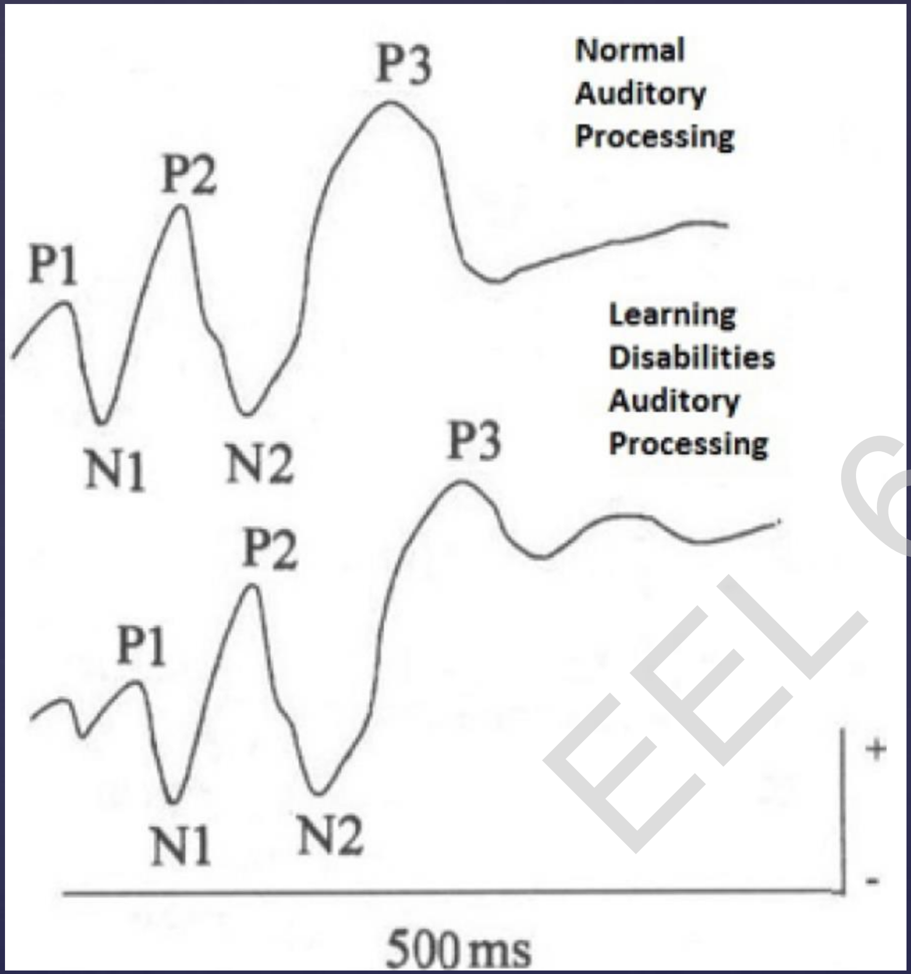
These responses correspond to a series of peaks with negative (N) and positive (P) polarities generated along the auditory pathway, by one or more events.

- The scalp distribution of P300 (or any ERP) may represent a cognitive phenomena.

- P300 is usually largest over Pz and smallest over Fz.



EEG Derivatives



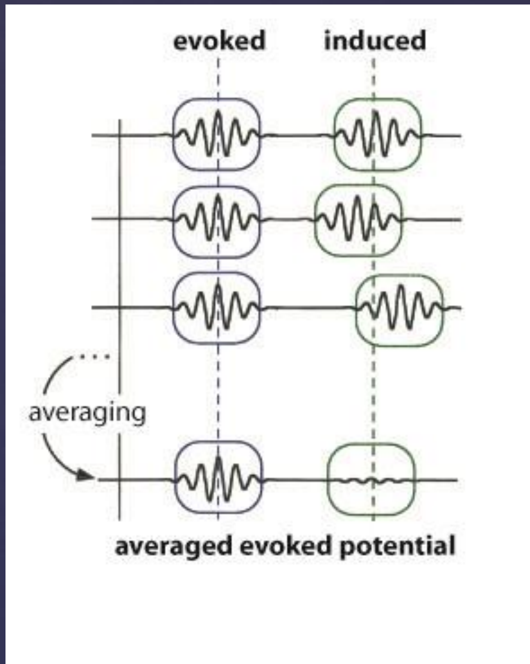
Advantage of ERPs analysis:

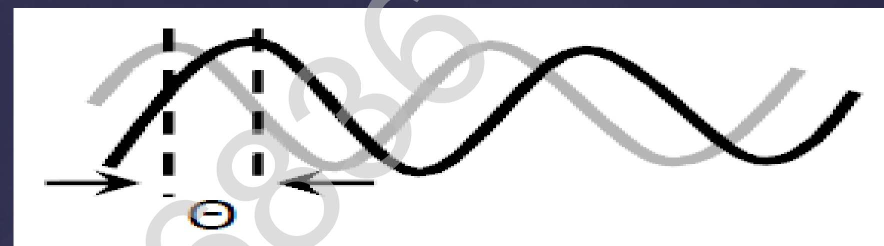
This research may provide the opportunity for a thorough treatment planning.

Example: an auditory-linguistic training and improvement of auditory skills, necessary for the acquisition of reading and writing.

Reference: Front. Psychol., 10 June 2015, **Auditory evoked potential: a proposal for further evaluation in children with learning disabilities,** Ana Frizzo.

EEG Derivatives





Note: Since out-of-phase signals will average to a straight line. That's why we need to see Event Related Spectral Perturbations (ERSPs).

Many <u>new neural signs of cognitive and emotional</u> events have been reported with the advent of these new methods.

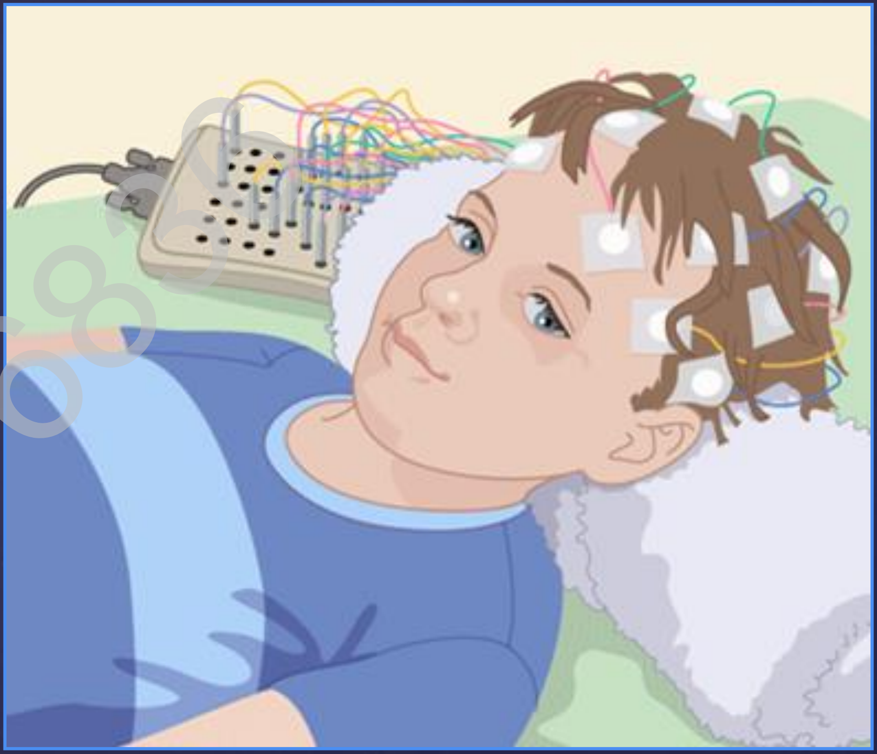
Strengths and Advantages of EEG Signals

- Is a measure of brain function; supplement neuroimaging studies.
- Provides direct rather than indirect evidence of epileptic abnormality.
- May be the only test that shows abnormalities in epileptic patients.
- Can be combined with fMRI, PET or TMS.

- Provides some spatial or localization information.
- More tolerant to subject movement than fMRI.
- Low cost.
- Readily repeatable.
- Portable / ambulatory.

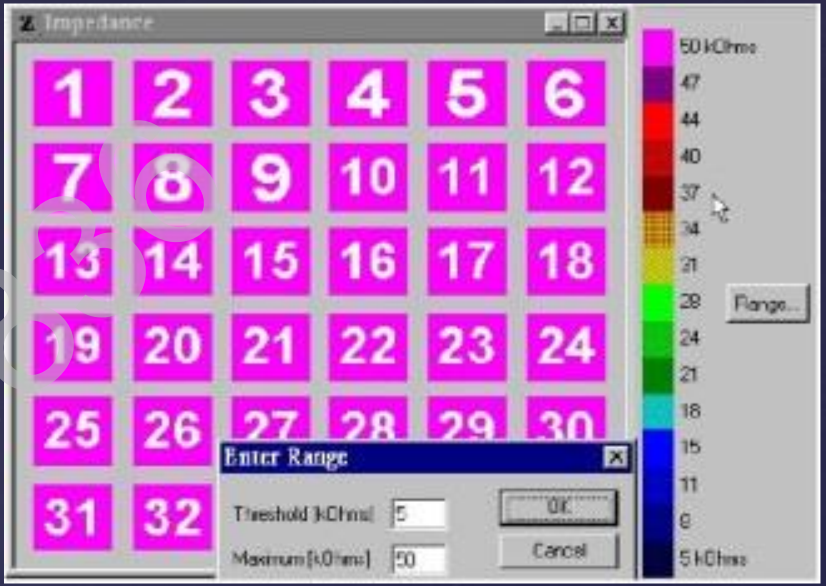
EEG Recording Techniques

- EEG is recorded from electrodes placed on key locations on the scalp.
- Electrodes consist of a conductor connected by a lead wire and plug to the input of the recording machine.
- The instrument picks up electrical impulses in the brain and records them.
- Scalp electrodes are applied with a conductive gel or paste after determining the precise location and after preparing the scalp to reduce electrical impedance.



Impedance from NeuroScan

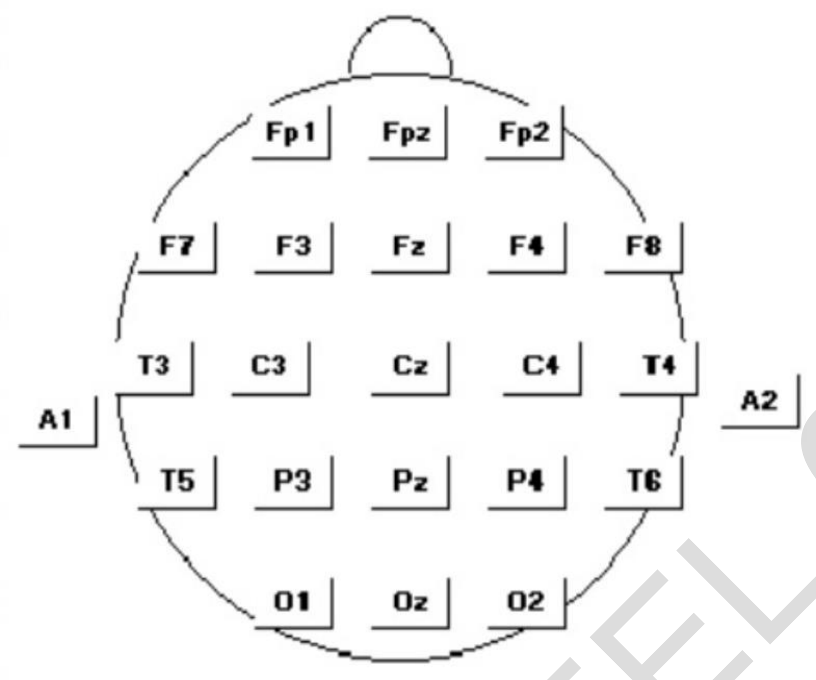
- The gel or paste helps to reduce the impedance between the scalp and the electrode.
- The impedance of each electrode should be measured routinely before every EEG recording and should be between 5-15kΩ.
- Both very high and very low impedances are undesirable.

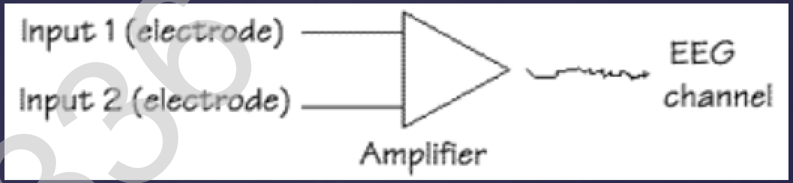


Note:

- very low impedance acts like a shunt between the recording electrodes and short-circuits the EEG potential differences.
- very high impedance is unwanted because it can attenuate the recordings leading to the so-called 60 Hz interference.
- $Z = \frac{V}{I}$ in AC current: opposition that a circuit presents to electric current.

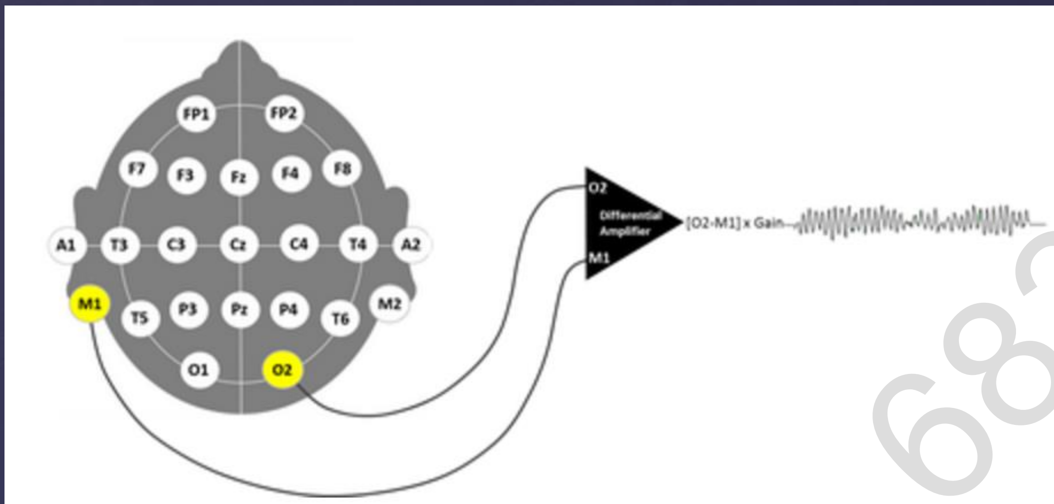
EEG Montage





- Pattern of connections between the electrodes and the recording channels is known as a montage.
- EEG montages vary according to the monitored procedure and the number of recording channels available.
- EEG montages are designed to be symmetrical about the midline in order to obtain information of the left and right hemisphere relating to amplitude and difference of the phases.

Montage Construction



•All biological recordings use differential amplifiers.

•These amplifiers eliminate any electrical noise detected by both inputs (electrodes).

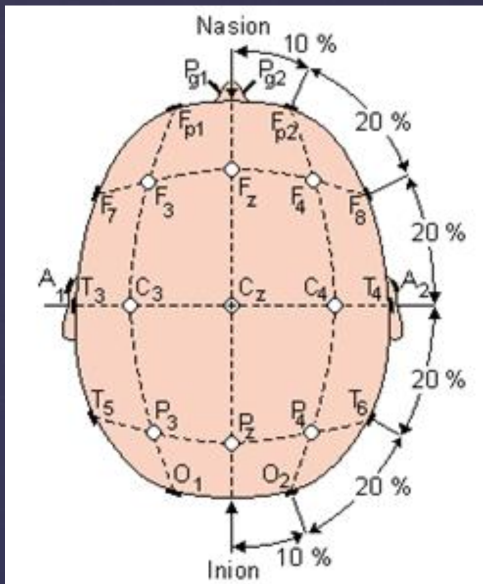
•By convention, a differential amplifier subtracts the voltage in input 1 from that in input 2 at any single point in time.

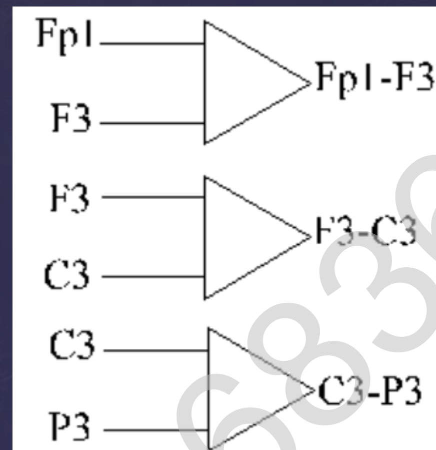
•EEG amplified signal =(input 1 voltage) – (input 2 voltage), therefore if input 1 (positive) < input 2 (positive), then the amplified signal would be negative.

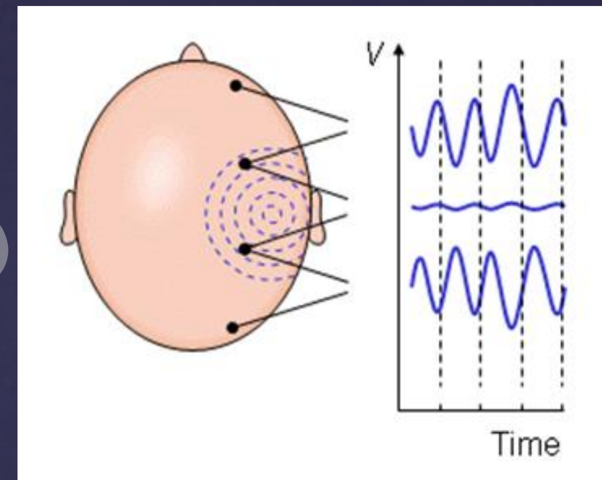
•Polarity is relative to the input 2 selected.

Amplifier input 1 = O2
Amplifier input 2 = M1
Amplifier output = (O2 - M1)* Gain

Bipolar montage





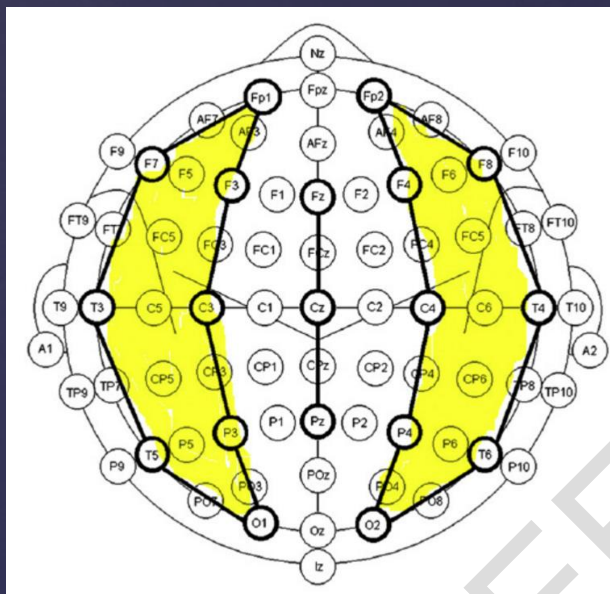


Each channel represents the <u>difference between two adjacent electrodes</u>.

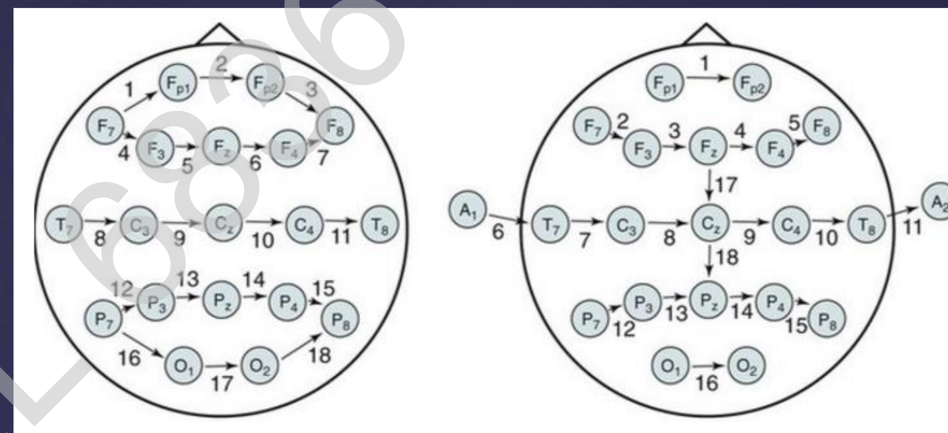
For example: channel "<u>Fp1-F3</u>" represents the difference in voltage between the Fp1 electrode and the F3 electrode. "<u>F3-C3</u>," represents the voltage difference between F3 and C3, and so on through the entire array of electrodes.

Bipolar montage

Longitudinal anterior-posterior
bipolar montage



Transverse Left to Right

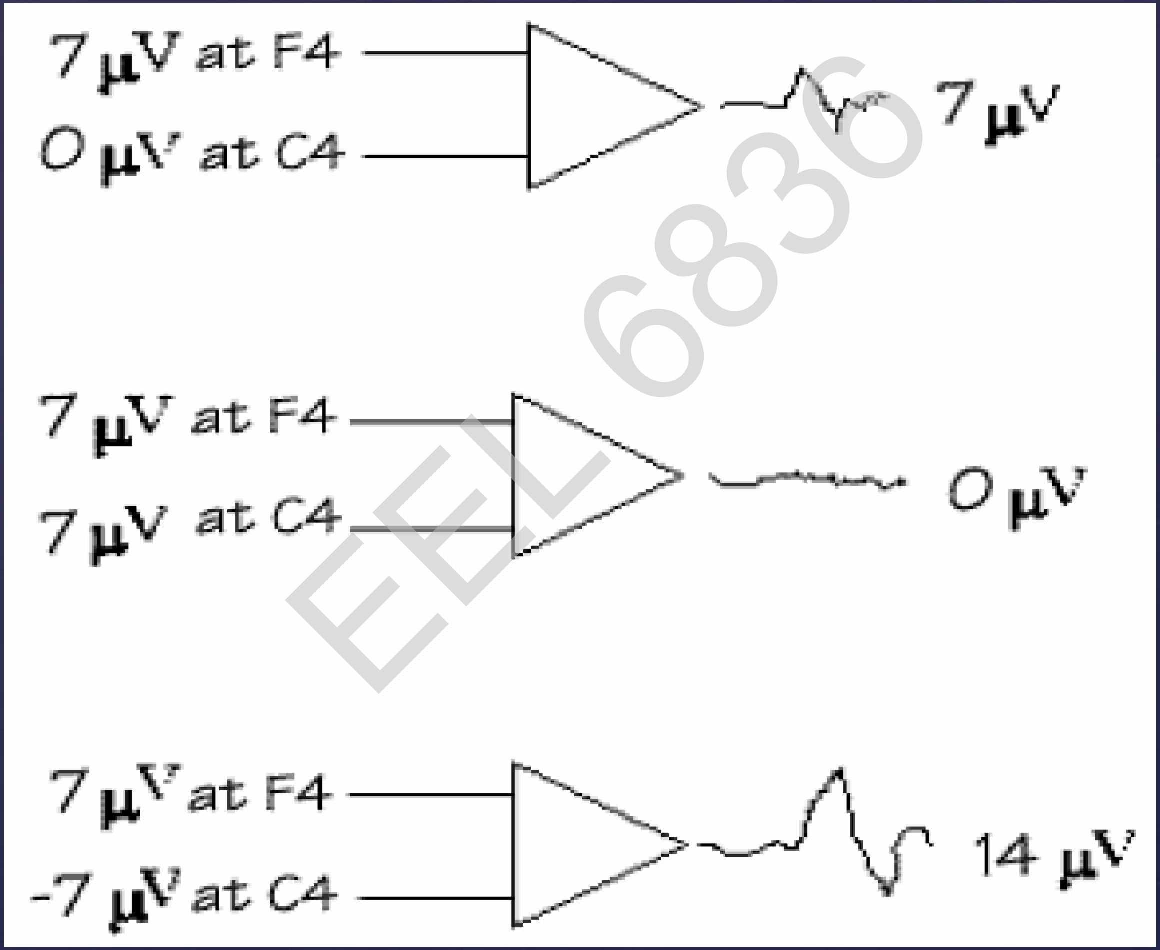


2 Types of Bipolar:

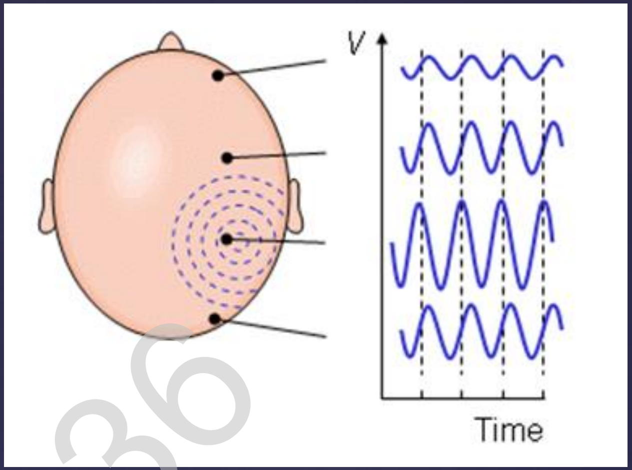
Bipolar anterior to posterior (Double Banana) or transverse

Bipolar montage

Potential Between 2 active electrodes



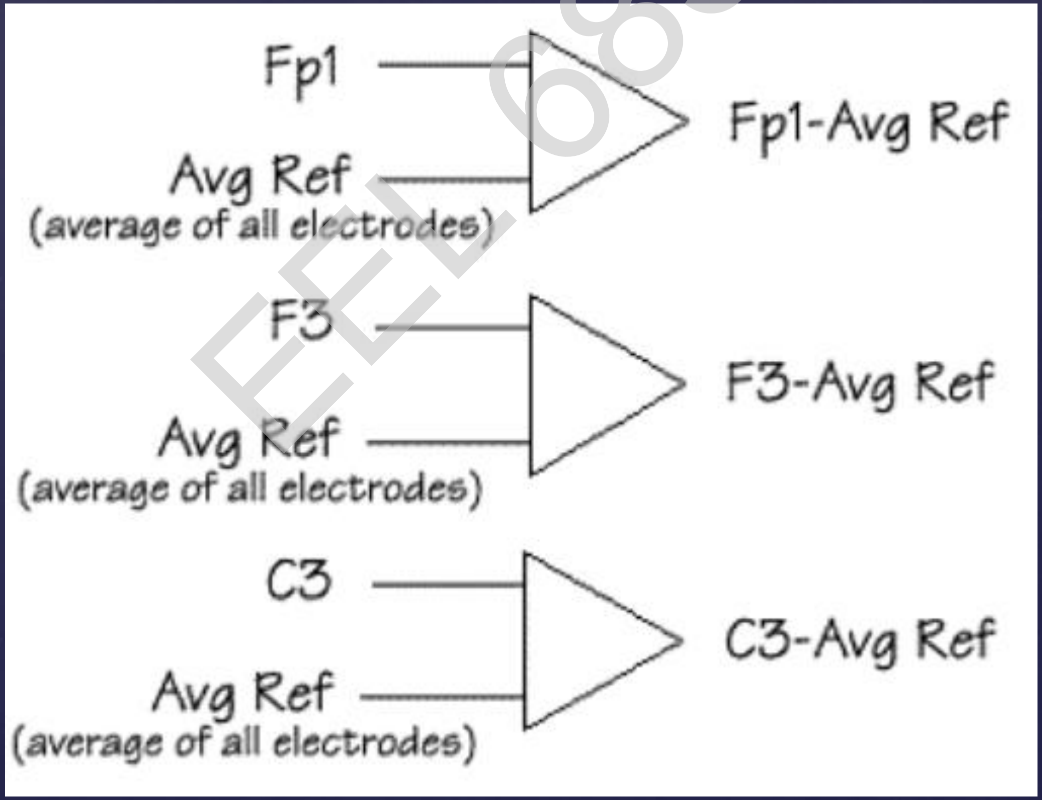
Referential montage



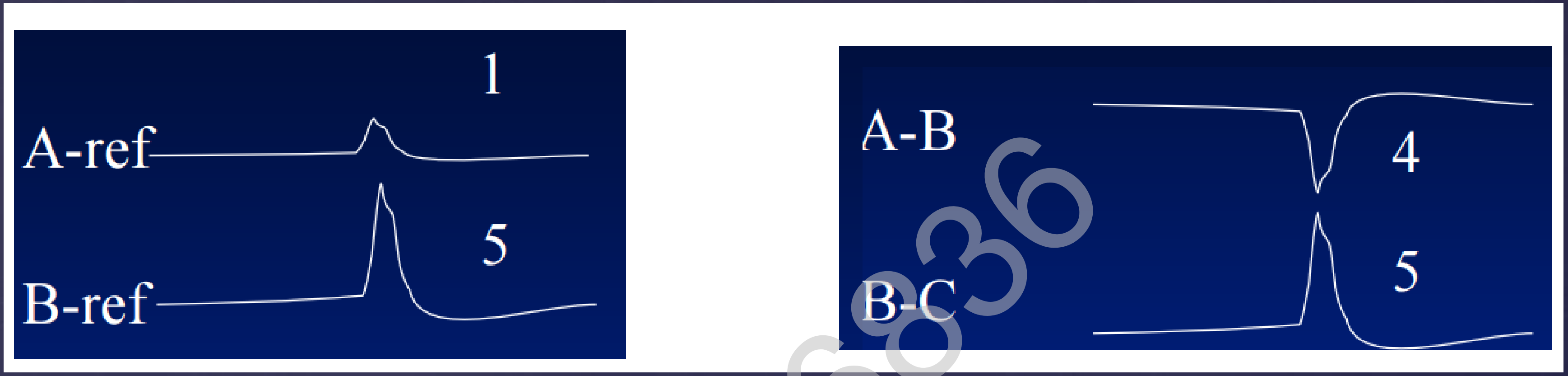
- Each channel represents the difference between a certain electrode and a designated reference electrode.
- There is no standard position at which this reference is always placed; it is, however, at a different position than the "recording" electrodes. Midline positions are often used because they do not amplify the signal in one hemisphere vs. the other.
- This referential recording can give an undistorted display of the shape of the potential changes. It is useful for recording a signal with a wide distribution of potentials.
- Disadvantage could be that it is usually impossible to find a reference electrode that is completely inactive.

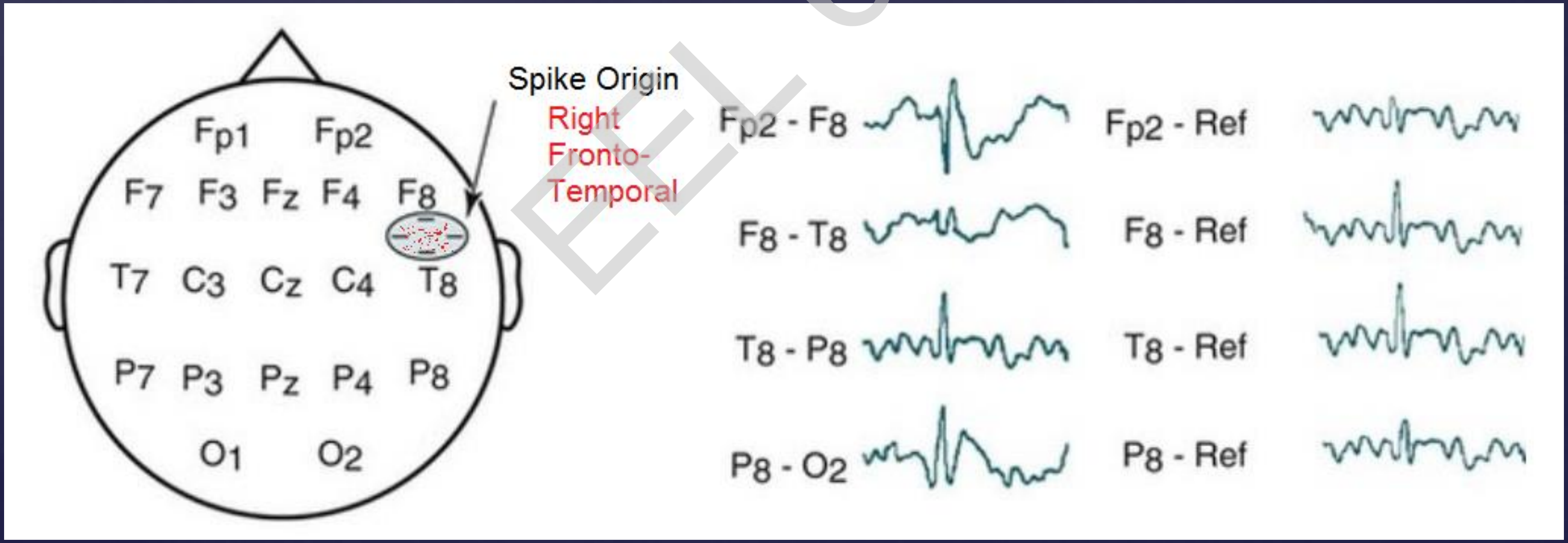
Average montage

The outputs of all of the amplifiers are summed and averaged, and this averaged signal is used as the common reference for each channel.



Referencial Vs. Bipolar

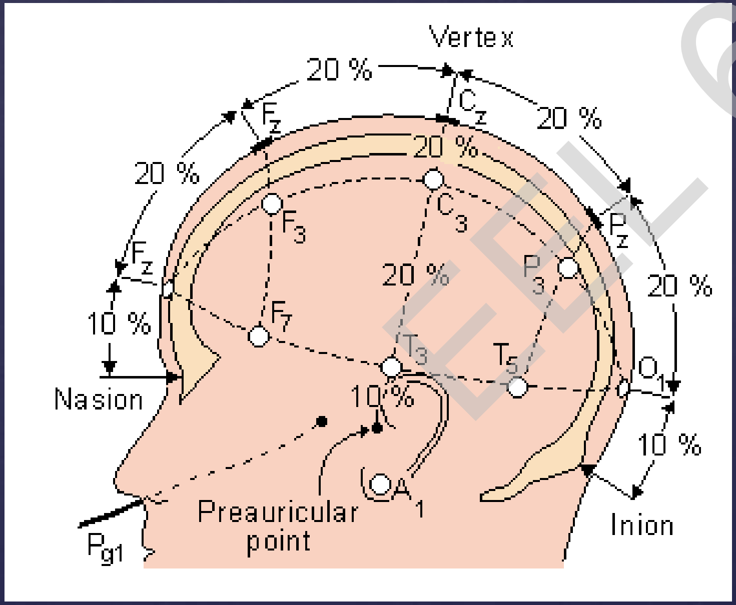


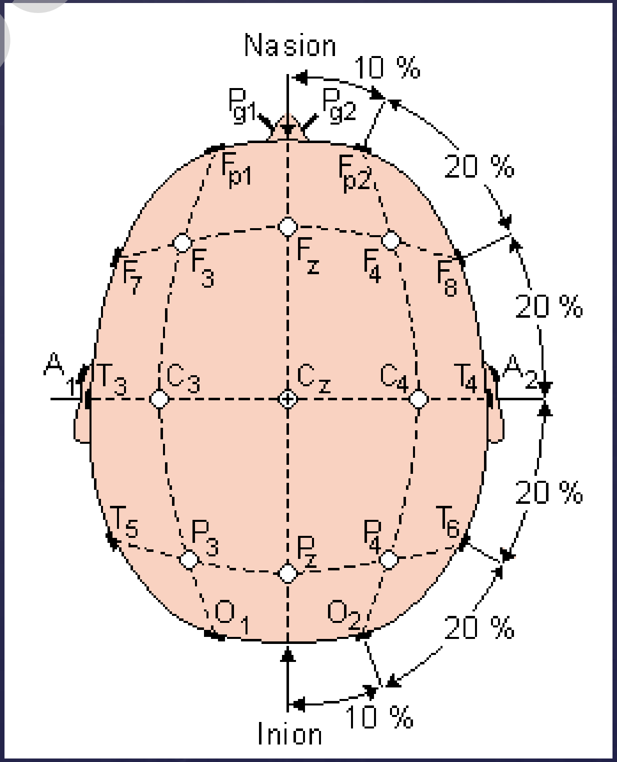


10-20 montage

- It is based on anatomical locations and on percentage of distance among these points giving the 10% or 20% in the system name.

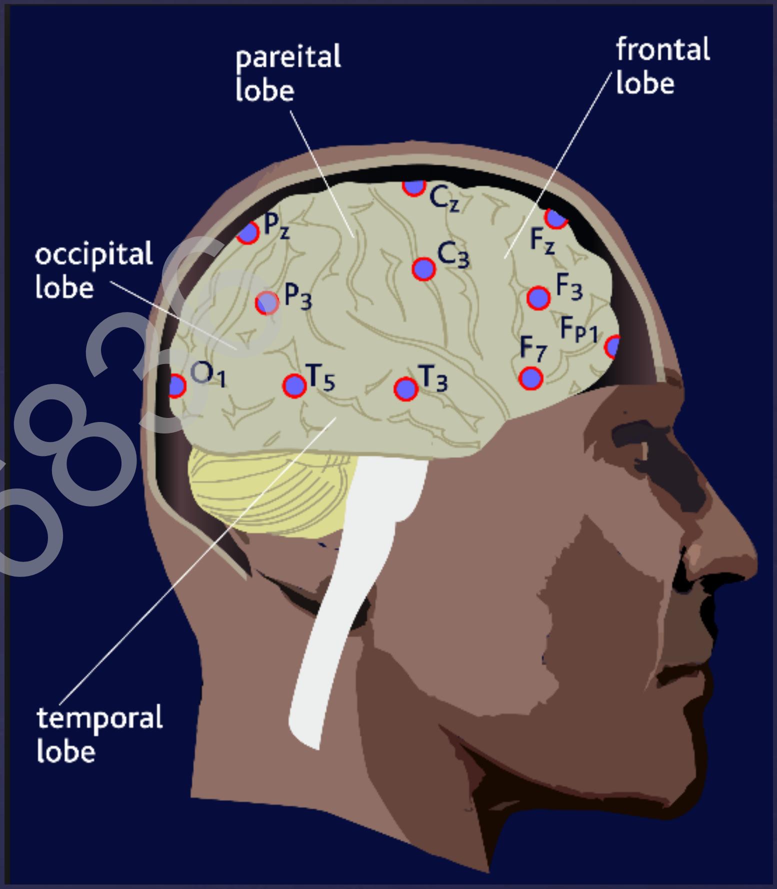
- The original 10-20 system has only 19 electrodes but has been extended to accommodate more than 200 electrodes.





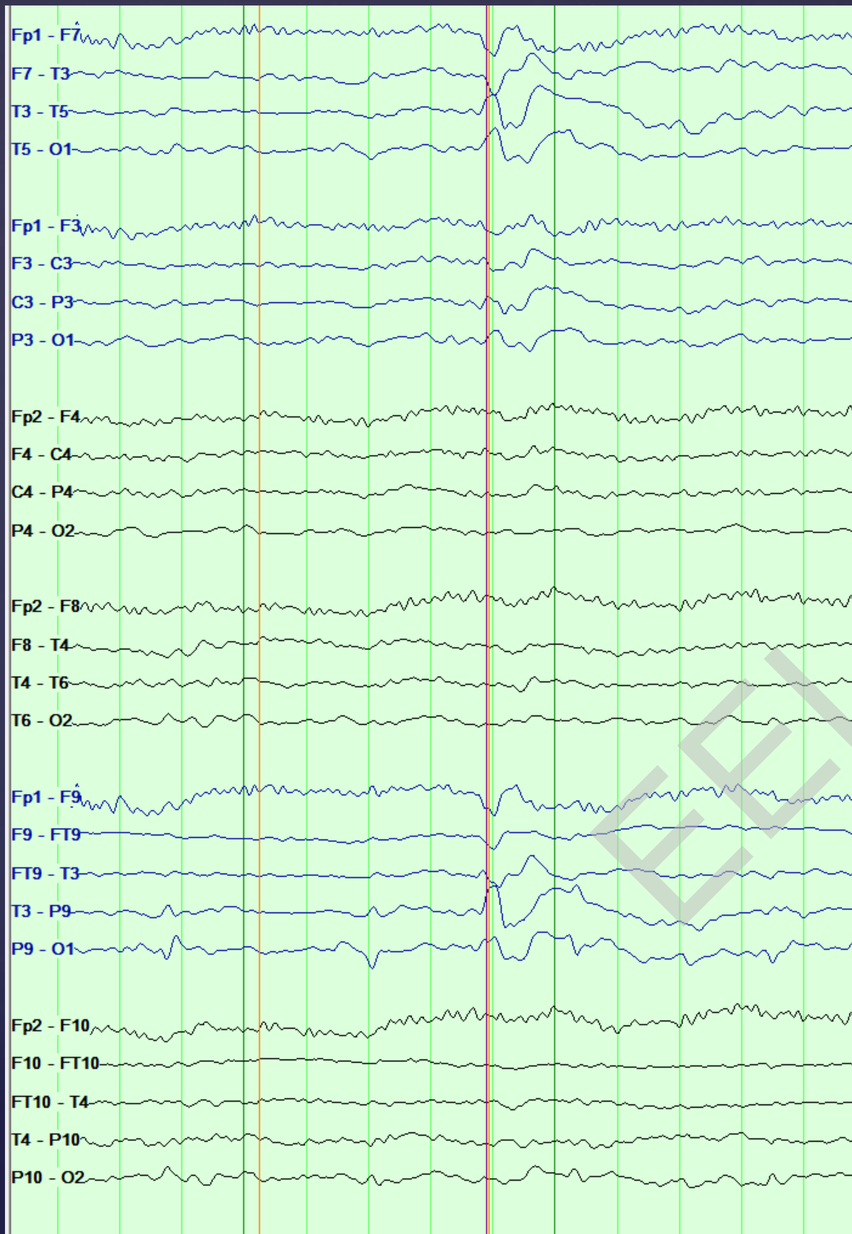
10-20 System

The 10-20 system using 19 electrodes is more practical for its simplicity of use and for the bigger spacing between electrodes which reduces the possibility of inter electrode interference.



The raw plot of one live electrode vs. reference (referential montage) can be always transformed into another representation to show the voltage difference of two specific live electrodes (bipolar montage). This allows personalizing the analysis without the need of repeating the recordings.

Bipolar montage



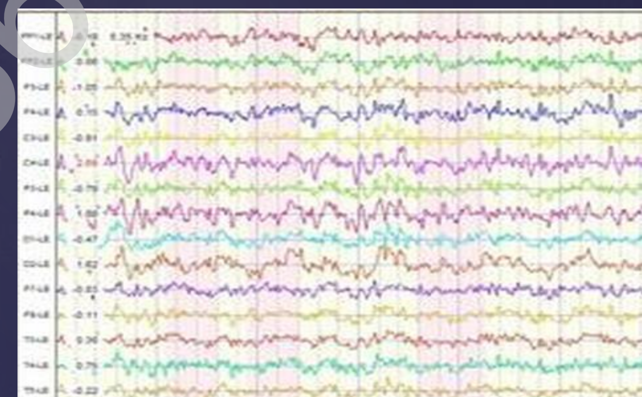
Referential montage

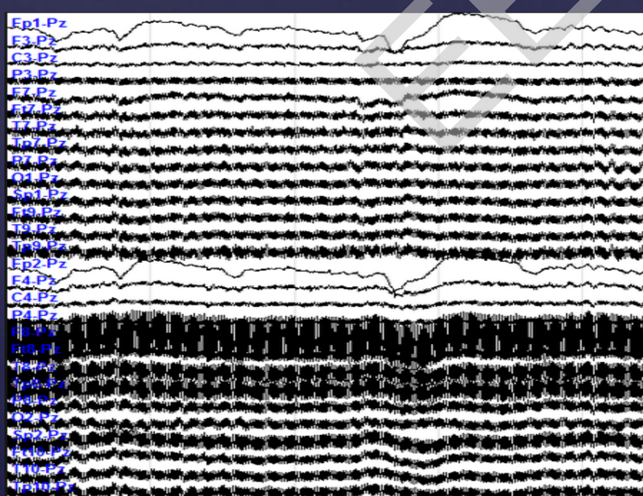
EEG Cap

To simplify and standardize electrode placement, caps are used which have a maximum number of openings to place as much electrodes as needed.

Sliver electrodes

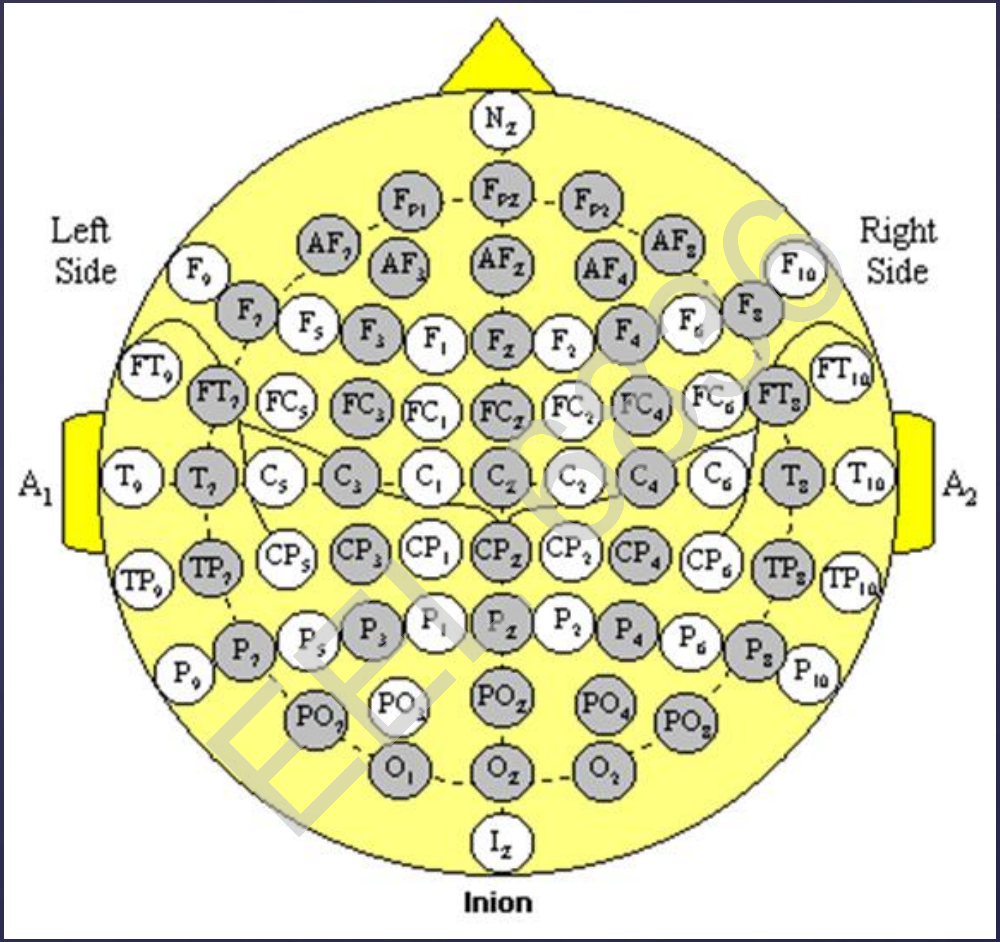
Individual Electrodes





EEG cap

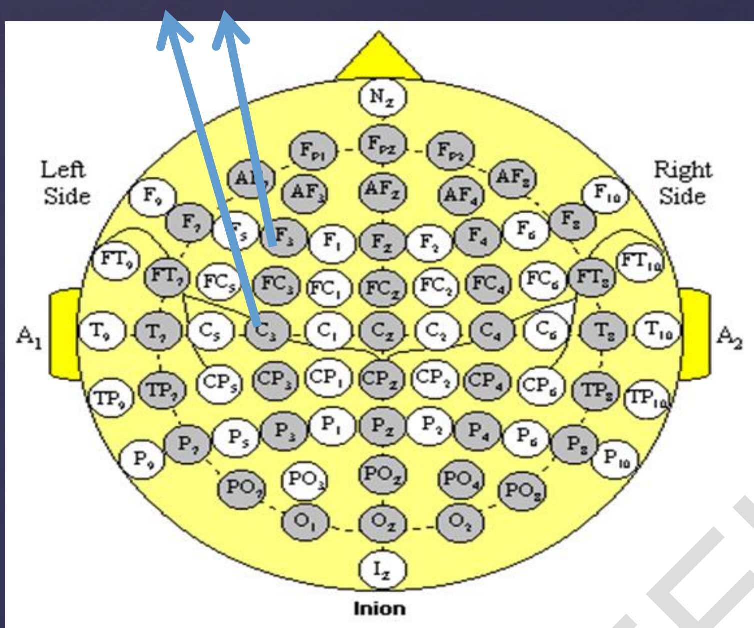
Modified Combinatorial Nomenclature (MCN)

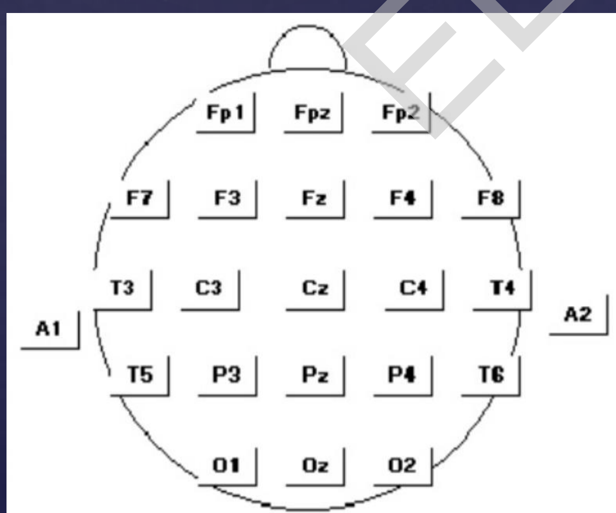


<u>When recording a more detailed EEG with more electrodes, extra electrodes are added </u>utilizing the spaces in-between the existing 10-20 system.

Modified Combinatorial Nomenclature

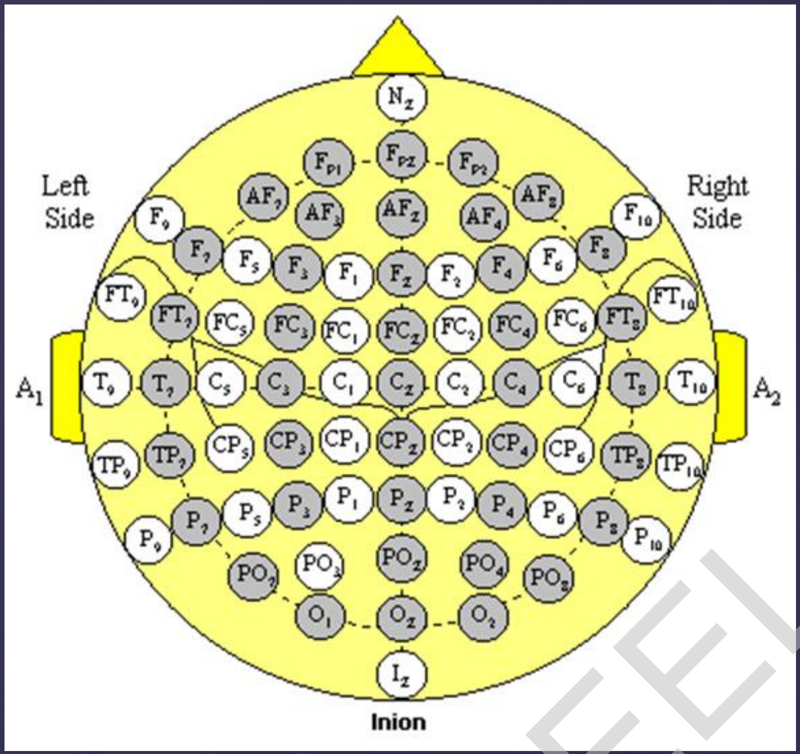
Electrodes between 2 10-20-system





- Electrode between 2 10-20-system electrodes uses combination of capital letters, for instance, FC between F and C.
- **Even numbers (2, 4, 6, 8) refer to the right hemisphere** and **odd numbers (1, 3, 5, 7) refer to the left hemisphere.** "Z" refers to an electrode placed on the midline.
- **The smaller the enumeration of the electrode, the closer is the position of it to the midline.**

Modified Combinatorial Nomenclature

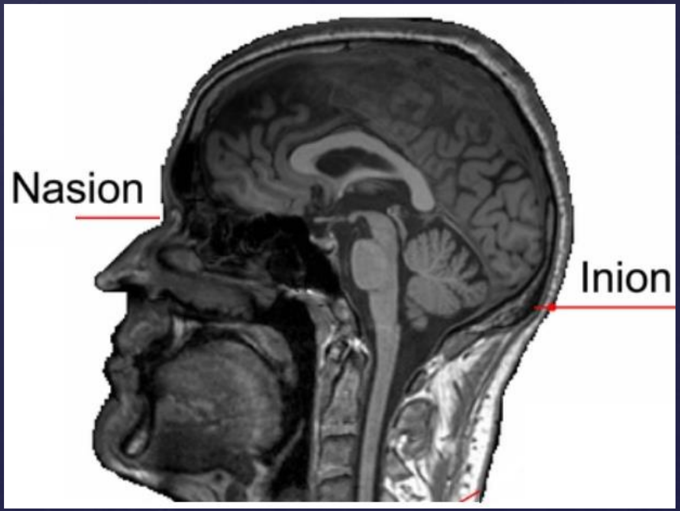


Each electrode site has a letter identifying its sub-cranial lobe and a number, or another letter identifying its hemispherical location.

Nasion, which is in the front of the head, is the point between the forehead and nose.

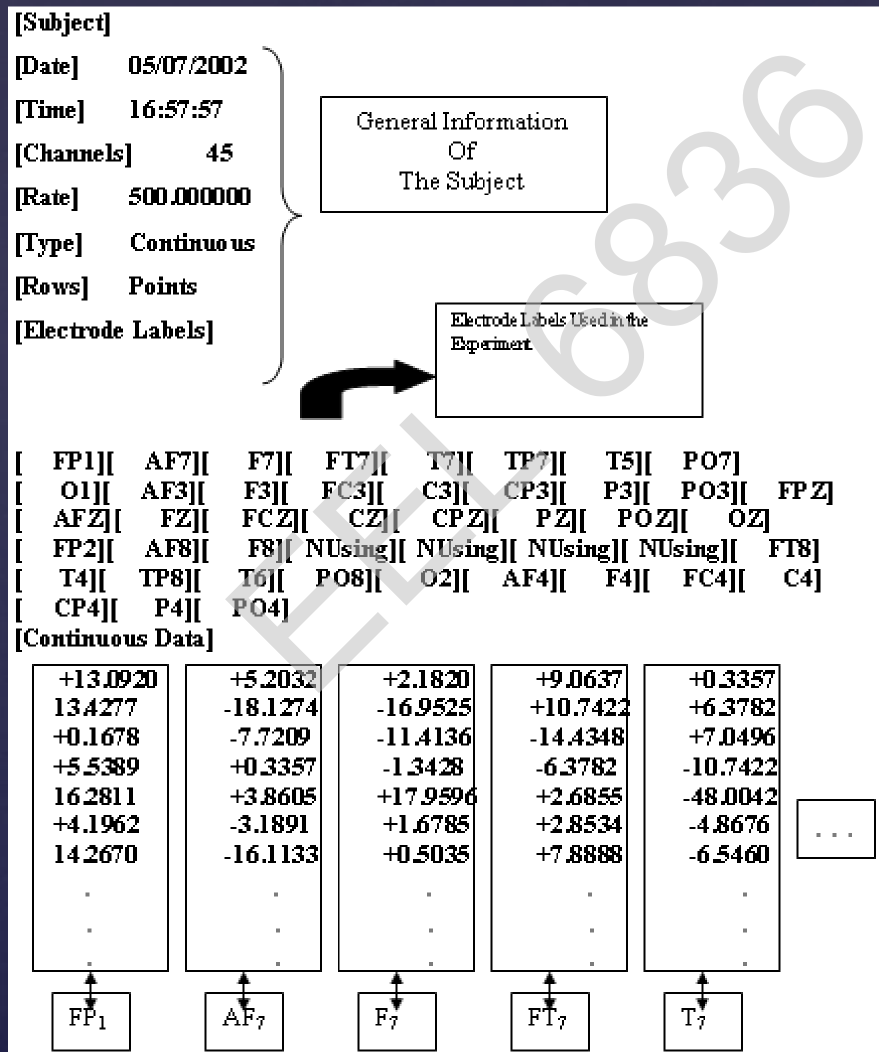
Inion is the bump at the back of the skull.

For example:
"FP" as the Front-polar or prefrontal lobe, "F" as Frontal lobe, "T" as Temporal lobe, "C" as Central lobe, "P" as Parietal lobe, and "O" as Occipital lobe.



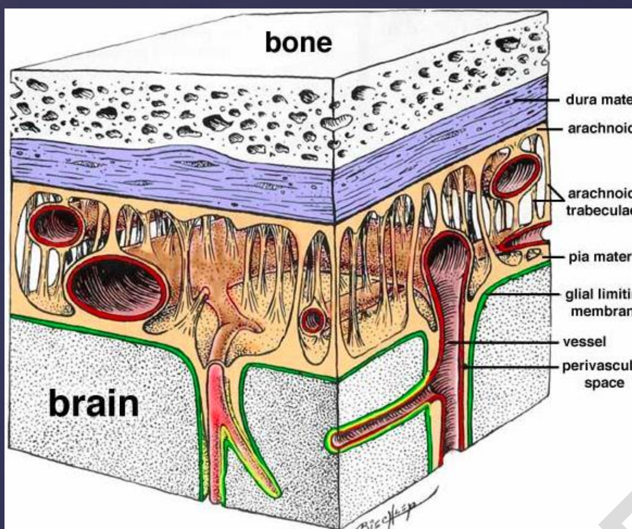
Example of an ASCII file

- The ASCII files are divided in columns depending of the number of electrodes used, and the rows represent the number of samples taken per channel.



* If SR= 500 HZ There are 500 points per second

EEG and Epilepsy Retrospective



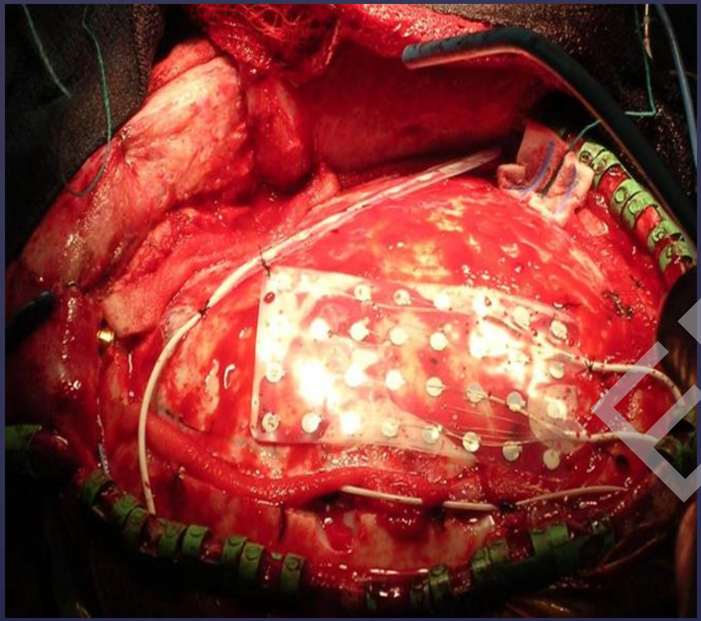
- **EEG is the most common diagnostic test for epilepsy.**

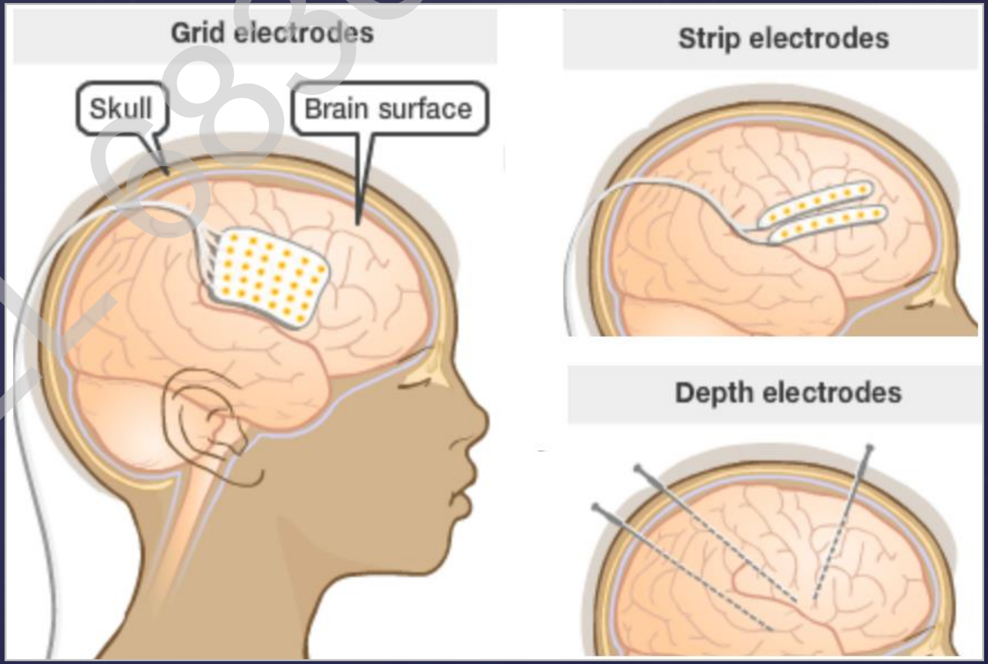
- **Scalp recording is not obviously invasive, but it provides a distorted signal because of the effects of intervening skull, tissue and cerebrospinal fluid.**

- **Intracranial EEGs (IEEG) provide high signal to noise ratio** measurements that are relatively artifact free. They are recorded by placing subdural grids and/or strips on the cerebral cortex and/or by inserting depth electrodes into the brain.

IEEG Recordings

Part of the pre-surgical evaluation of patients with refractory seizures is the implantation of electrode arrays which are placed in the cortex of the brain called Electrocorticography (ECoG).





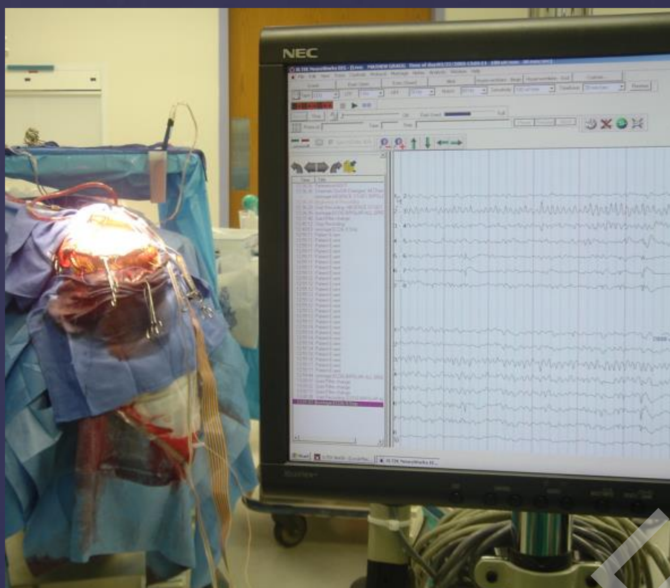
IEEG Recordings

- The EEG of epileptic patients can be divided into interictal and ictal EEG.
- The interictal EEG is the EEG data taken in the time between seizures, i.e. when seizures are not present.
- The ictal EEG activity is when the actual seizure occurs.

ECoG

As opposed to scalp EEG, ECoG is typically recorded at higher sampling rates since higher frequencies are better revealed in subdural signals.

IEEG Recordings



An electrode grid being implanted on the cortex of the brain of a patient

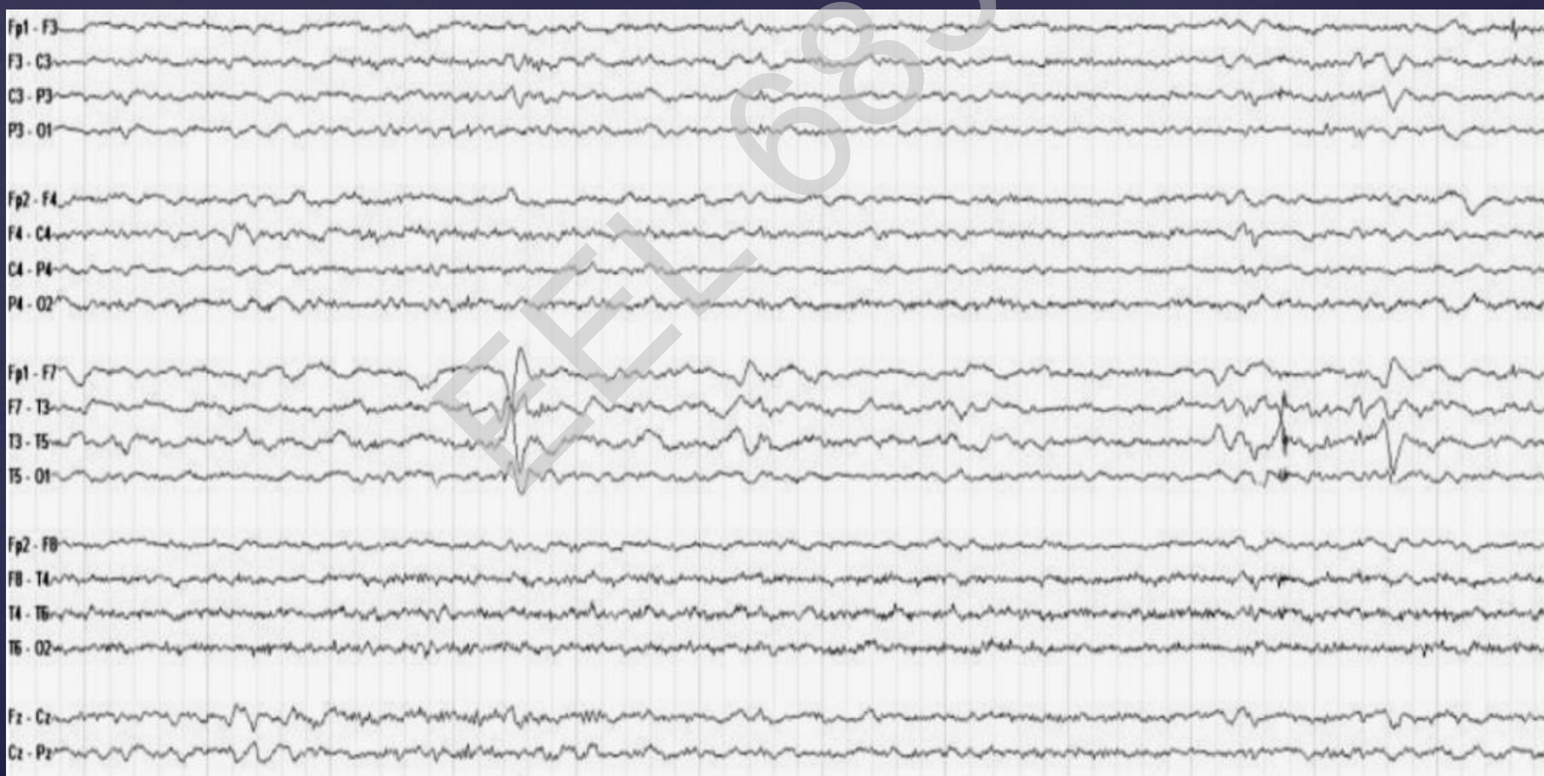
Subdural grid arrays are used when seizure activity cannot be located by ictal scalp recordings and when functional cortical mapping is required before surgery.

The placement of these arrays coincides with the location where the seizure focus was suspected by using scalp EEG.

ECoG is considered in clinical practice the golden standard for locating epileptogenic zones due to its high spatial resolution and lower degrees of noise than the scalp EEG, whose recordings are attenuated due to high scalp inductivity.

Scalp EEG

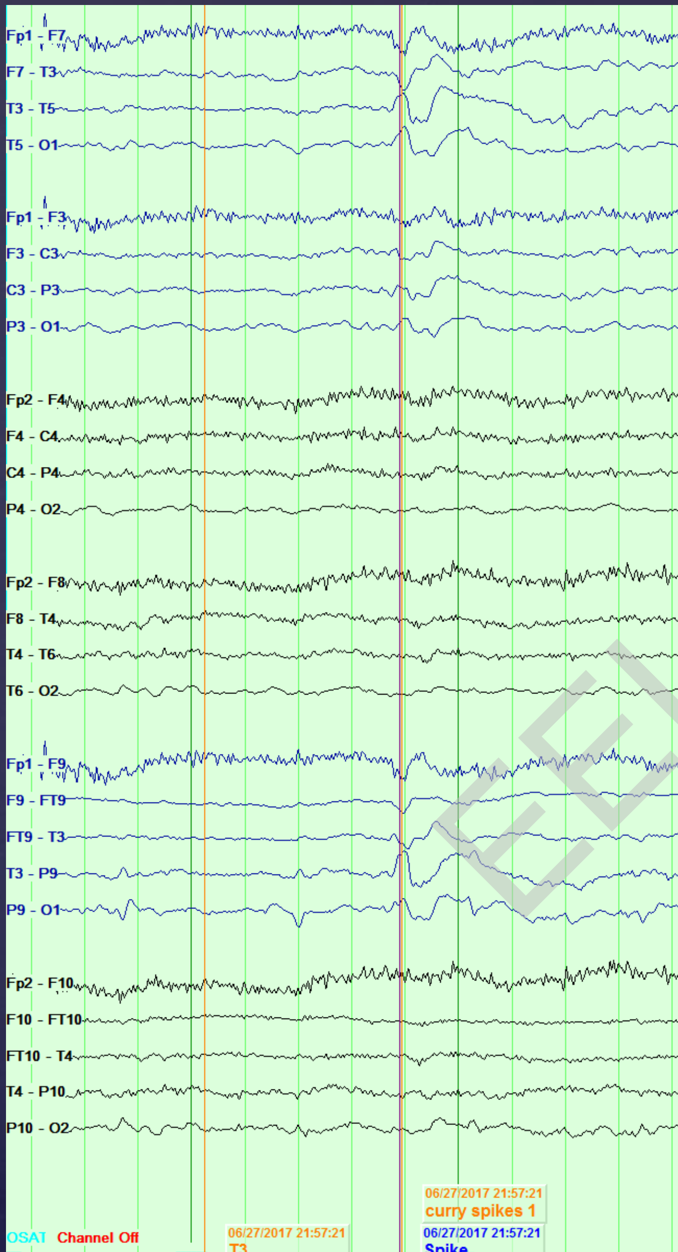
Most scalp EEG is nowadays digitally sampled between 256 and 512 Hz, although higher frequencies are used sometimes for research purposes.



Digitizing the EEG Signals

- Digitizing is performed by sampling the continuous EEG signal.
- How small should the intervals be to ensure a faithful representation of the signal? The sampling theorem states that no information is lost in the sampling process if the sampling rate is at least twice the highest frequency in the signal .
- In theory, if a signal includes frequencies up to 256Hz, then sampling at 512Hz will ensure a perfect representation of the signal.
- Half the sampling frequency is called the Nyquist frequency.

1 to 70 Hz



1 to 35 Hz

Digital Filtering

After the EEG has been digitized, it is possible to filter it with digital filters, which are computer programs. There are low-pass, high-pass, band-bass and band-reject filters

There are two basic types of digital filters:

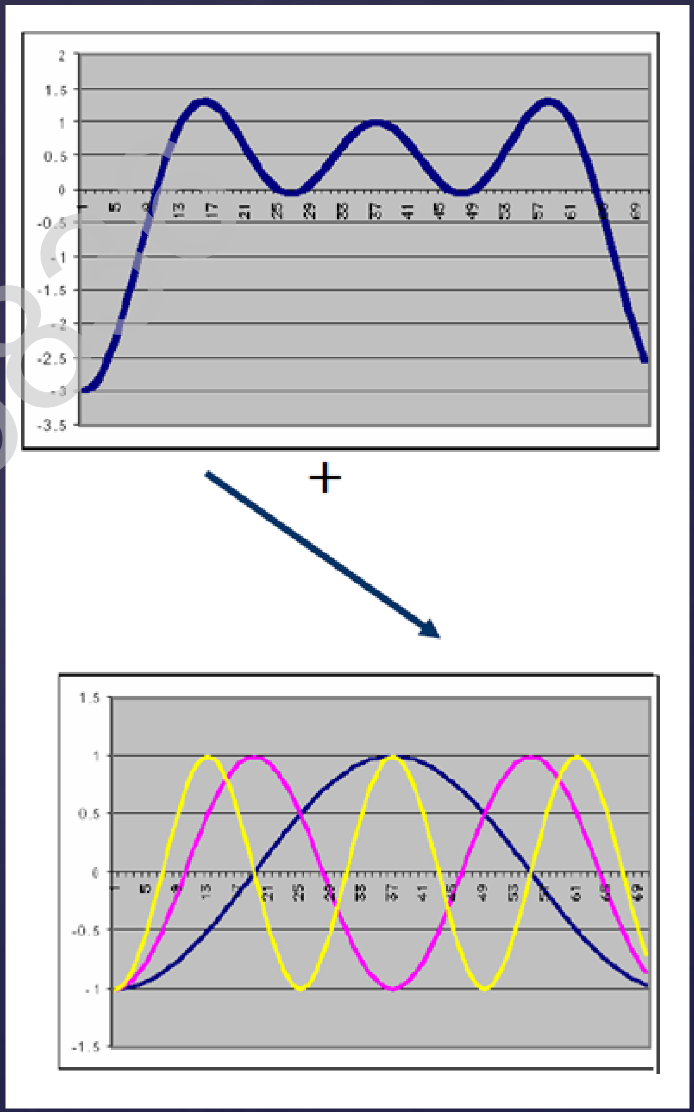
– Infinite Impulse Response (IIR) filters. They are fast but result in distortions similar to those generated by analog filters.

– Finite Impulse Response (FIR) filters, which can be designed without any distortion, but require more computing power. FIR filters are preferable.

EEG Filtering

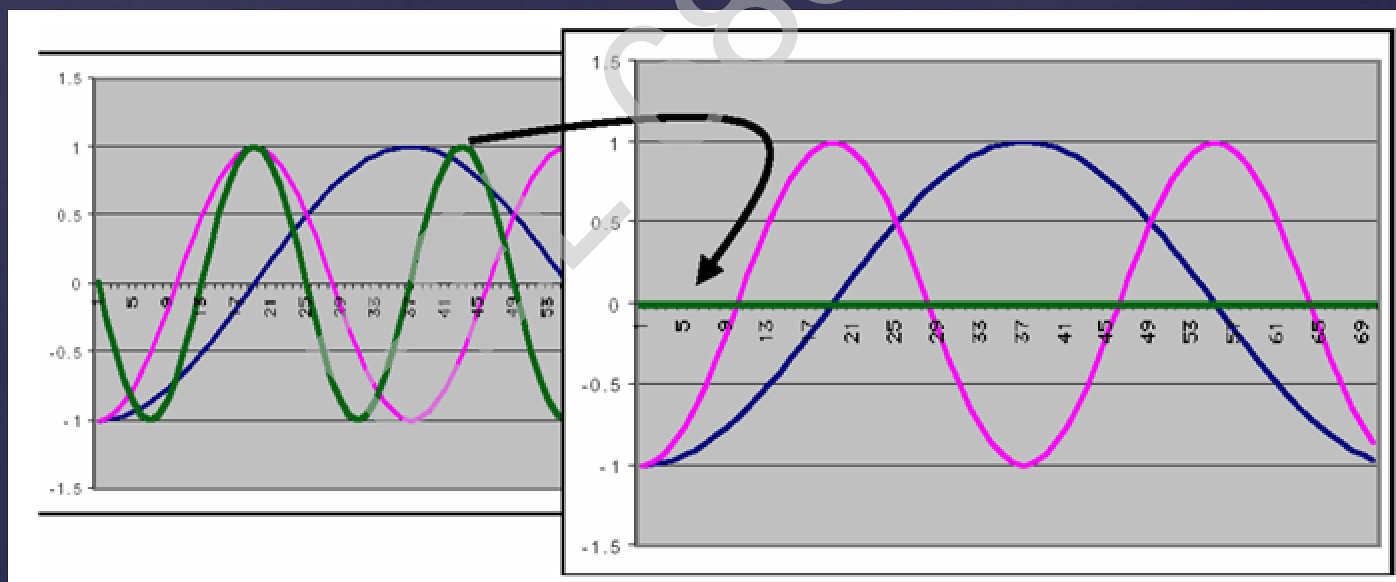
- Any EEG wave can be thought of a number of sinusoidal waveforms that vary in amplitude, frequency and phase.

- The EEG recordings are low-pass filtered to remove low-frequency artifacts (usually between 0.5 and 1 Hz) and high-pass filtered to remove high-frequency artifacts (usually between 35 and 70 Hz).



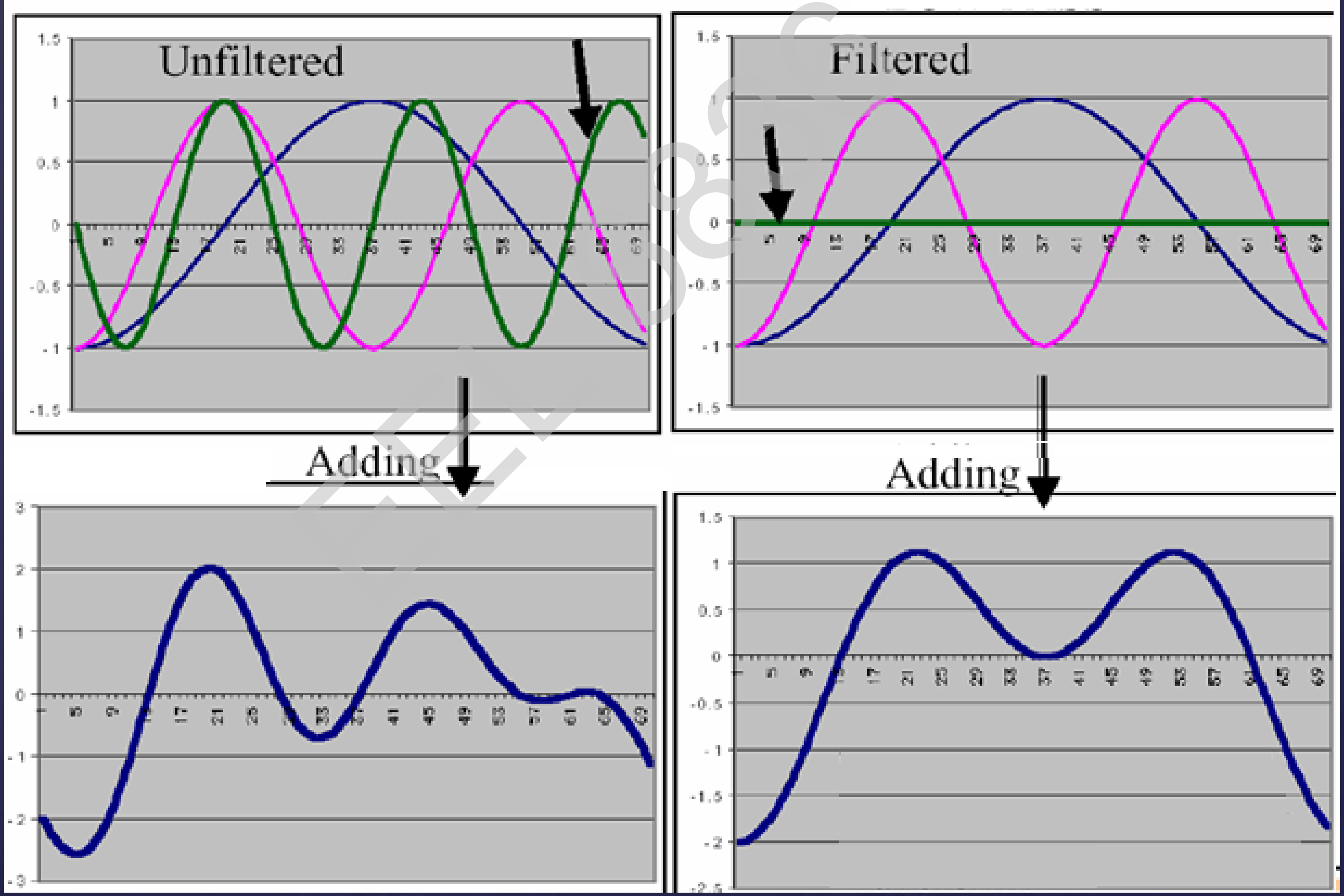
EEG Filtering

Filtering is the operation that results in zero amplitude for the waves at frequencies that we do not want in our output signal.



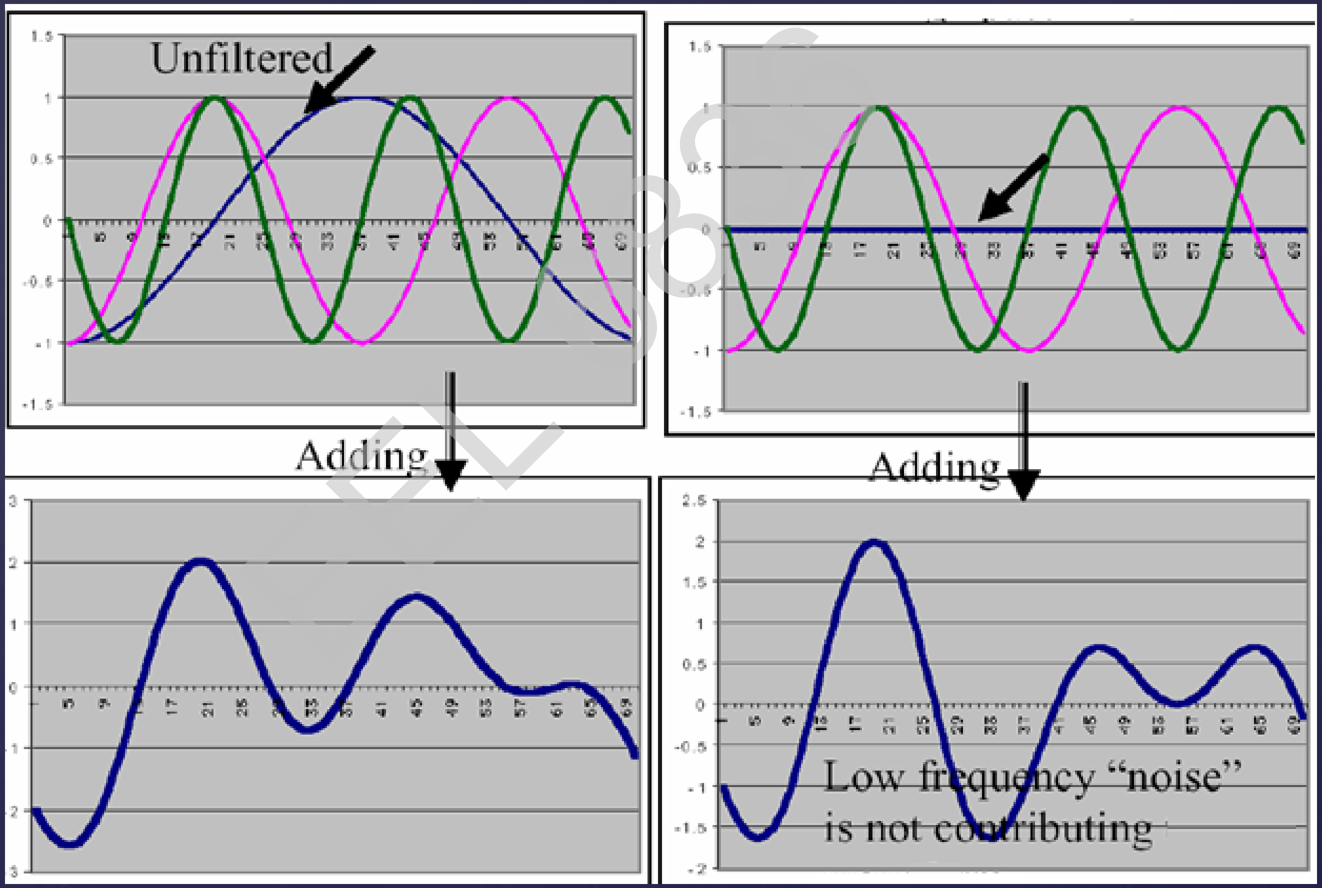
EEG Filtering

<u>Low Pass Filter </u>: only low frequencies contribute to the output signal.



EEG Filtering

High Pass Filter : Low frequencies (EEG noise) not contributing to the output signal.



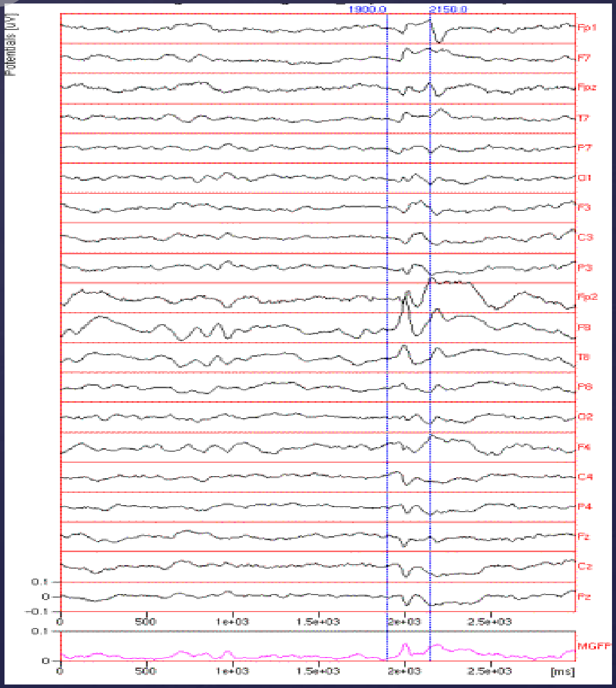
Epileptiform Activity

- Epileptiform activity is a term used in EEG to describe waves that are clearly distinguishable from the background activity and are similar to the waves found in EEG from epileptic subjects.

- Epileptiform activity refers to the waves recorded in the interictal activity (the time between seizures) but not during the seizure itself.

Epileptiform activity can be divided in:

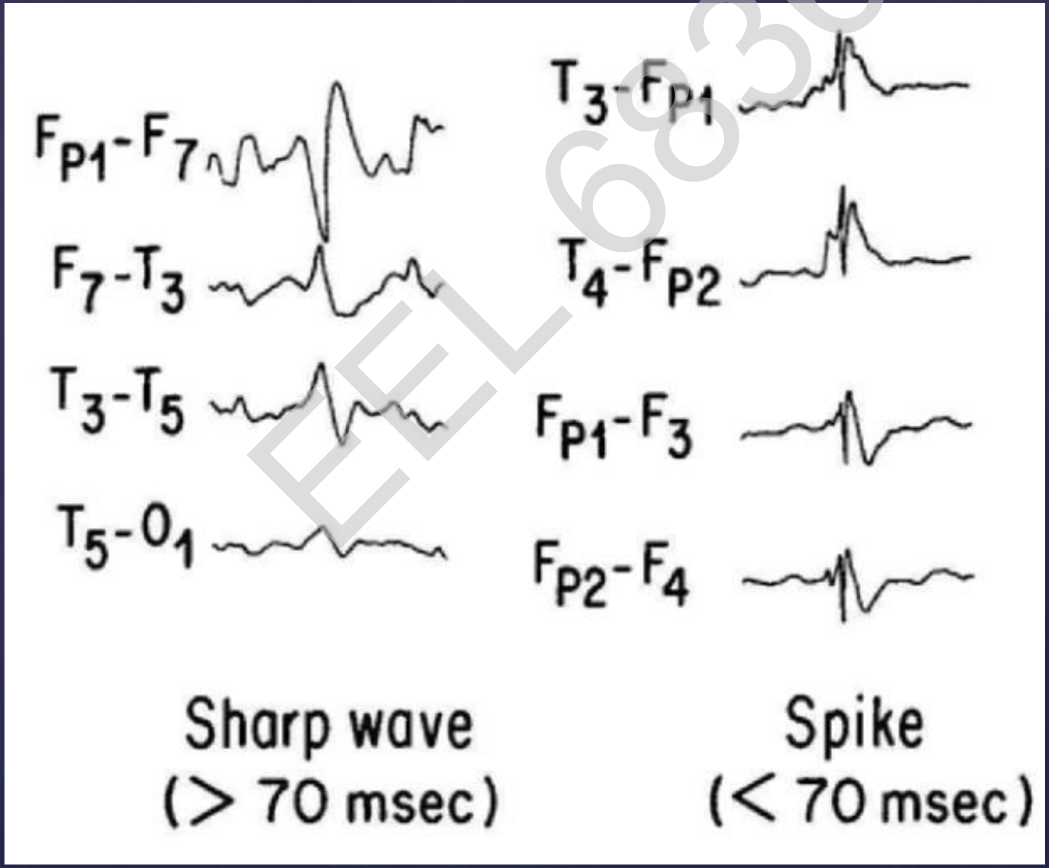
- spikes,
- sharp waves,
- spike-and-slow-wave-complex,
- multiple spike-and-slow-wave complexes.



Epileptiform Activity

- A Sharp wave is a transient event distinguishable from EEG background which lasts 70 to 200 milliseconds.

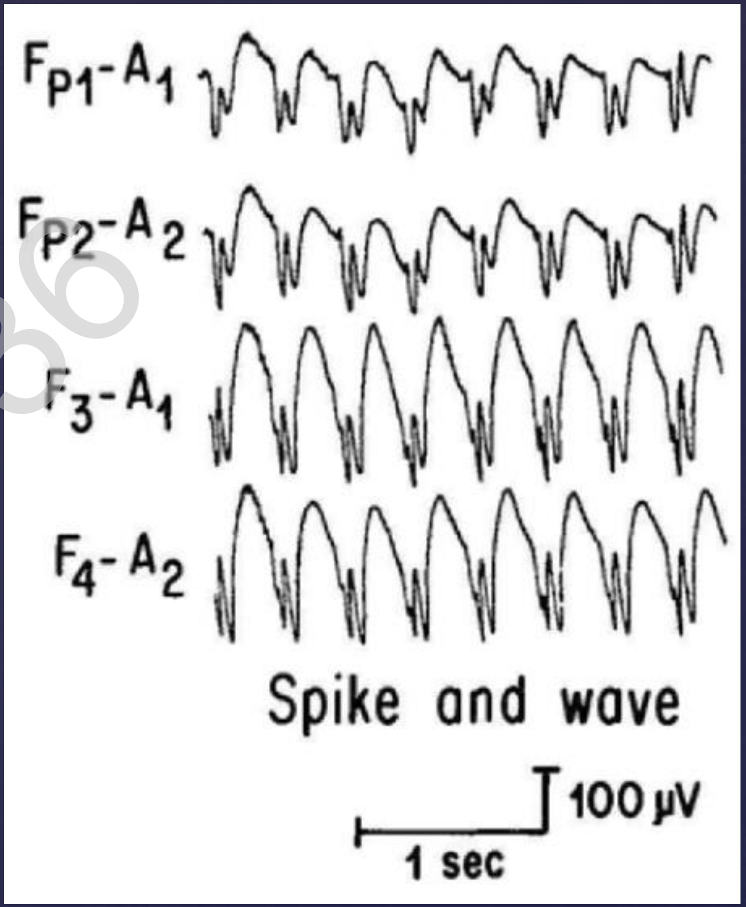
- A Spike is a sharp wave with a duration of 20 to 70 milliseconds.



Epileptiform Activity

- A Spike-and-slow-wave complex is a spike followed by a slow wave, whereas the later has usually higher amplitude.

- Multiple spike-and-slow-wave complex is a concatenation of spike-and-slow-wave complexes.



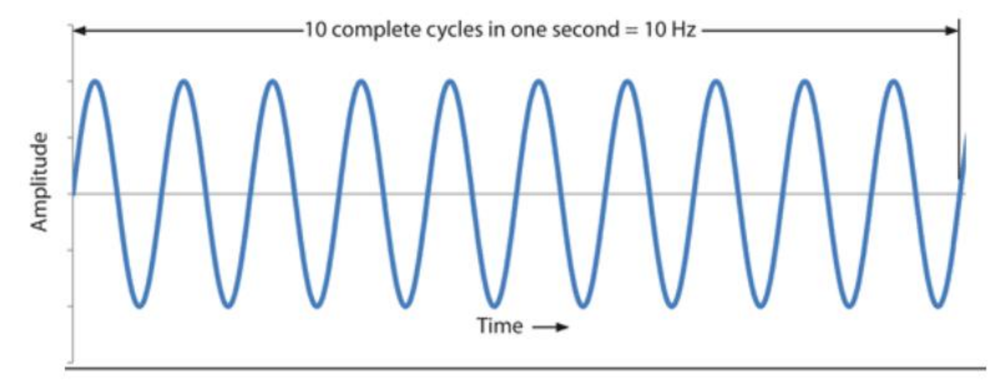
* In practice, however, it is more important to distinguish them from the background activity than to detect their morphological distinctions.

Frequency Contents of the EEG

- EEG of humans either at rest or awake commonly contains rhythmical potential changes. These rhythms are called brainwaves and they are measured in frequency (speed of electrical pulses) and in amplitude (intensity of the brainwave).

- Frequency is measured in cycles per second, or Hertz (Hz). Thus, one frequency is one cycle, or one pulse per second. The frequencies of the EEG signal range from 0.5 to 100 Hz, depending on the degree and type of activity of the brain, such as alertness and sleep.

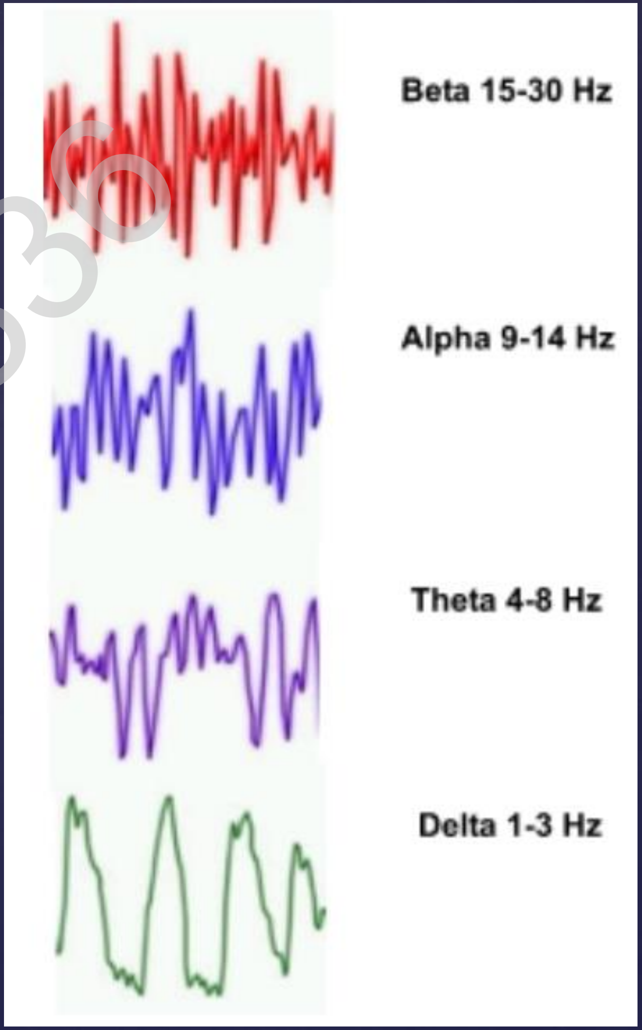
- When "f" is the frequency, we have:
- $f = 1/T$
  f is in Hertz (Hz)
  T is in seconds (sec)



Frequency Contents of the EEG

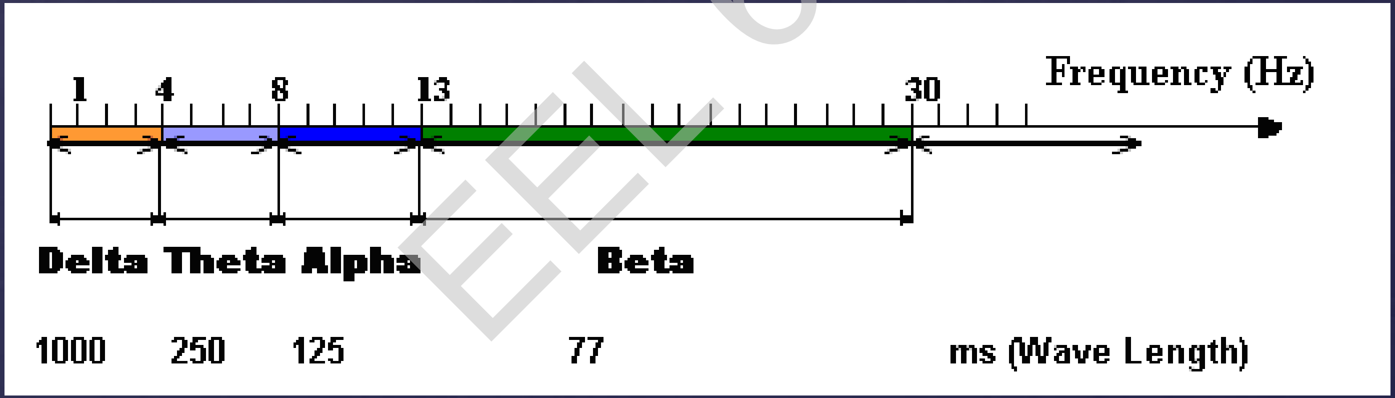
- Electrical activity emanates from the brain in the form of brainwaves. There are **4** brainwave states that range from the low amplitude/high frequency **Beta** to the high amplitude/low frequency **Delta**.

- According to the activity level of an individual, one brainwave state may be dominant at any given time, **even though all brainwave states will remain present at minimal levels.**



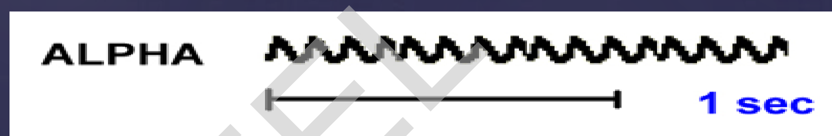
Frequency Contents of the EEG

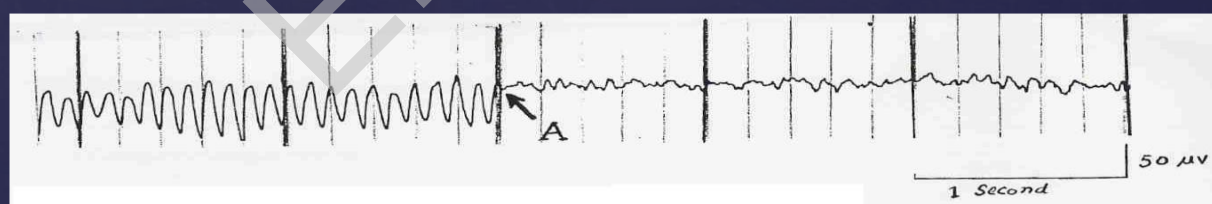
- There are 4 broad spectral bands of clinical interest: D**elta (0-4 Hz), Theta (4-8 Hz), Alpha (8-12 Hz), and Beta (12-30 Hz).**



Alpha (8-12 Hz)

- **Alpha waves** are those between 8 and 13 (Hz). **It is the major rhythm seen in normal relaxed adults**, and occurs whenever the person is alert, but not actively processing information. In general, alpha waves decrease when the subjects have their eyes opened and are attentive to external stimuli.
- **Location:** posterior region of the head, both sides, higher amplitude on dominant side (20-200 μ V).





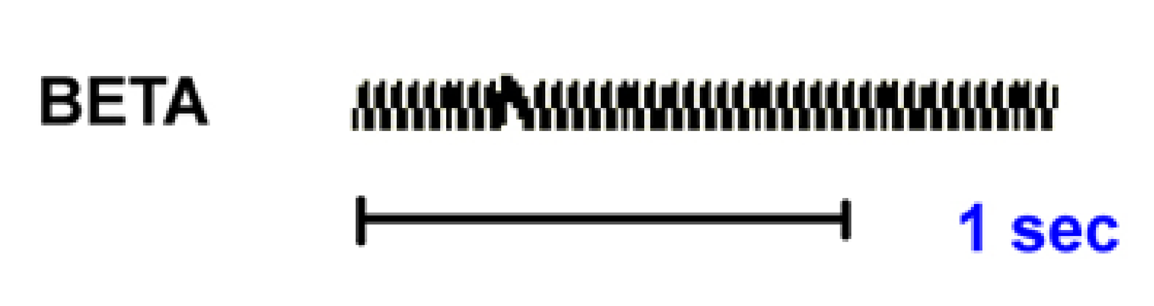
Alpha rhythm changes to beta on eye opening (desynchronization)

Beta (12-30 Hz)

Beta activity is 'fast' activity. It has a frequency of 12 Hz and greater. It is generally the **dominant rhythm in those who are alert or anxious or who have their eyes opened,** and are listening and thinking during analytical problem solving, judgment, decision making and processing information.

This band has a relative large band and it has been subdivided in several sub-bands: low beta (13-15 Hz), midrange beta (15-18 Hz) and high beta (>18 Hz). A subdivision into beta I (13-20 Hz) and beta II (20-36 Hz) is also found in the literature.

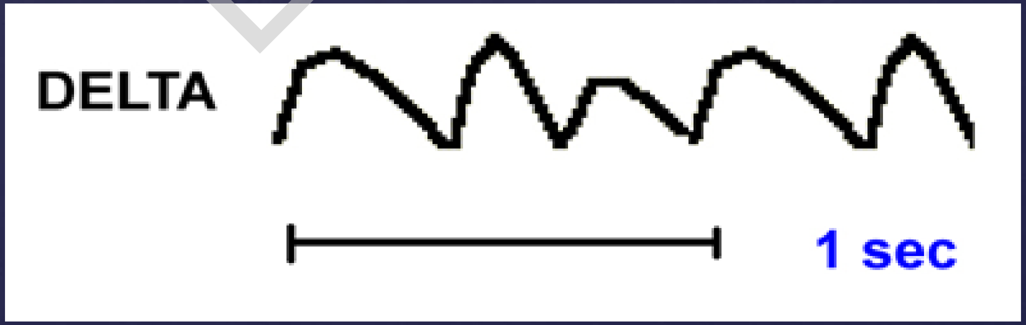
Location: most evident frontally, both sides, symmetrical distribution, low amplitude wave. Also on temporal lobe.



Delta (0-4 Hz)

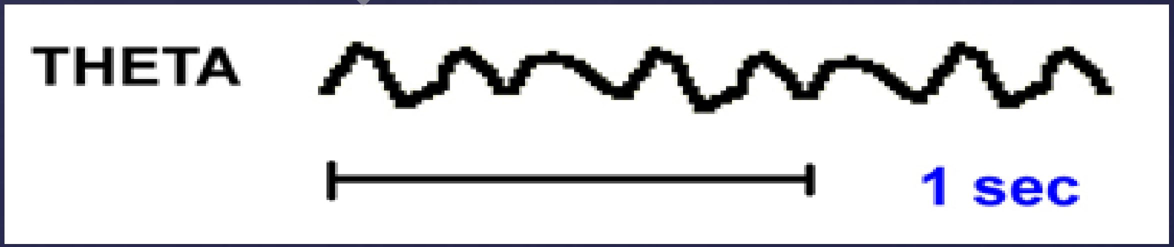
The lowest frequencies are delta, these are less than 4 Hz, and occurs in deep sleep. It reflects unconscious mind. We increase delta waves in order to decrease our awareness of the physical world. These waves are normal in adults during sleep, although are the dominant rhythm in infants up to 1 year of age.

Location: frontally in adults, posteriorly in children; high amplitude waves.



Theta (4-8 Hz)

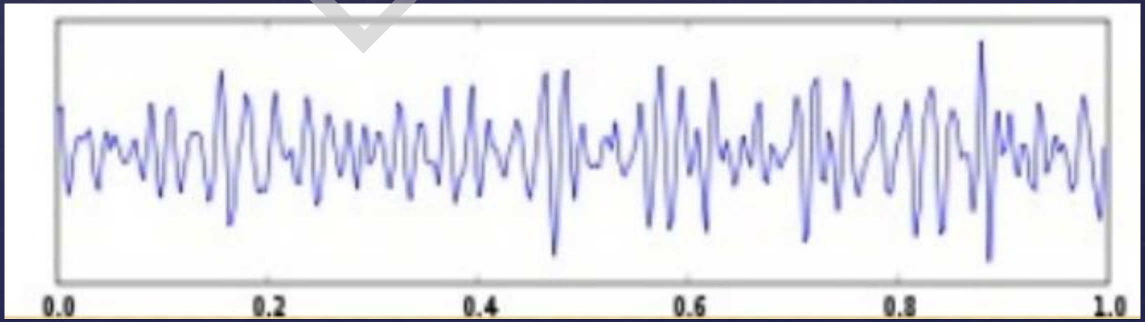
- Theta activity has a frequency of 4 to 8 Hz and is considered as slow activity. **Theta waves are strong during internal focus and meditation.** It is seen in connection with creativity and intuition. They reflect the transition from sleep to wakefulness (Drowsy, sleep). They are normal in children up to 13 years old.
- A presence of excessive Theta waves during a normal awake state could reflect problems with focus and attention, head injuries, and learning disorders.
- Children and adults with ADHD will produce excessively lower frequency Theta waves.
- Location: Occipital, also found in locations not related to task at hand.



Gamma (>25 Hz)

- Frequency range 25-100 HZ.
- It is associated with perception and consciousness.
- It is sometimes defined as the frequencies above 36 Hz.
- It is sometimes defined between 36 and 70 Hz.
- High-frequency (60-100Hz) oscillations can be observed in those channels where seizures originate.

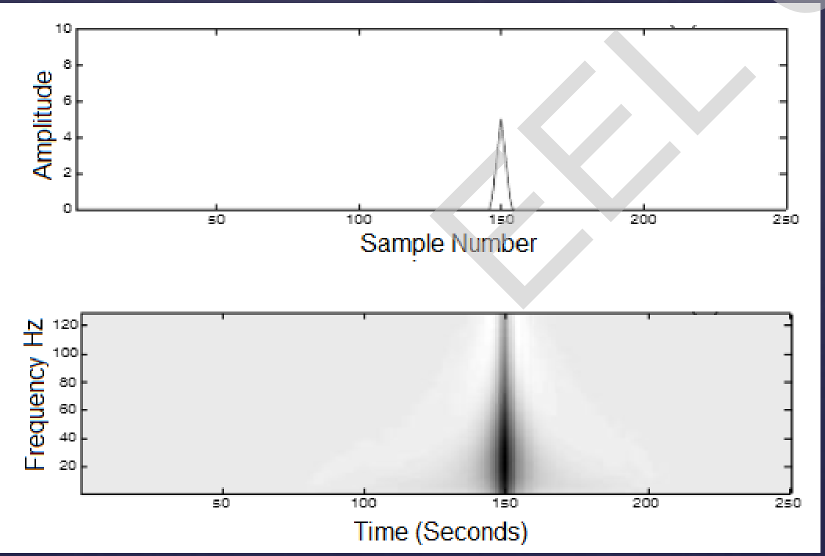
- **Location:** mostly in the somatosensory cortex.

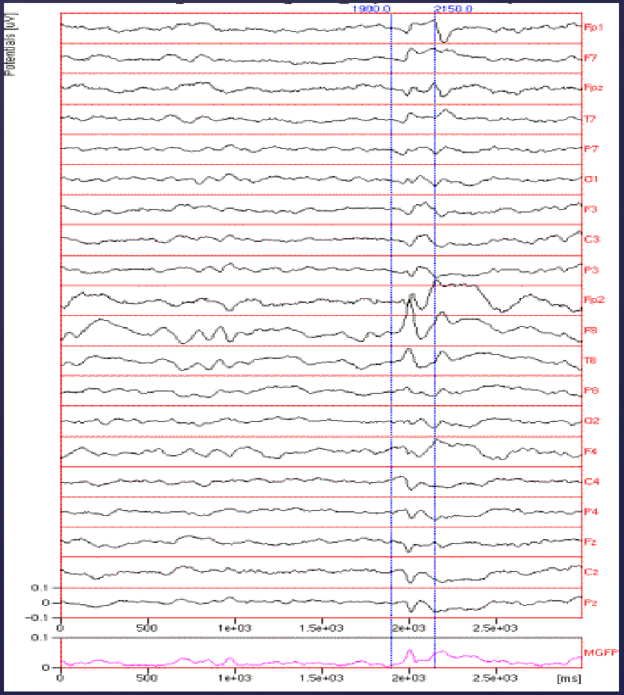


Spike Detection

- The detection of epileptiform discharges in the EEG is an important component in the diagnosis of epilepsy.

- If detection of the onset of seizures were possible, devices could be implanted within the brain in order to abort a seizure by using electrical stimulation.

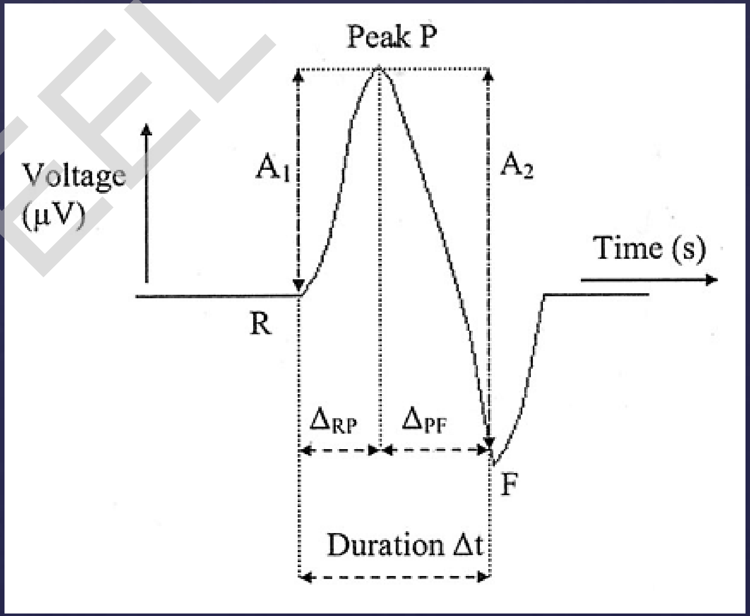




Spike Detection

- The detection of the neural spike activity is a technical challenge that is a pre-required for studying many types of brain functions and abnormalities.

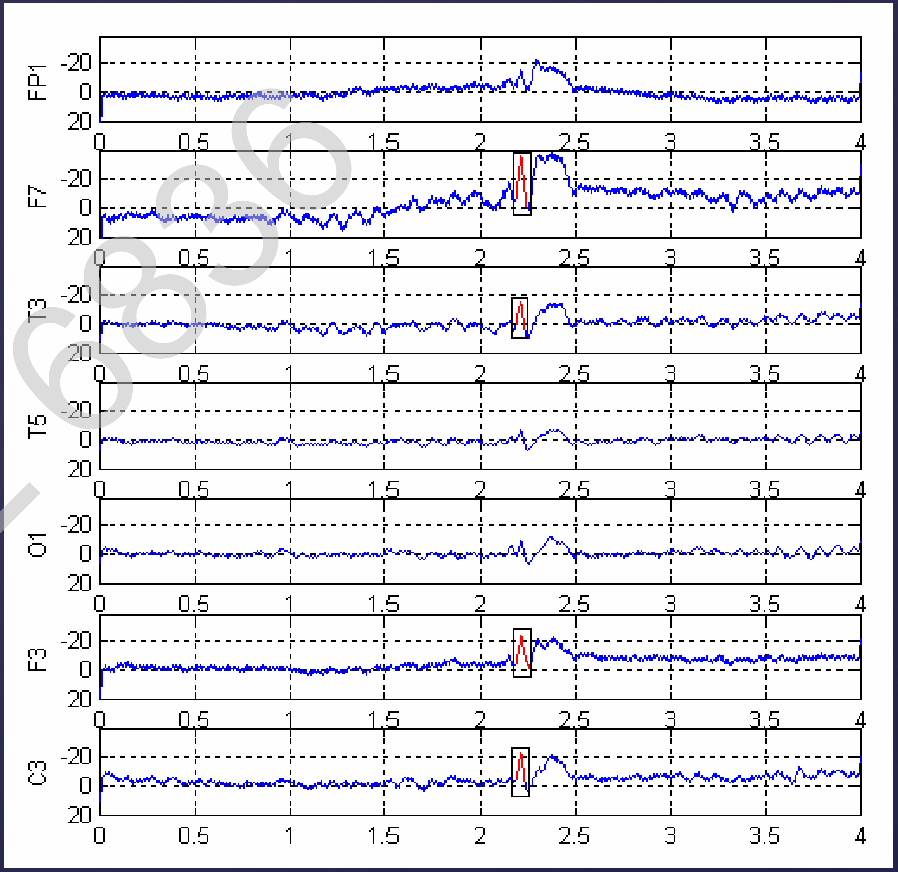
- **These spikes serve as indicator of eminent or potential seizures to come.**



Spike Detection

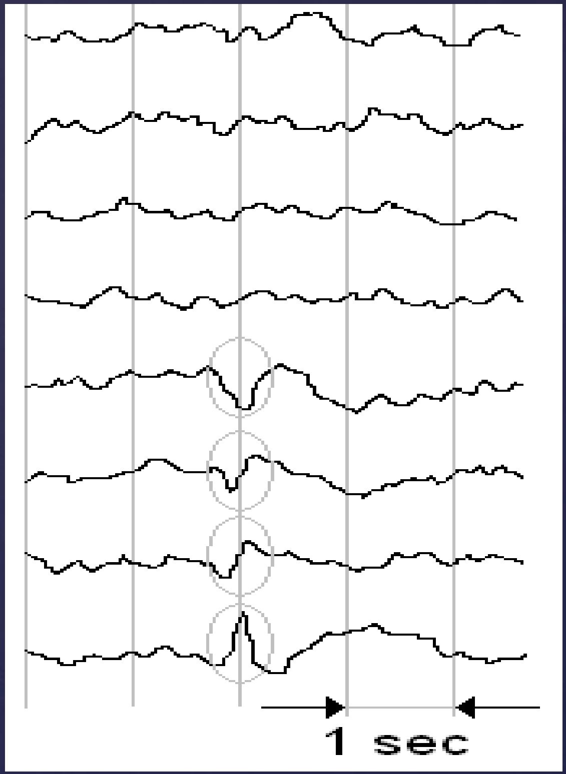
- The <u>spatio-temporal context of the EEG</u> is taken into account in several of the pattern recognition or rule-based systems.

- **These rules are based on the <u>morphology and the multi-channel characteristics of the spikes and sharp waves</u>**, and are developed to simulate the way in which humans visually identify spikes.



Interictal Spikes

- Interictal spikes are spikes recorded in the time between seizures, while the subject is not having any seizures.
- It is critical in locating the seizure focus.
- Interictal spikes usually occur in neighboring electrodes (spatio-temporal context) and at the same time.
- Key aspects of the morphology of an interictal spike consist on raising and falling amplitude and duration.



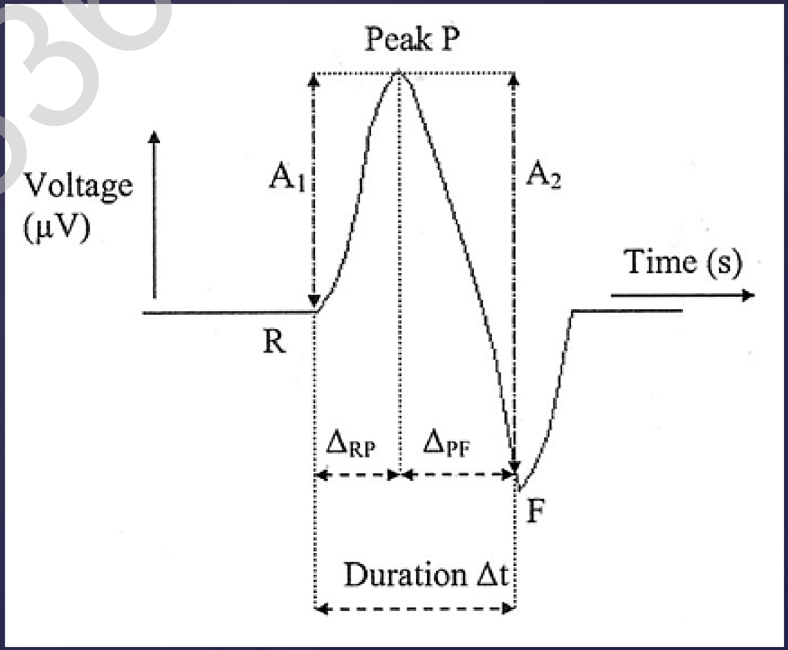
Interictal spikes occurring synchronously in 4 distinct electrodes

Clinical Criteria Characterizing Interictal Spikes

- It is defined as a waveform RPF, with two half waves RP and PF.

- Sharpness of a spike is continuous, displaying sharpness in both narrow and wide intervals of observation.

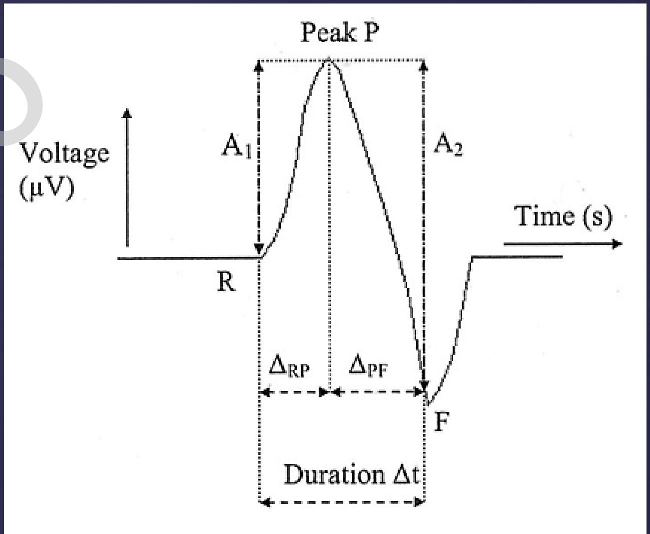
- The rising mRP and falling slopes mPF of the spike are both steep. The rising slope mRP is measured from the first trough R to the peak of the spike, and the falling slope mPF is measured from the peak to the second trough F.



Clinical Criteria Characterizing Interictal Spikes

- A sharp peak P characterizes the spike, which is due to a sudden change in polarity of the voltage signal recorded. This sharpness may occur in both the time and spatial domains.

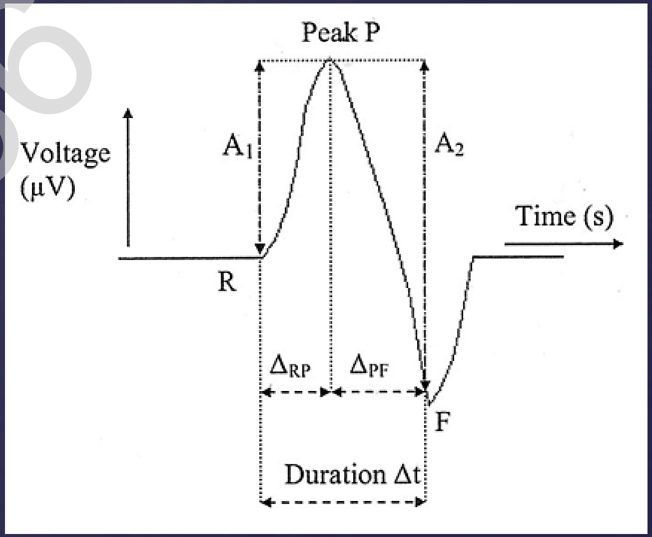
- A spike is estimated to have a total duration of **20 to 70 milliseconds** (ms). The total duration of the spike is measured from *R* to *F*, as the sum duration of the two half waves. P_x, R_x, and F_x denote the respective latencies in the *x*-axis for points *P*, *R*, and *F*.



$$\Delta_t = \Delta_{RP} + \Delta_{PF}$$ Where $$\Delta_{RP} = P_x - R_x$$ $$\Delta_{PF} = F_x - P_x$$

Clinical Criteria Characterizing Interictal Spikes

The two half waves are observed to satisfy the condition that their absolute difference is less than or equal to their calculated average. This implies that the duration of the shorter half wave must be at least half of that of the longer half wave.



$$\left|\Delta_{RP} - \Delta_{PF}\right| \leq \frac{(\Delta_{RP} + \Delta_{PF})}{2}$$

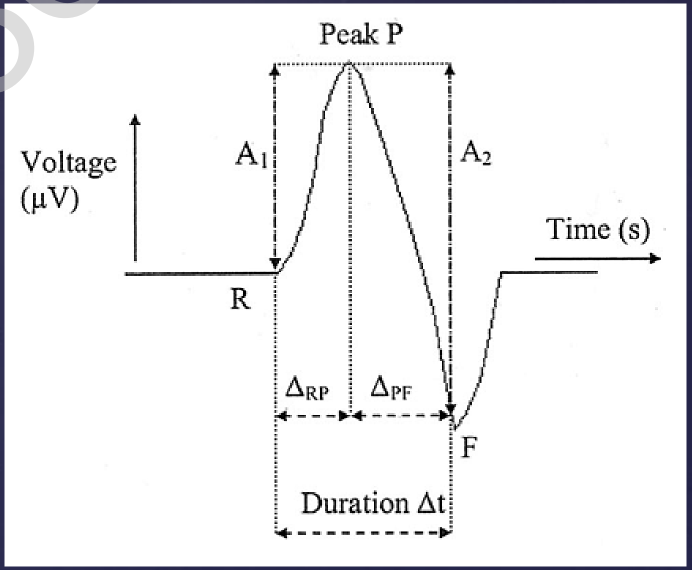
Clinical Criteria Characterizing Interictal Spikes

- The amplitude A_a of a spike is greater than **20 microvolts** (μV). The amplitude is defined as:

With $$A_a = (A_1 + A_2)/2$$

$$A_1 = P_y - R_y$$

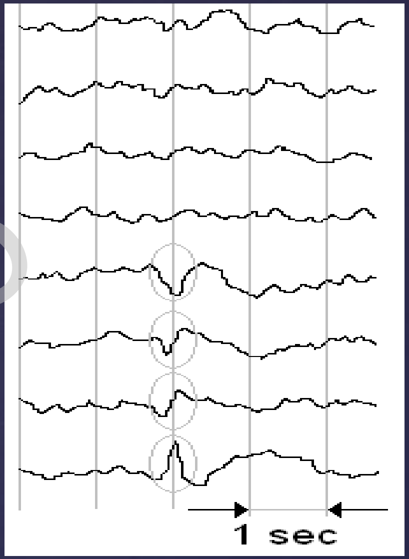
$$A_2 = P_y - F_y$$

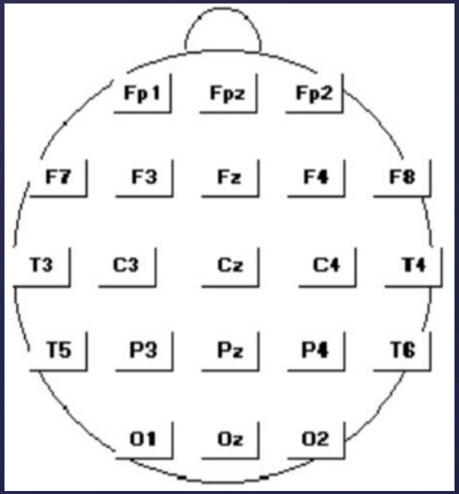


Clinical Criteria Characterizing Interictal Spikes

- Multi-channel activity may be reported, where one spike observed in a given channel may also be observed in another neighboring channel. In other words, spikes do not occur in isolation.

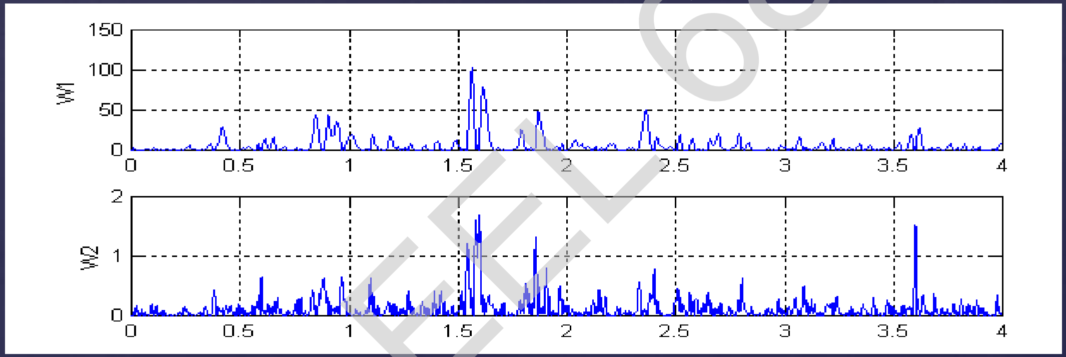
- This can be assumed provided that the inter-electrode spacing of the recording system used is small. Neighboring channels are identified as those that are of closest physical proximity, in direct relation to the system's electrodes configuration used.



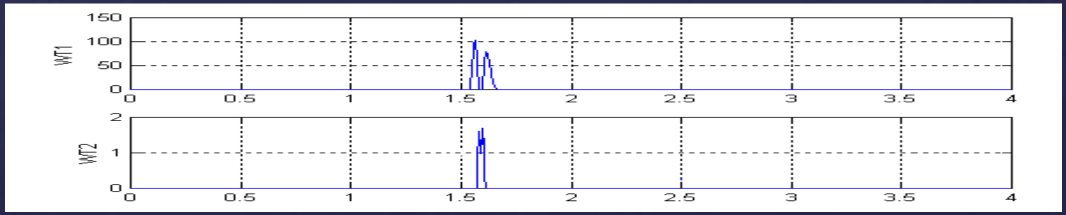


Clinical Criteria Characterizing Interictal Spikes

The maximum amplitude of a spike is at least 1.5 times larger than that of the background signal, where the background signal may be defined as the EEG activity lasting twice the duration of the spike (assumed in this case to be 140 ms) at either side of a potential spike.



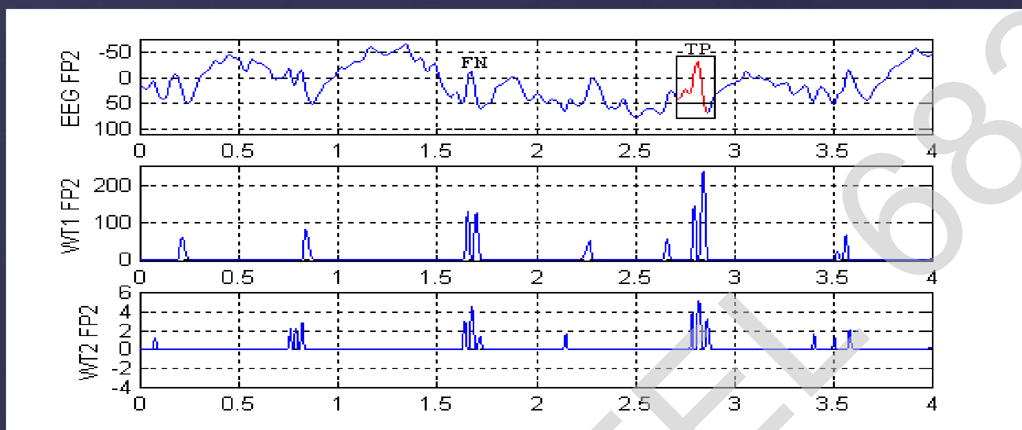
W1=[1 1 -1 -1]

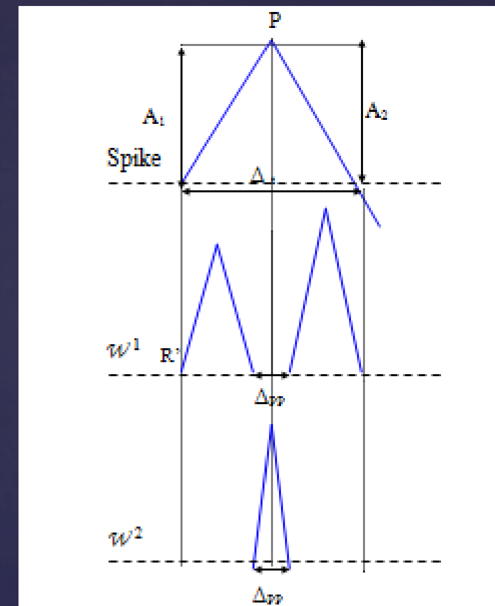


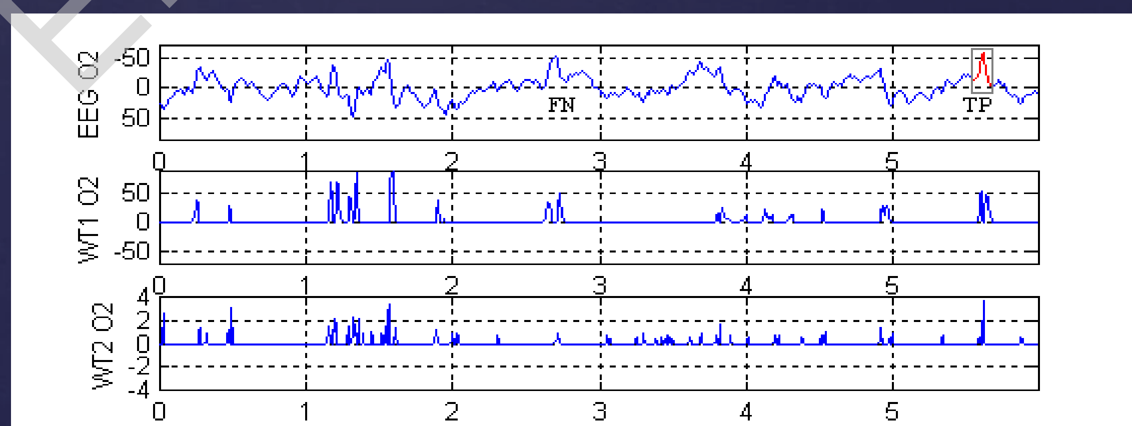
W2=[1 -1 -1 1]

Operators used in EEG

- The behavior of Walsh operators WT1and WT2







Artifact rejection Methods

- Visual inspection of the data
- Thresholding (e.g., everything above 100μV)
- Independent Component Analysis (ICA)
- Help if you have EOG, EKG and EMG channels

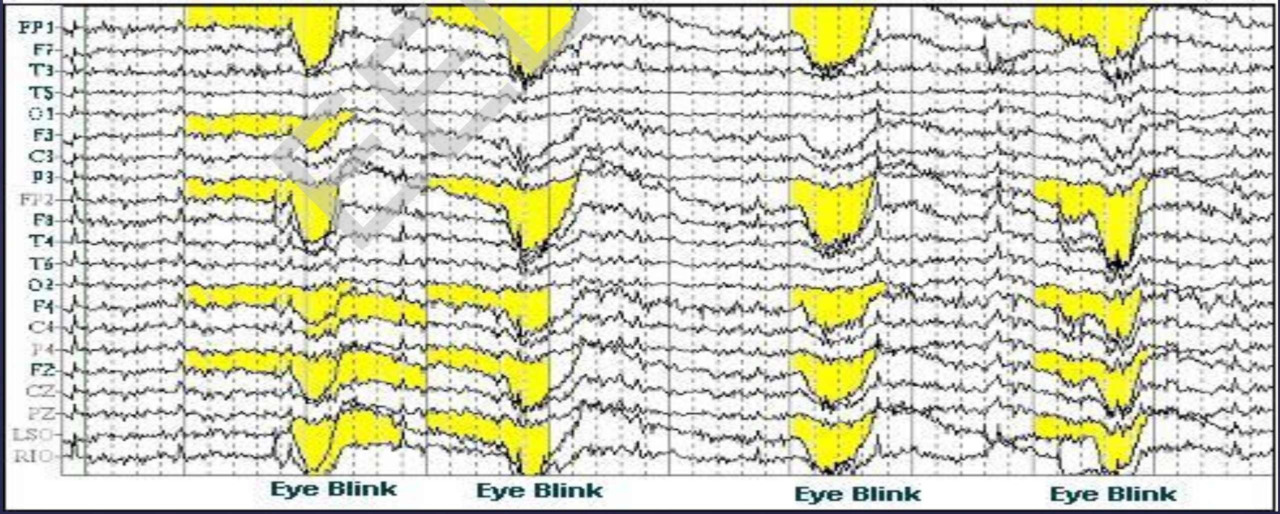
Importance of Artifact Removal

- The various waveforms of the EEG convey clinically valuable information.
- It is important to develop methods for the detection and objective quantification of the characteristics of the signal, to facilitate its interpretation.

Artifactual Activity in the EEG

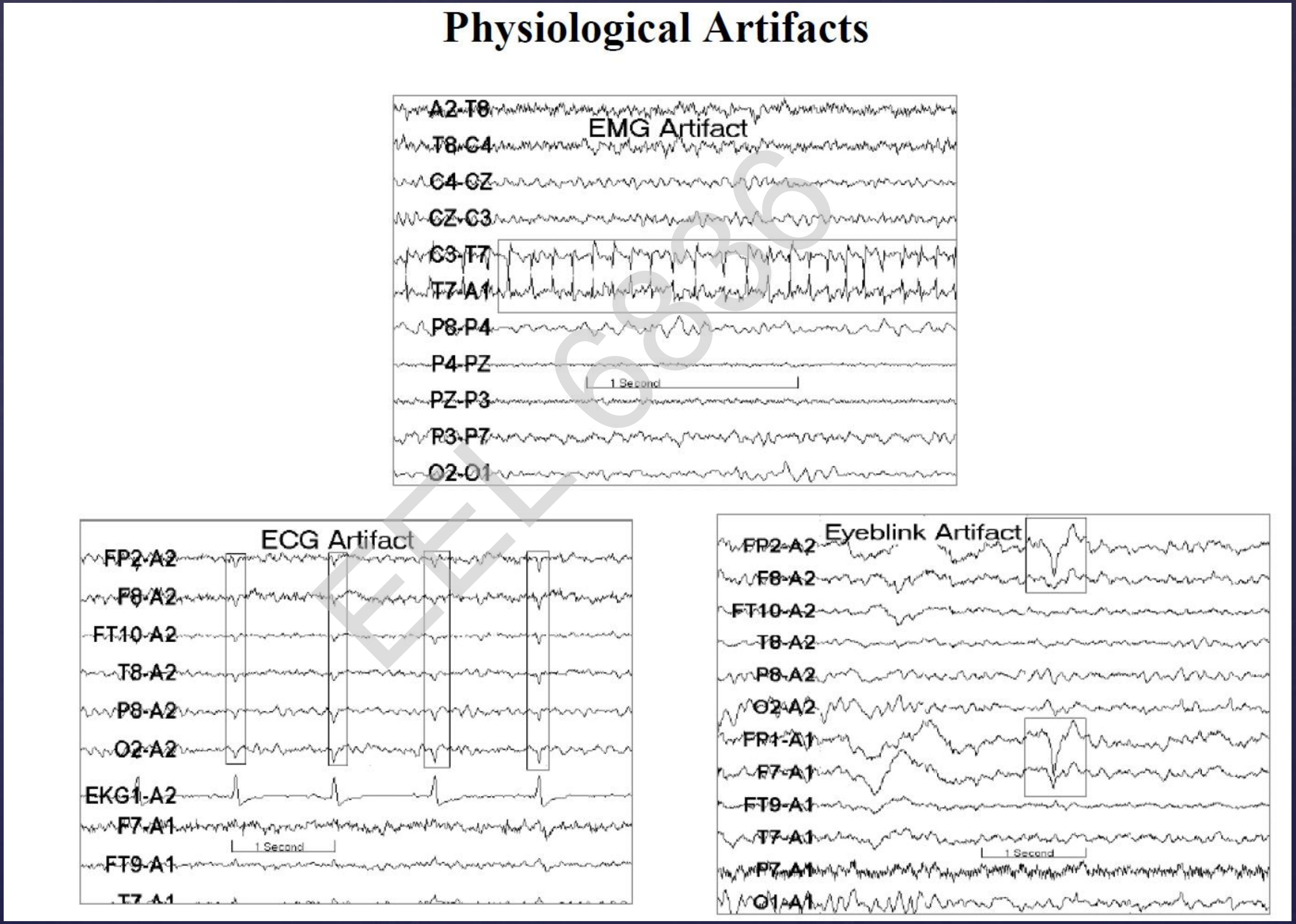
When recording EEG, artifacts may appear and they are not generated by cerebral activity. They may be due to other physiological activity originating from the subject, for instance:

- eye blink
- body movement (EMG)
- heart beat (EKG)
- interference from power lines and electrical sources from EEG machine



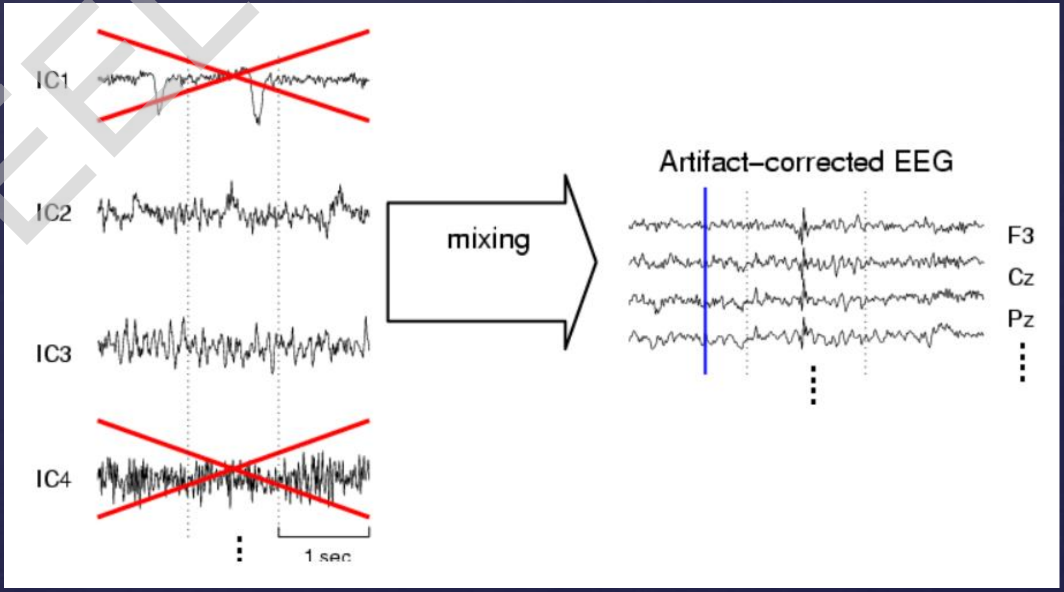
Artifacts such as eye blinks are the most common in scalp EEG data

Artifactual Activity in the EEG

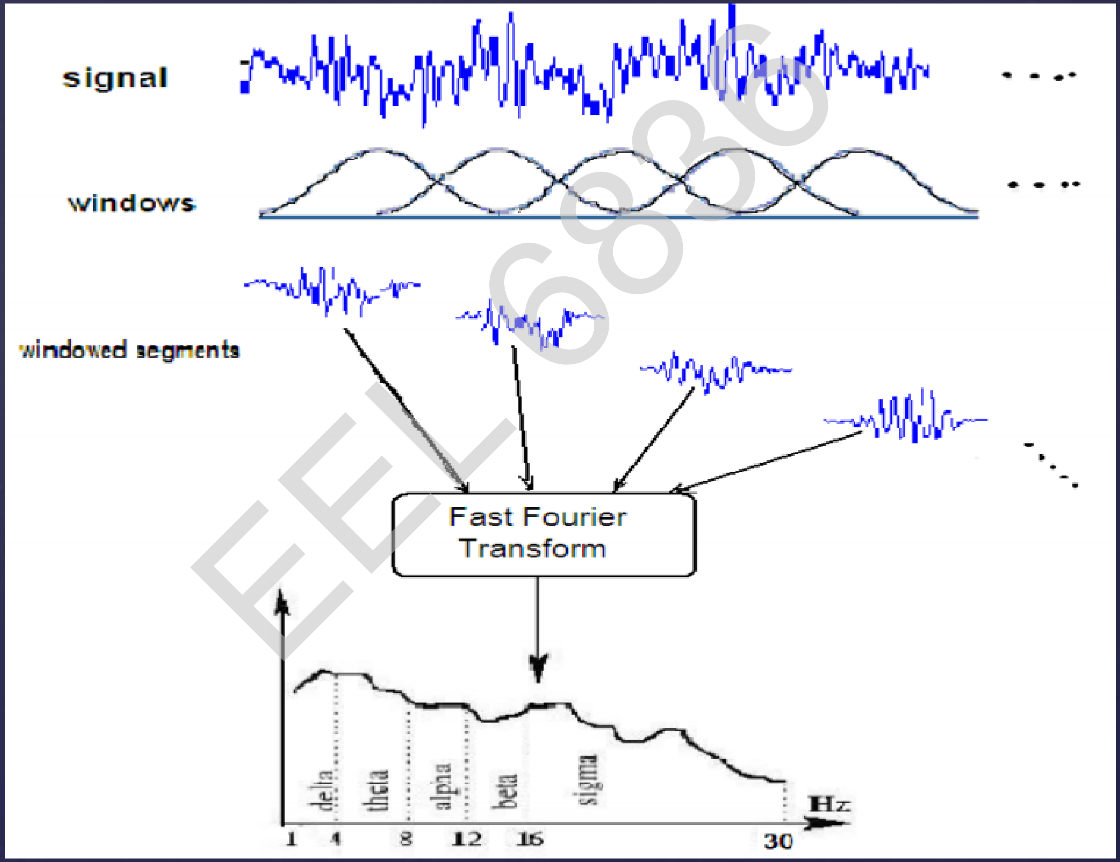


Artifactual Activity in the EEG

Jaw Movement Artifacts



EEG Features

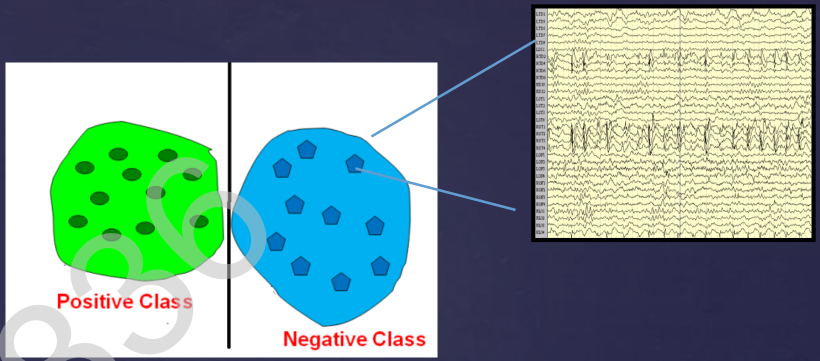


EEG Features

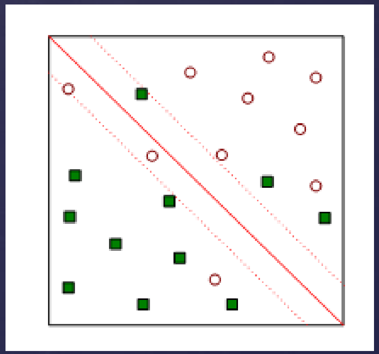
- Average, minimum, and maximum values of voltage in time domain.
- Activity (Variance).
- Autocorrelation of the signal in time domain.
- Area under the curve.
- Entropy.
- Lyapunov exponent.

Model-Based Classification

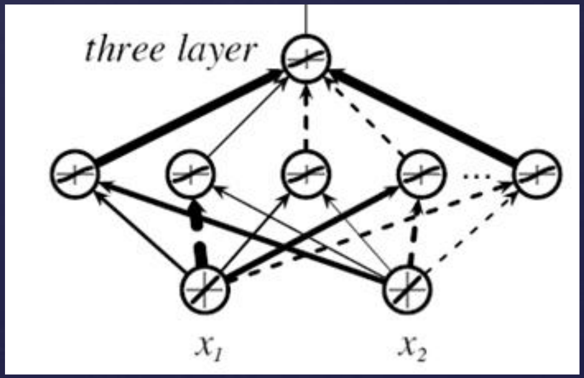
- Linear Discriminant



- Support Vector Machines



- Neural Networks



Coherence of EEG Signals

- The EEG coherence analysis is designed to find out whether the brain waves from two different parts of the brain are synchronized.

$$K(f) = \frac{\left|\sum_{i=1}^{N} P_{xy}(f,i)\right|^2}{\sum_{i=1}^{N} P_{xx}(f,i) * \sum_{i=1}^{N} P_{yy}(f,i)}$$

- The EEG coherence was calculated for the alpha activity of different combinations of pair of electrodes.

- P_{xx} and P_{yy} are the power spectrum corresponding to the pair of electrodes analyzed, and P_{xy} is the cross spectrum between the two electrodes.

$$P_{xx}(f,i) = X_i(f) * X_i^*(f)$$

$$P_{yy}(f,i) = Y_i(f) * Y_i^*(f)$$

$$P_{xy}(f,i) = X_i(f) * Y_i^*(f)$$

- The results demonstrated that for those electrodes that lead to seizure, the coherence values were higher than for the electrodes that do not lead to seizure.

Parameters used

$$R(r) = \frac{1}{N^2} \sum_{j=1}^{N-1} \sum_{i=j+1}^{N-1} \theta\left(r - \left|x_i - x_j\right|\right)$$

Correlation integral: It is a measure of spatial organization.

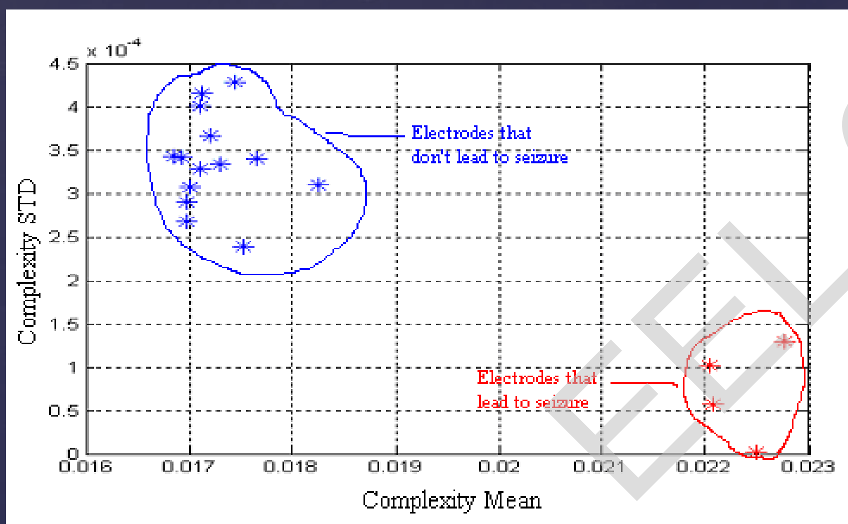
$$M(y) = \sqrt{\frac{\sigma(y')}{\sigma(y)}}$$

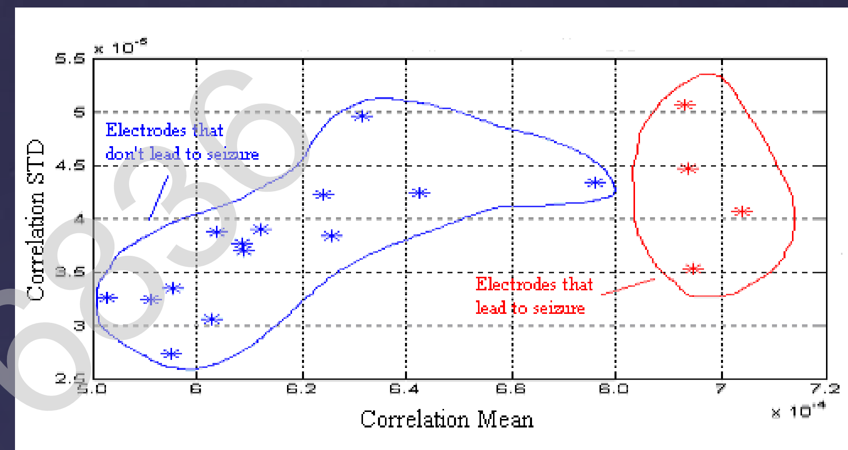
Mobility: It is a measure of deviation of voltage changes.

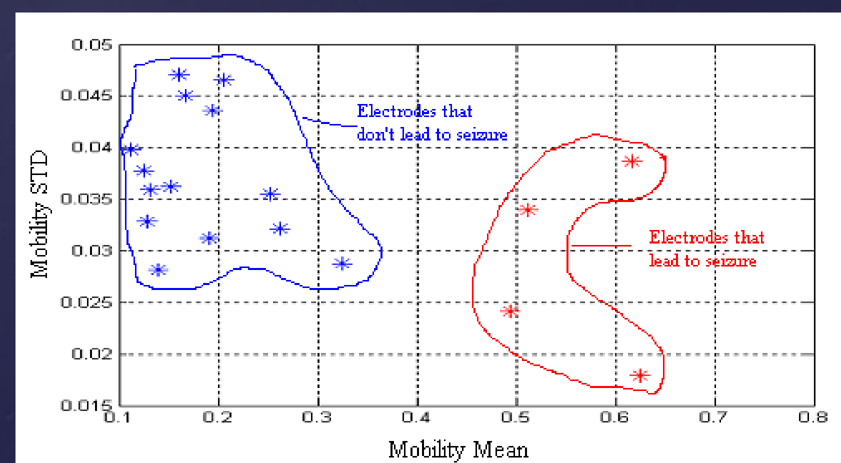
$$C(y) = \sqrt{\frac{M(y')}{M(y)}}$$

Complexity: It is a measure of details

Assessment of the EEG Nonlinear Dynamics







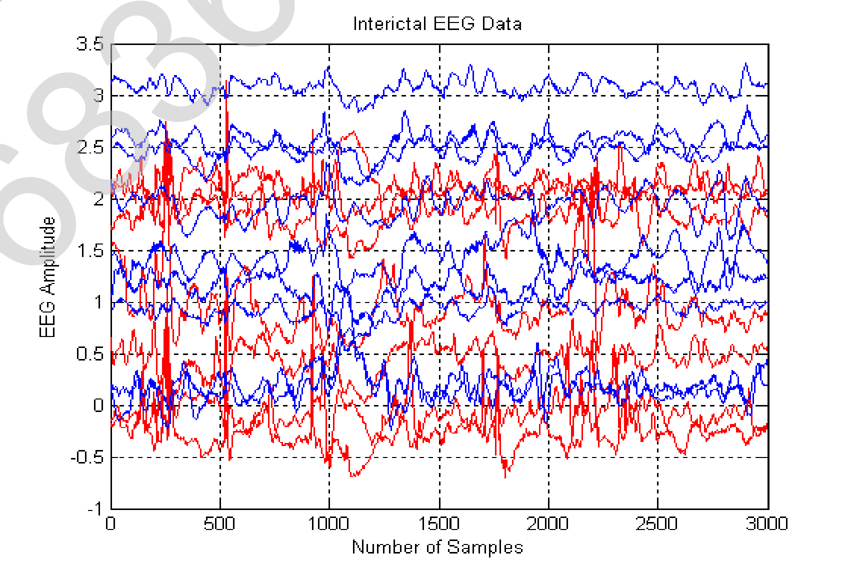
iEEG and EEG Applications

Subdural Interictal EEG Classification for Seizure Focus Localization

Objectives

- ➢ To extract features that best <u>characterize those EEG electrodes that lead to an ictal activity.</u>

- ➢ To <u>classify</u> and to group EEG channels that lead to seizures.



Combining TMS and EEG

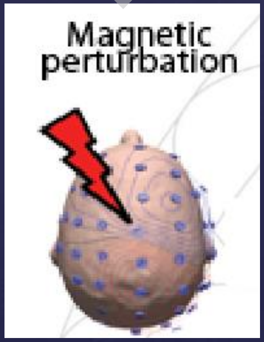
What do we know about TMS?

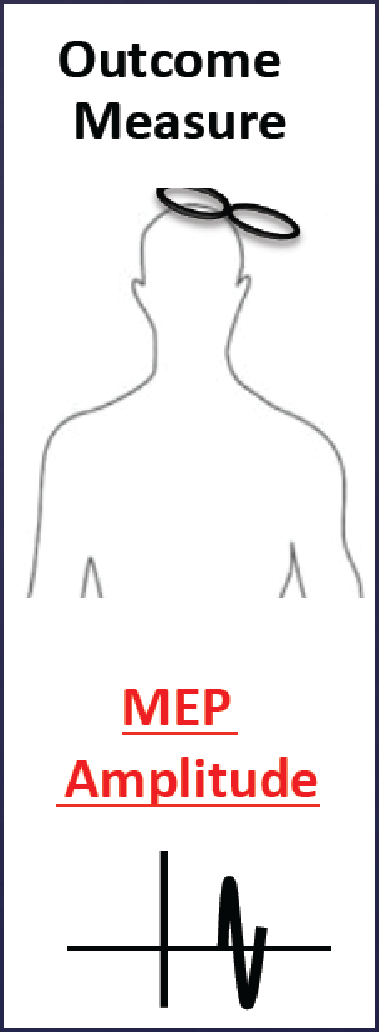
TMS Protocol:

Single Pulse TMS
- Cortical Mapping
- Motor Threshold
- Central Conduction Time

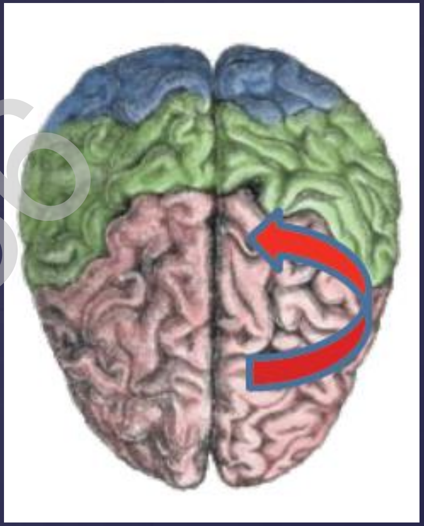
Repetitive TMS

- Many things happen at the physiology level in few milliseconds. EEG has an excellent temporal resolution (up to 5KHz sample frequency)
- What happens outside of M1? How does information travel from the stimulation site to connected areas?
- We know where the activation starts: TMS pulse in target area triggers the information flow





This is really interesting, but ….. more details needed, Right?



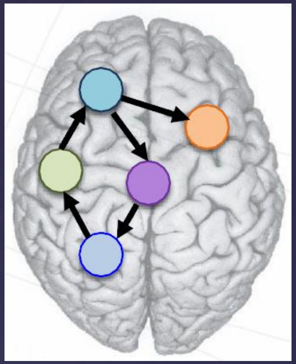
- **Cortical origin?**
- **Non motor regions?**

Then, EEG to the Rescue!!!

In summary what can EEG tell us?

- Excitability of cortical tissue, and the balance of Excitation and Inhibition
- Brain state and the integrity of different networks
- Dynamics of interactions within and between different brain regions.

Clinical Applications

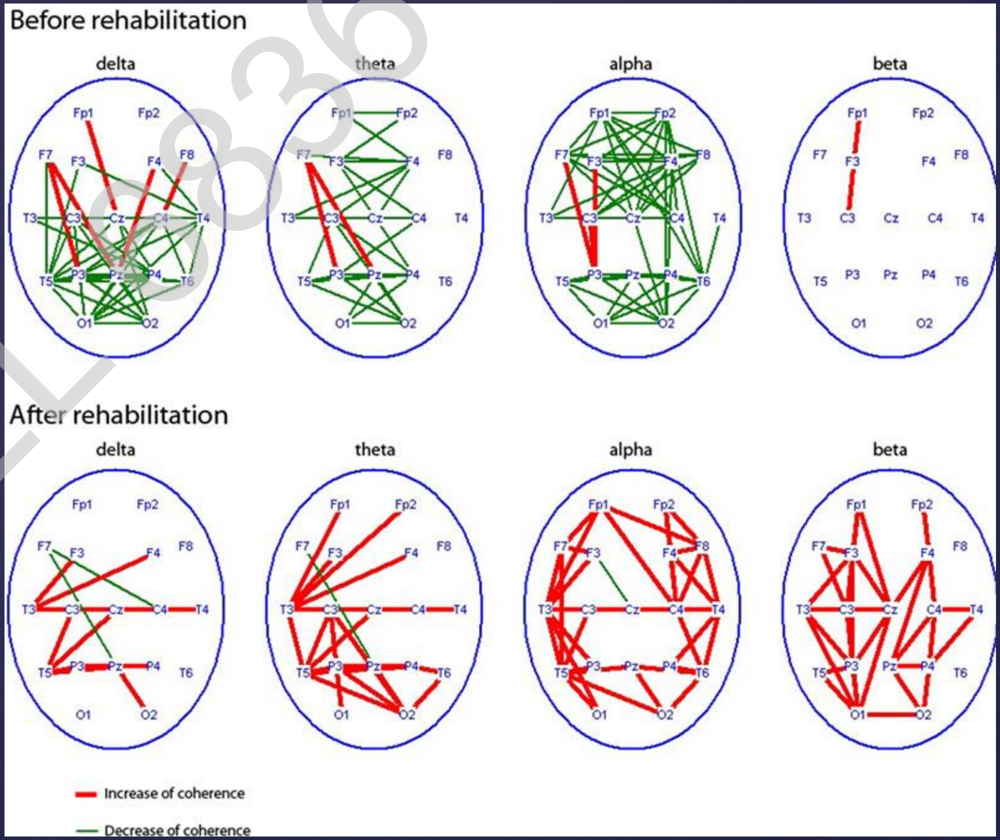


Potential Diagnosis Aspects of TMS:

TMS-EMG measures of inhibition, excitation, connectivity, and plasticity observed across several Neuropsychiatric disorders such as:

- Epilepsy
- Parkinson's Disease
- Stroke
- Schizophrenia
- Autism
- Bipolar Disorder
- Depression
- Alzheimer's Disease
- etc.

- Spread of activation from hotspot (effective connectivity studies)



Reference: **Journal of Behavioral and Brain Science** Vol.3 No.6(2013), Article ID:38056, Zhavoronkova[1], A. Zharikova[1,2], O. Maksakova[2]
[1]Institute of Higher Nervous Activity and Neurophysiology, Russian Academy of Sciences, Mosco Russia

Added Value of TMS+EEG

- Monitor cortical activation with **high temporal resolution**
- A more **direct** measure of TMS effect

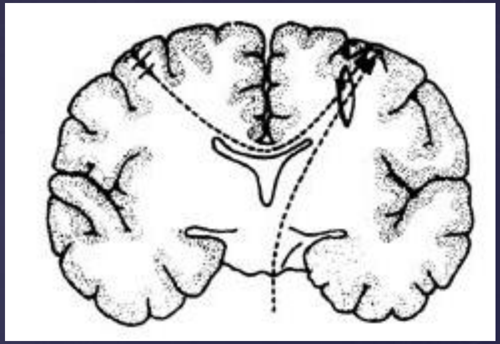
Examine physiology of motor AND non motor regions at various mental states of sleep, rest, cognitive processing:

  - Local excitation, inhibition and plasticity
  - Functional connectivity between regions
  - Disrupt behavior to examine causality

  - Improve diagnosis
  - Investigate the mechanism of actions of rTMS therapy
  - Safety monitoring during rTMS (e.g. in epilepsy)

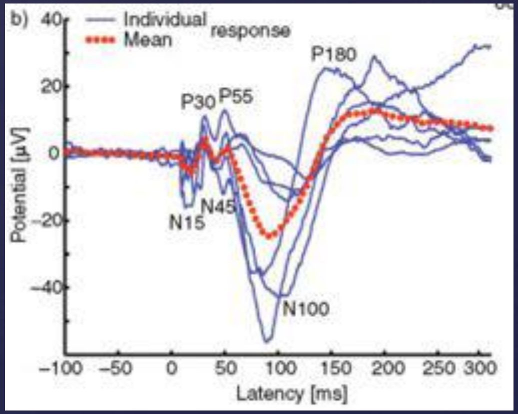
Some Examples

Transcallosal Transfer Time in Motor Cortex:



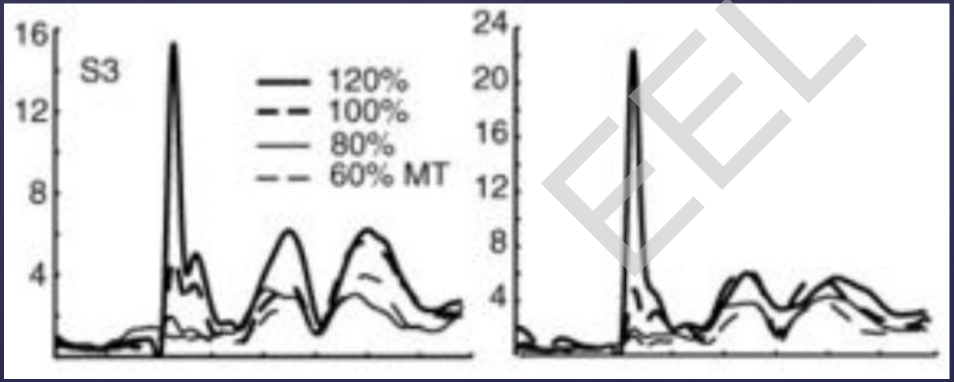
In **1989**, (Cracco et al. 1989, Electroencephalogr Clin. Neurophysiol.) examined transcallosal responses by applying TMS to one side and recording EEG from the other side.

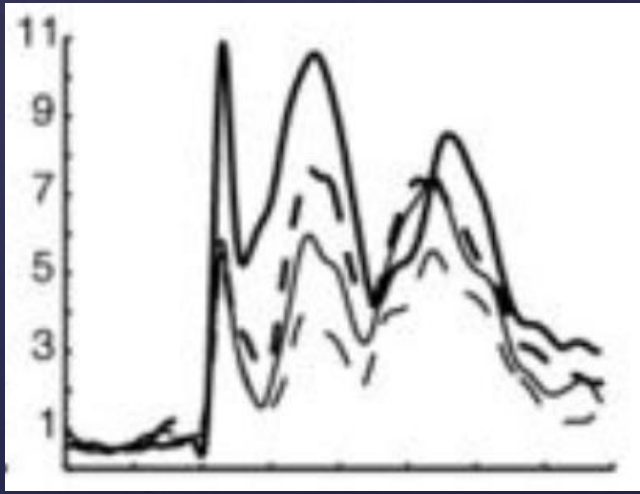
TMS Induces Several EEG Peaks:
N15, P30, N45, P55, N100, P180
(Komssi, Human Brain Mapping, 2004)



TMS generates a clear EEG response even below motor threshold……

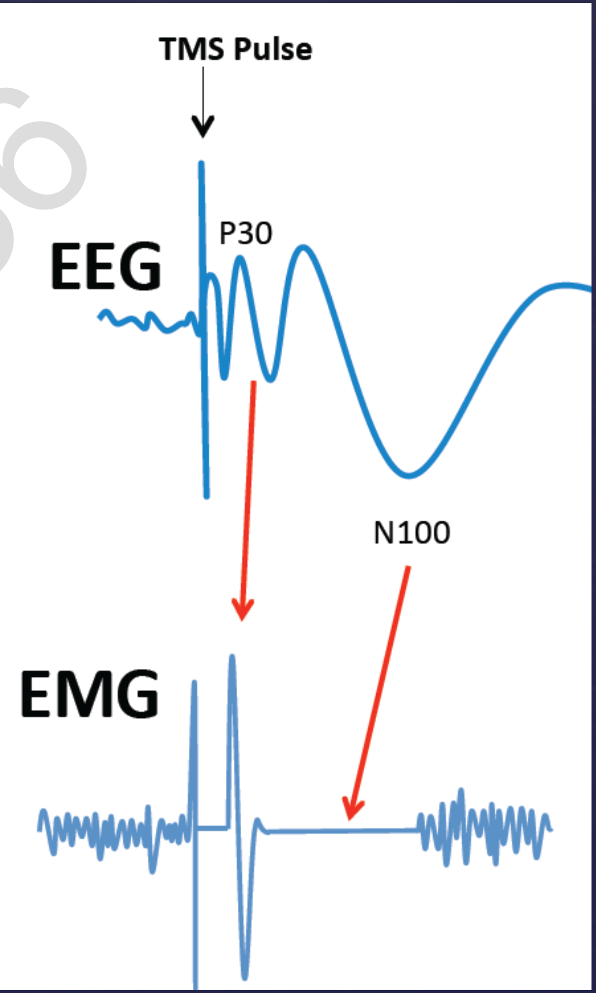
- According to Komissi et al, Human Brain Mapping, 2004. **60% of motor threshold was enough to evoke a Cortical response.**





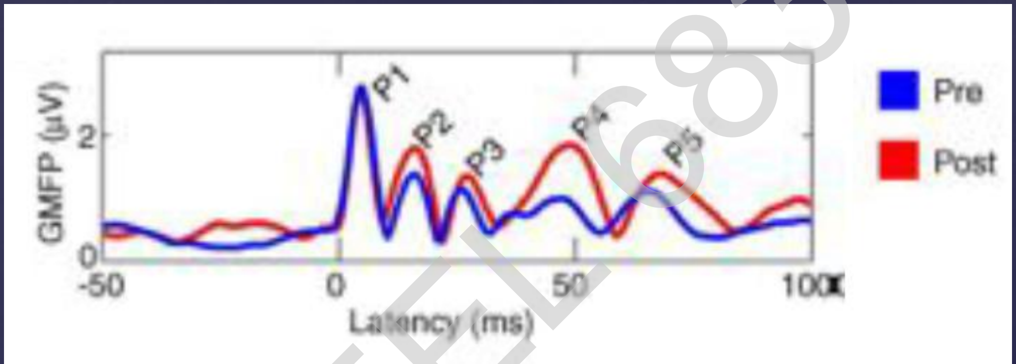
TMS Induced Cortical vs. Motor Response

- **The N15-P30 correlated with the amplitude of MEP at the periphery.** (Maki & Ilmoniemi 2010).
- **N100 may be related to Inhibitory mechanism.** (Bender et al., 2005; Bonato et al.,2006; Farzan et al.,2013)



LTP-like Plasticity with rTMS

- Esser 2006: Following, 5 Hz rTMS to motor cortex, a potentiation of the EEG potentials between 15 and 55ms.



Note:

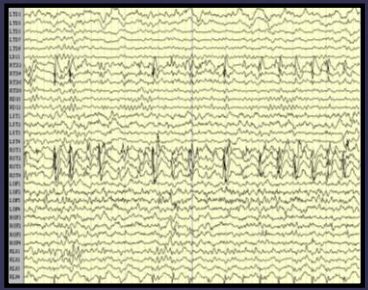
- The use of EEG to assess brain responses to TMS rather than muscle output allows the effects of rTMS to be investigated in non-motor brain areas that may be linked to various neuropsychiatric disorders.

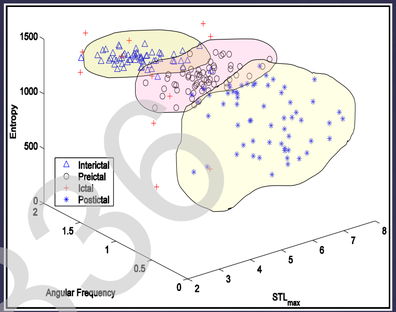
- Potentiation may occur at sites distant to the site of stimulation to a larger extent than where stimulation is delivered.

Automated EEG Algorithm Paradigm

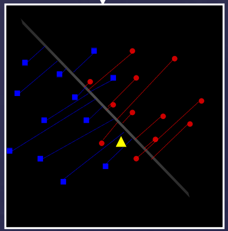
Data Acquisition

Multichannel
Brain Activity





Optimization:
Feature Extraction/
Clustering



Statistical Analysis:
Pattern Recognition

Interface Technology
(Electrodes)

Stimulator

User/Patient

Initiate a variety of therapies
(e.g., electrical stimulation,
rTMS, drug injection)

Drugs