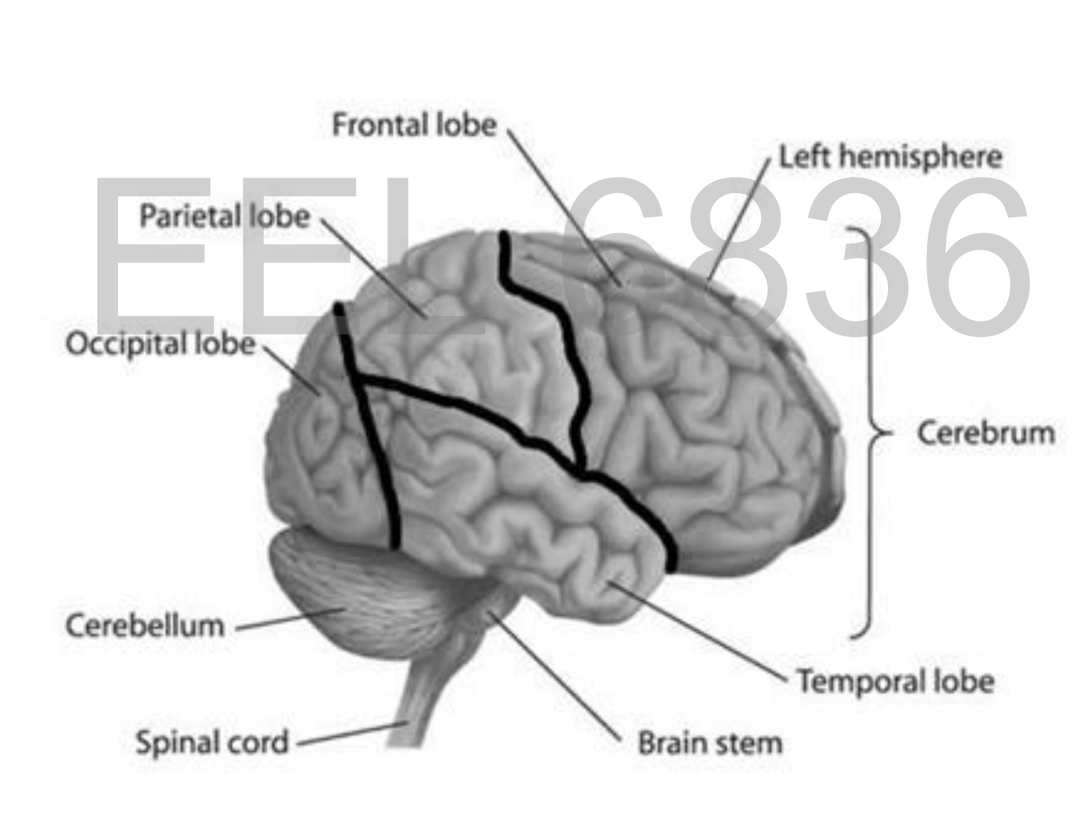
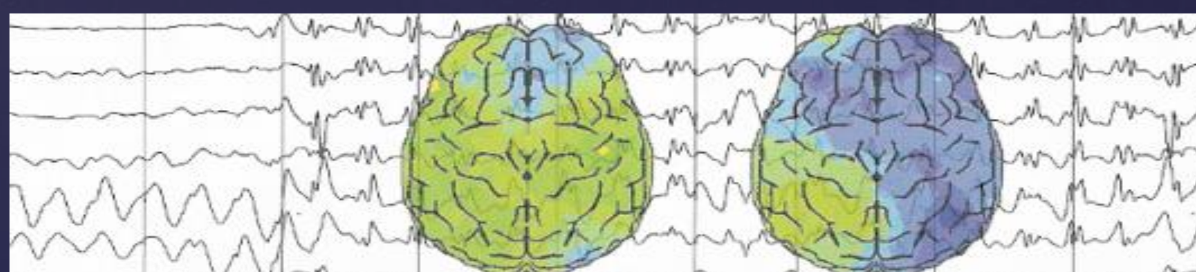
Electroencephalogram (EEG)

EEG records the brain's electrical activity by measuring differences of potentials in electrodes located on the scalp.



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.



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

Electroencephalogram (EEG)

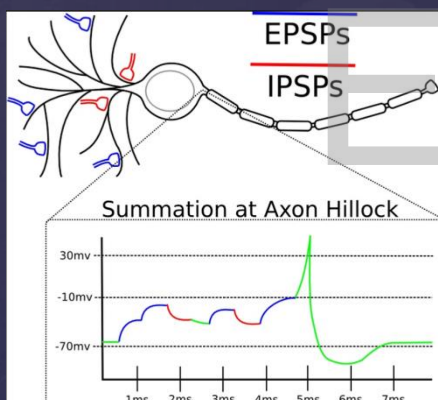
What is measured?

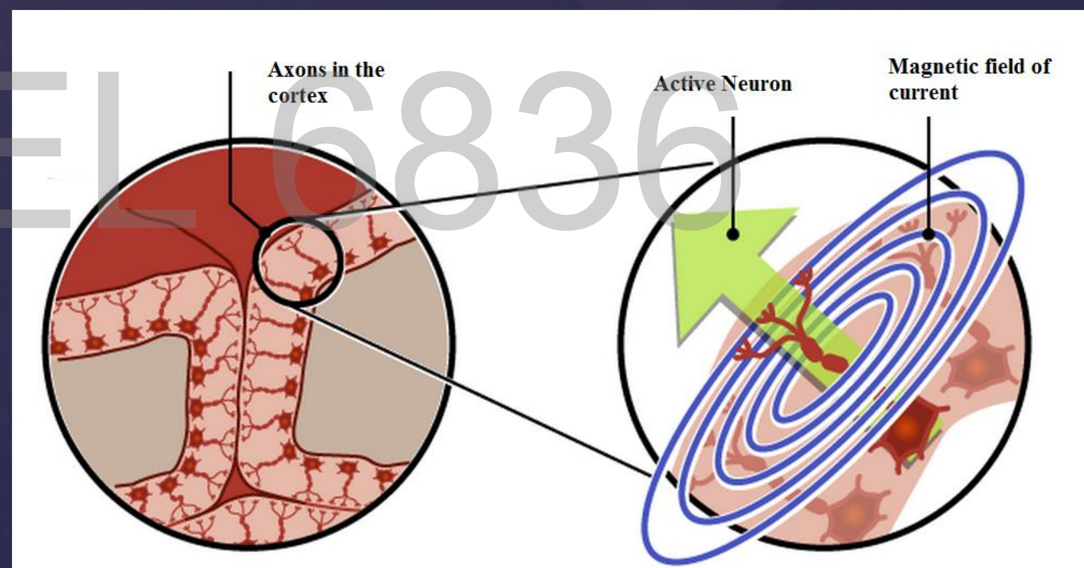
Electrical changes in groups of neurons.

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

Electroencephalogram (EEG)

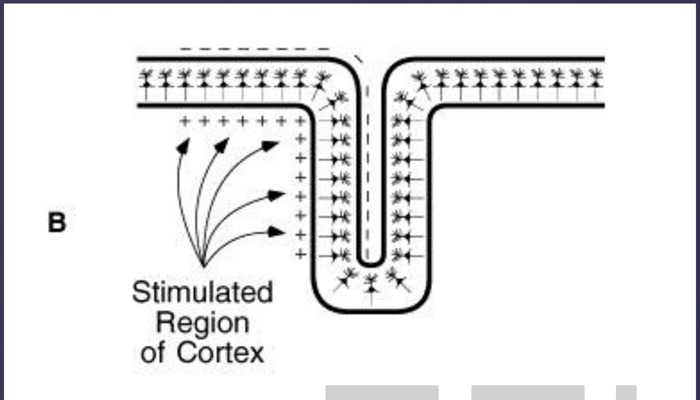
Scalp-recorded EEG oscillations are hypothesized to be generated by the summation of excitatory and inhibitory post-synaptic potentials in cortical pyramidal neurons.





EPSP + IPSP generated by synchronous activity of neurons.

Pyramidal Cell Orientation in Cortex



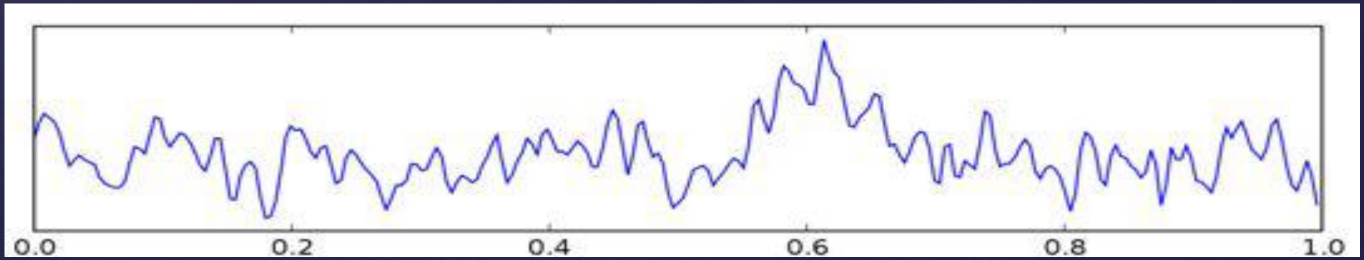
5 Electrical activity from **gyri** more detectable at scalp than activity from **sulci**

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

↓

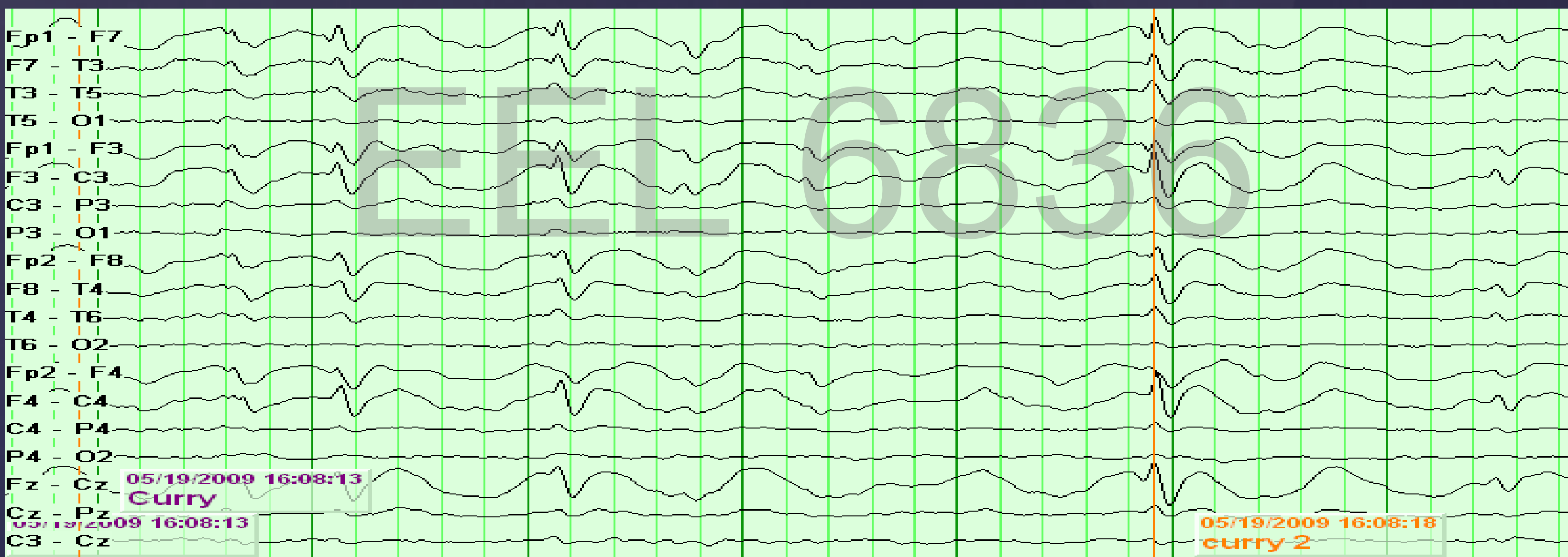
"Not Fully Understood"

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.

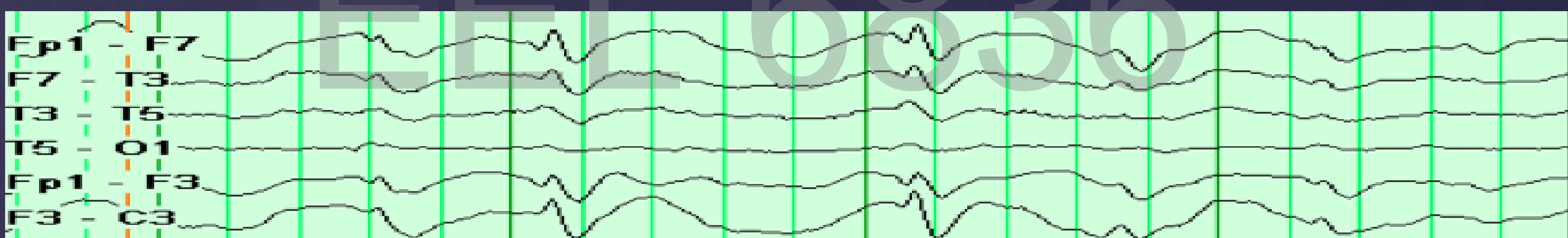


EEG showing Epileptiform activity (Interictal Spikes) in some channels

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 is 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.

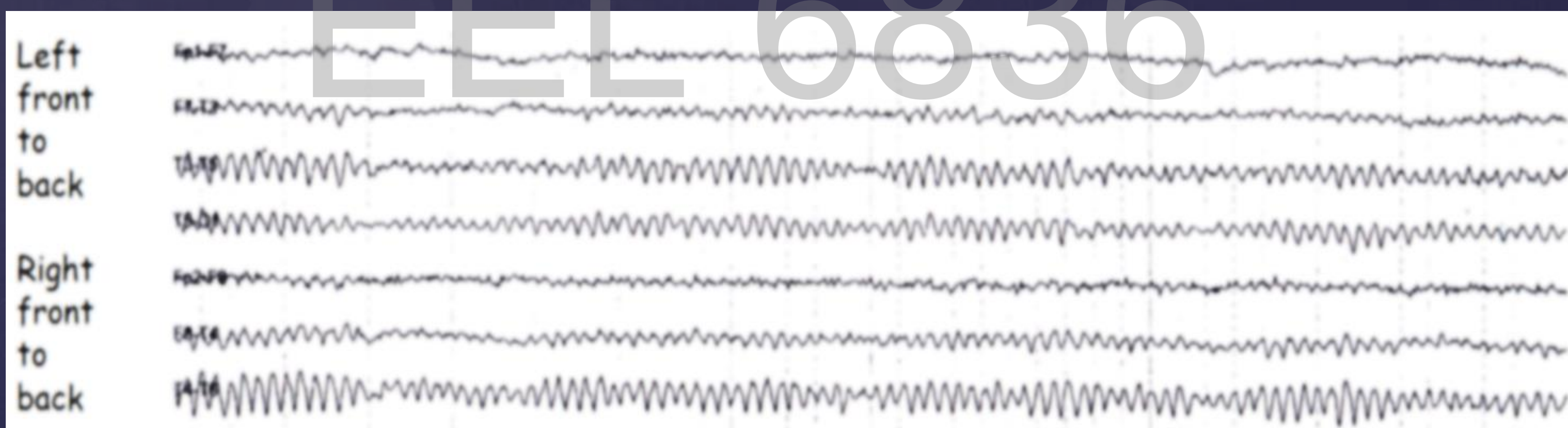
EEG

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 may favor different types of computation, direction of attentional control, or level of connectivity.**

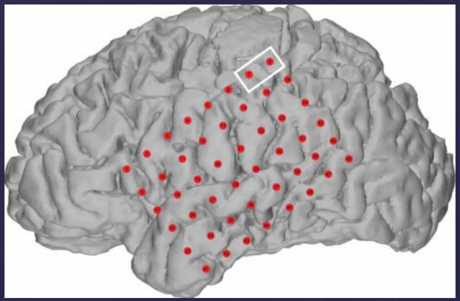
- **Interactions between cortical oscillations within and between brain regions may mediate <u>optimal information processing.</u>**

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.**

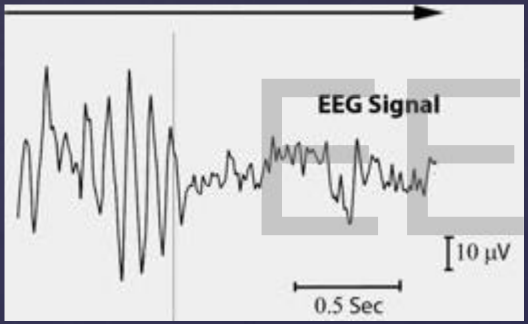
External

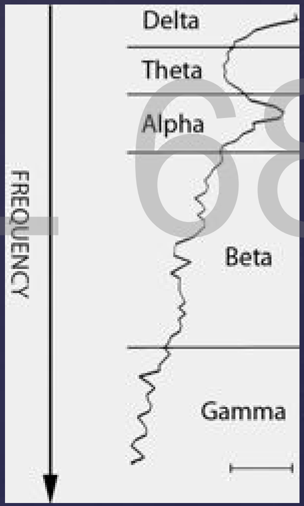
Internal

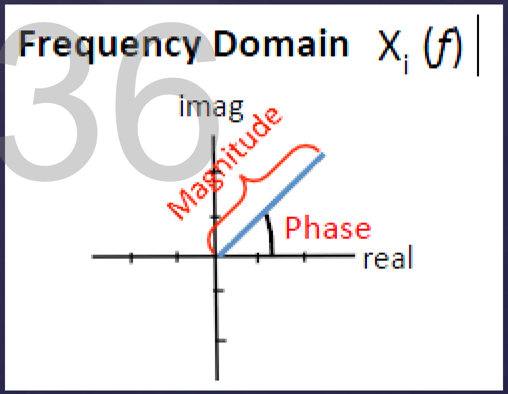


Ho to Analyze EEG?

TIME vs. FREQUENCY DOMAIN



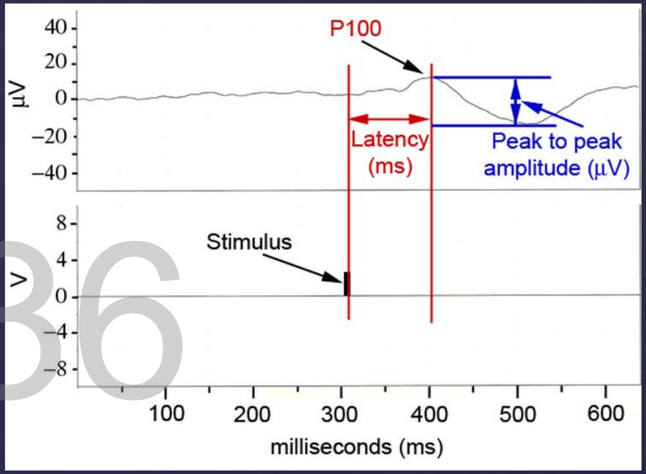


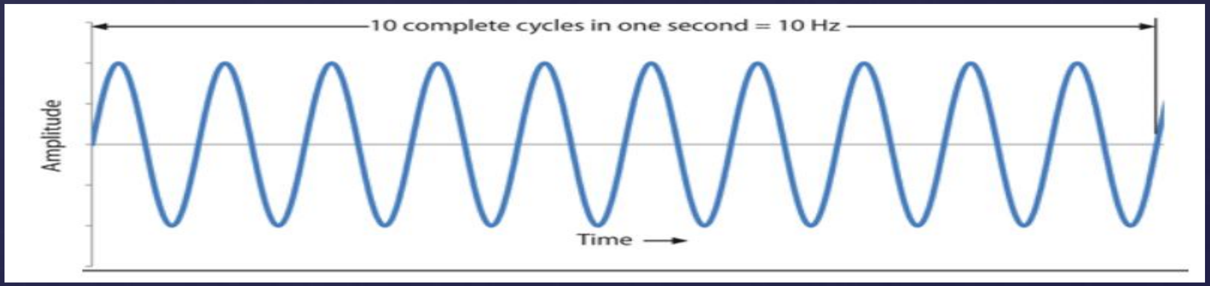


Local Response:
- Amplitude
- Frequency (Power)
- Phase

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 sec the signal crosses 0 microvolts (uV) and goes from plus to minus.

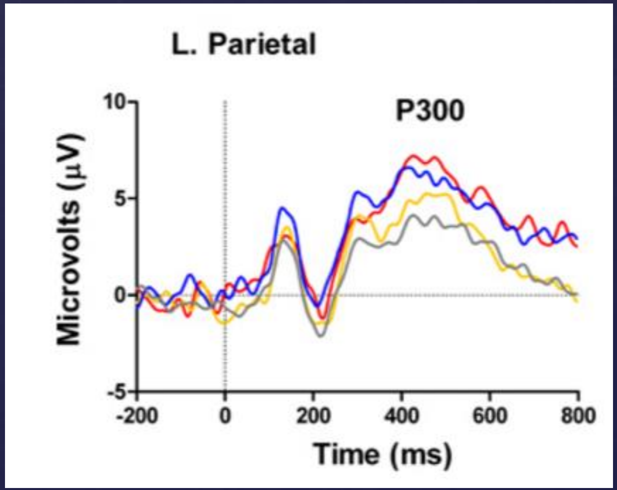




EEG Derivatives

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

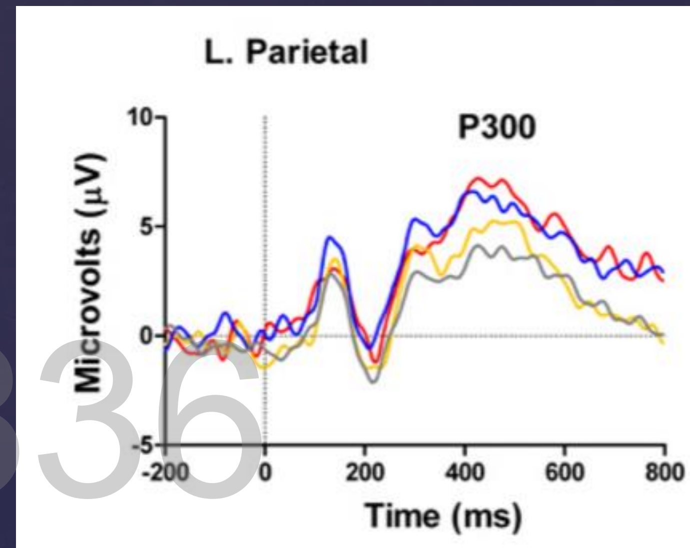
- Event-related potentials (ERPs) are very small voltages generated in the brain structures in response to specific events or stimuli.
- Event-related potentials can be elicited by a wide variety of sensory, cognitive or motor events.
- ERPs in humans can be divided into 2 categories: The early waves, 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…

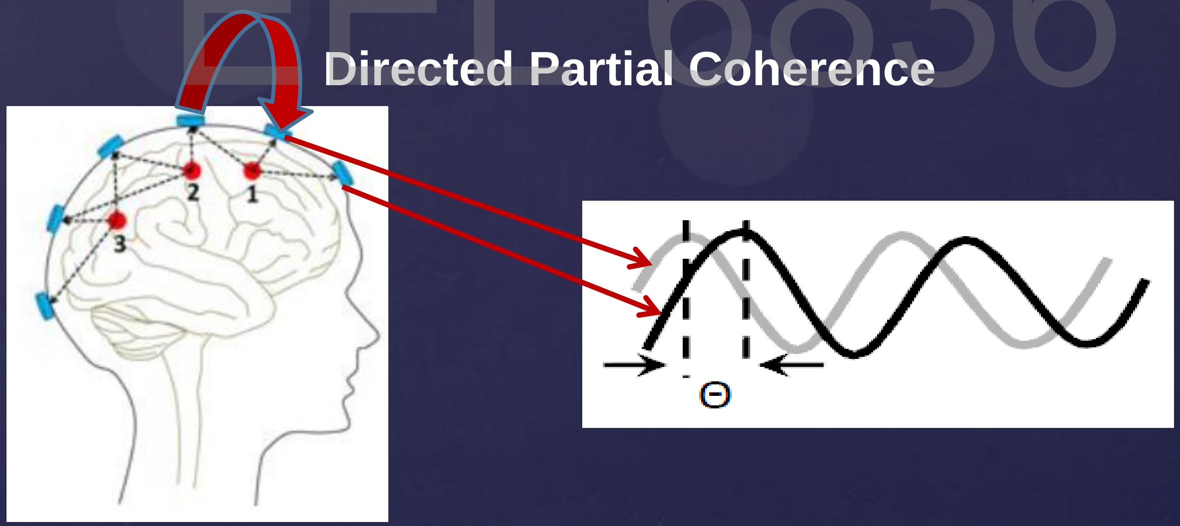
- Time-locked average of EEG from many trials involving the same ‘event’
- **EEG =20 - 50μv / ERP=1-10 μv**



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

EEG Functional Connectivity

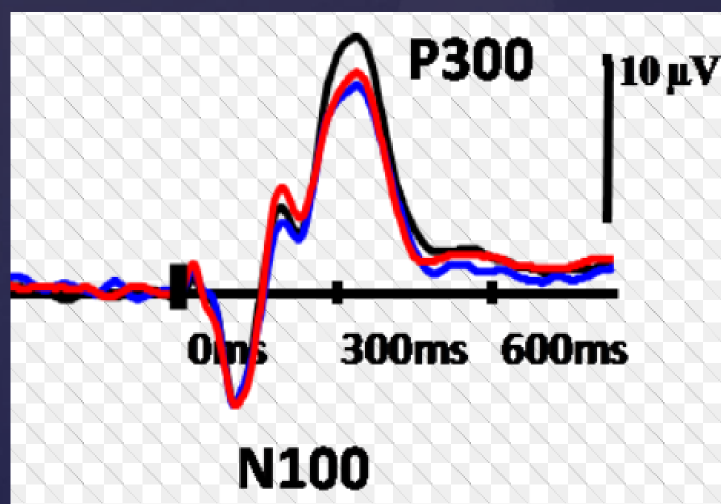
- Correlation (time)
- Coherence(frequency)
- Synchrony(phase-locking)



EEG Derivatives

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

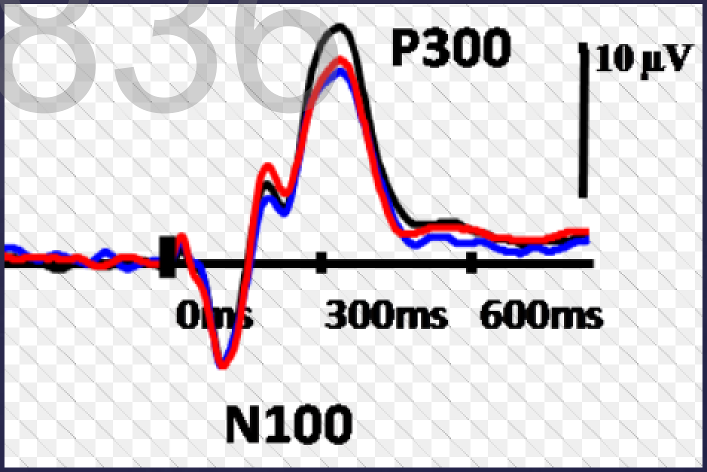
- You can average ERPs because the stimulus generates a series of synaptic events always time-locked and phase locked to the evoking event. But it's impossible to predict what the spontaneous EEG is doing when stimulus is presented.



EEG Derivatives

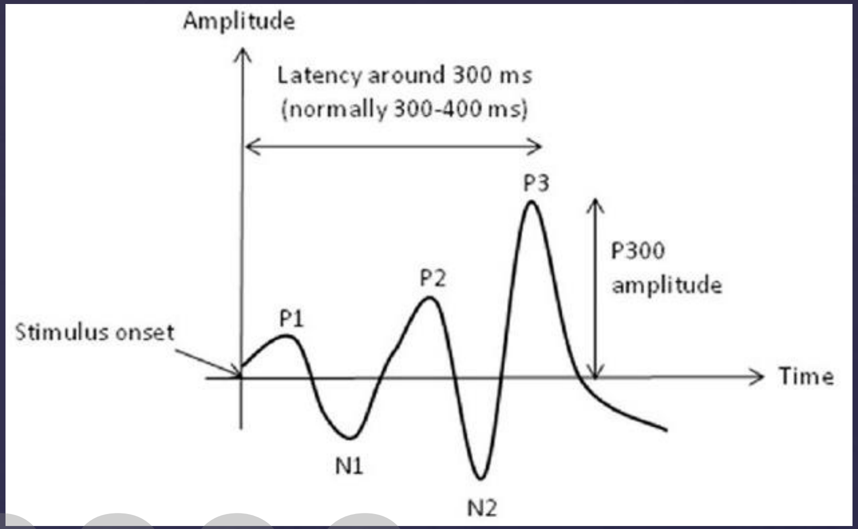
P300 wave is the major component of research in the field of ERP. For auditory stimuli, the latency range is 250-400 msec for most adult subjects between 20 and 70 years of age. Reduced P300 amplitude is an indicator of some disorders (alcohol dependence, drug dependence, nicotine dependence, conduct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

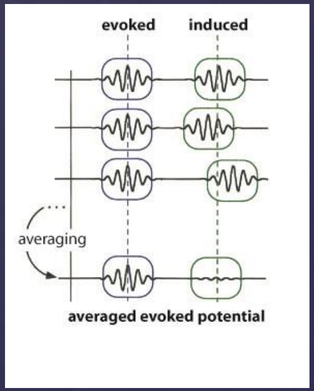
- The signal is typically measured most strongly by the electrodes covering the parietal lobe.
- Magnitude and timing of this signal are often used as metrics of cognitive function in decision making processes.



EEG Derivatives

- The scalp distribution of P300 (or any ERP) may represent a cognitive phenomena.
- P300 is usually largest over Pz and smallest over Fz.





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 new neural signs of cognitive and emotional events have been reported with the advent of these new methods.

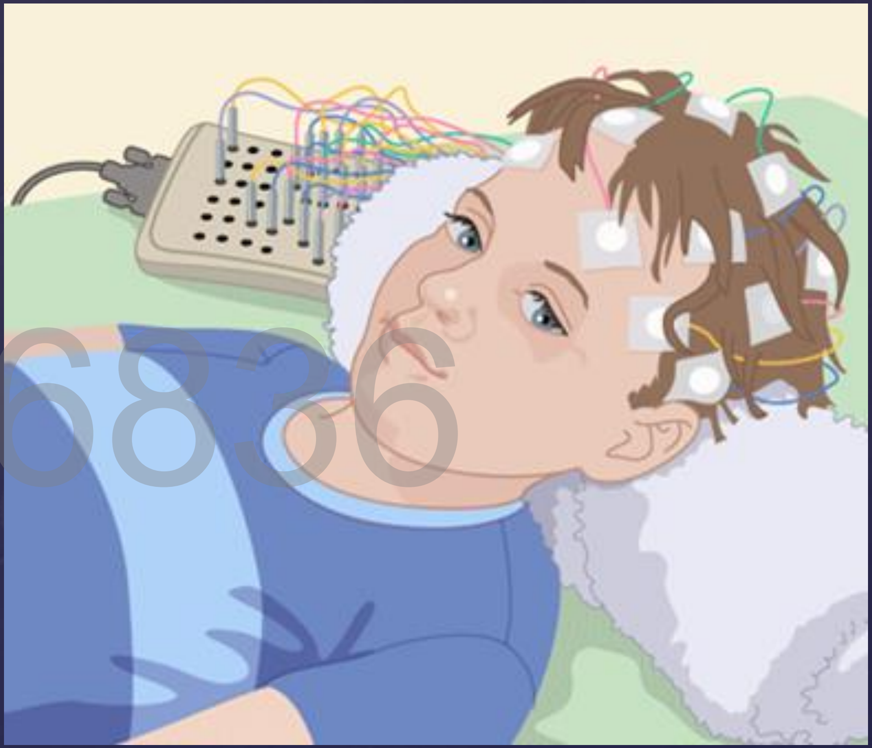
Strengths and Advantages of EEG Signals

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

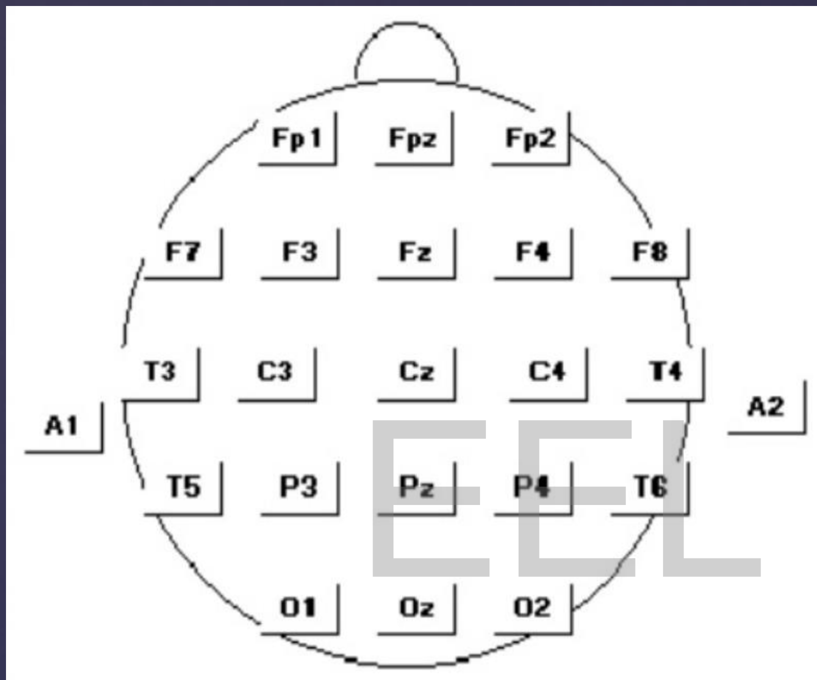
- Provides some spatial or localization information.
- More tolerant to subject movement than fMRI
- Low cost.
- Readily repeatable.
- Portable / ambulatory.

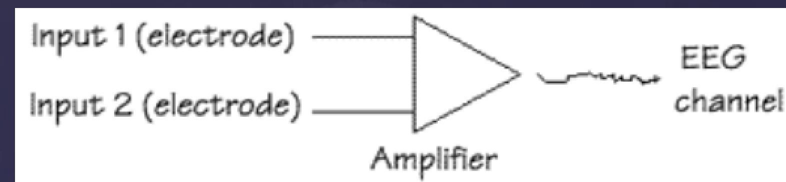
EEG Recording Techniques

- 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.



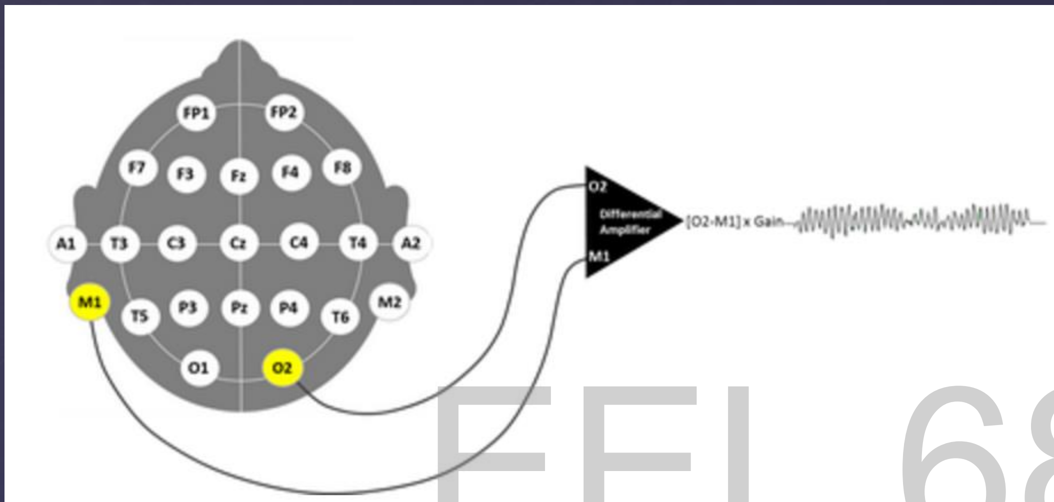
EEG Montage





- 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

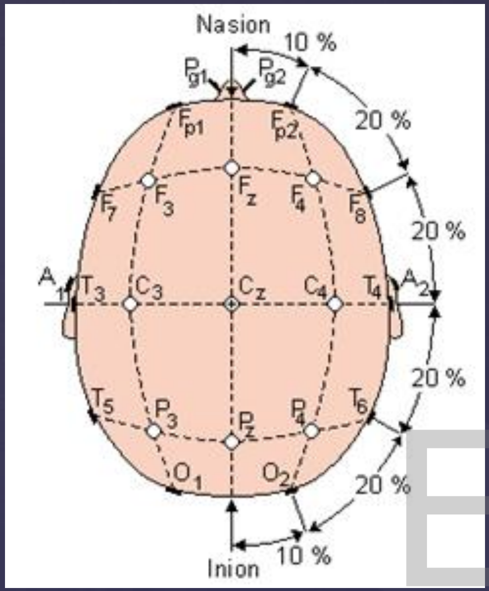


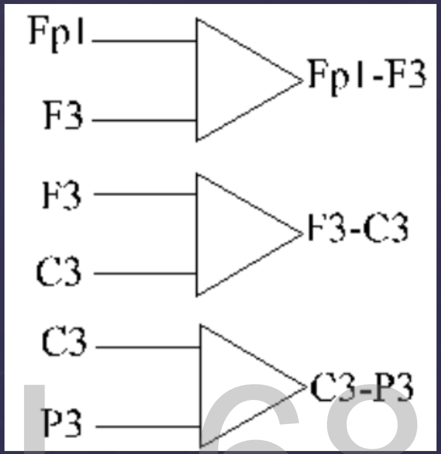
- All biological recordings uses differential amplifiers.
- These amplifiers eliminates any electrical noise detected by both inputs (electrodes).

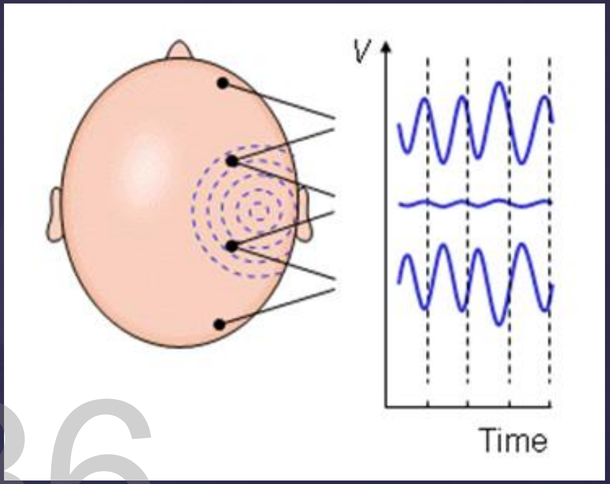
- By convention, a differential amplifier subtracts the voltage in input 1 from that in input 2 at any single point in time.
- EEG amplified signal =(input 1 voltage) – (input 2 voltage), therefore if input 1 (positive) < input 2 (positive), then the amplified signal would be negative.
- Polarity is relative to the input 2 selected.

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

Bipolar montage



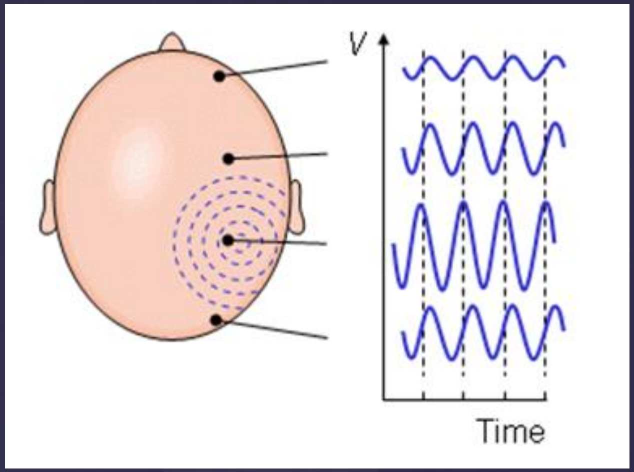




Each channel represents the <u>difference between two adjacent electrodes</u>.

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.

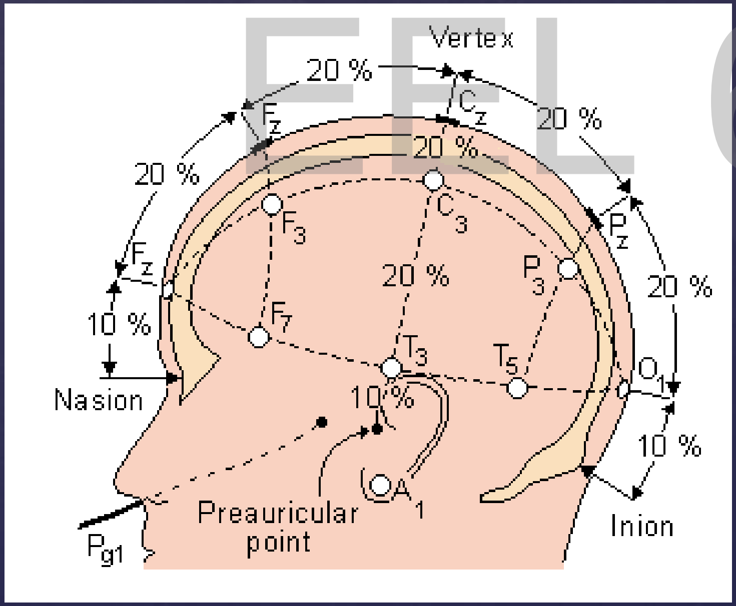
Referential montage

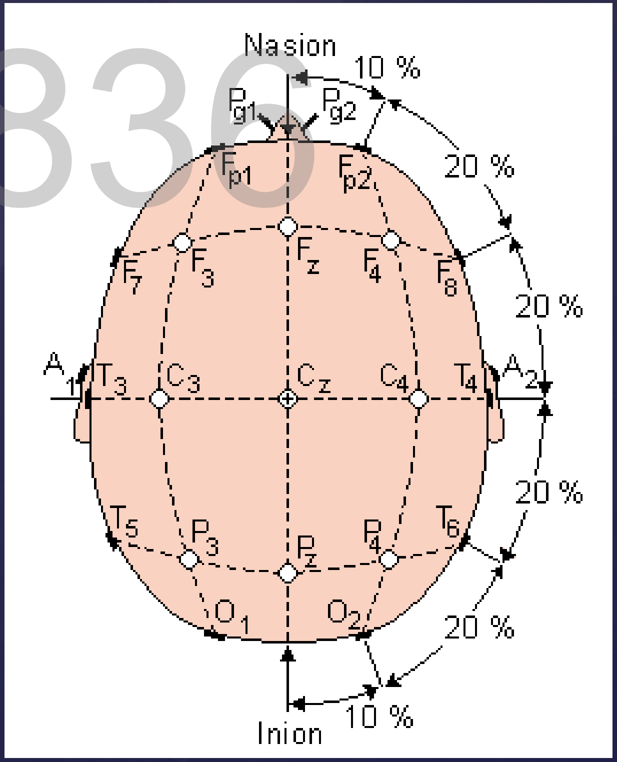


- Each channel represents the difference between a certain electrode and a designated reference electrode.
- There is no standard position at which this reference is always placed; it is, however, at a different position than the "recording" electrodes. Midline positions are often used because they do 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.

10-20 montage

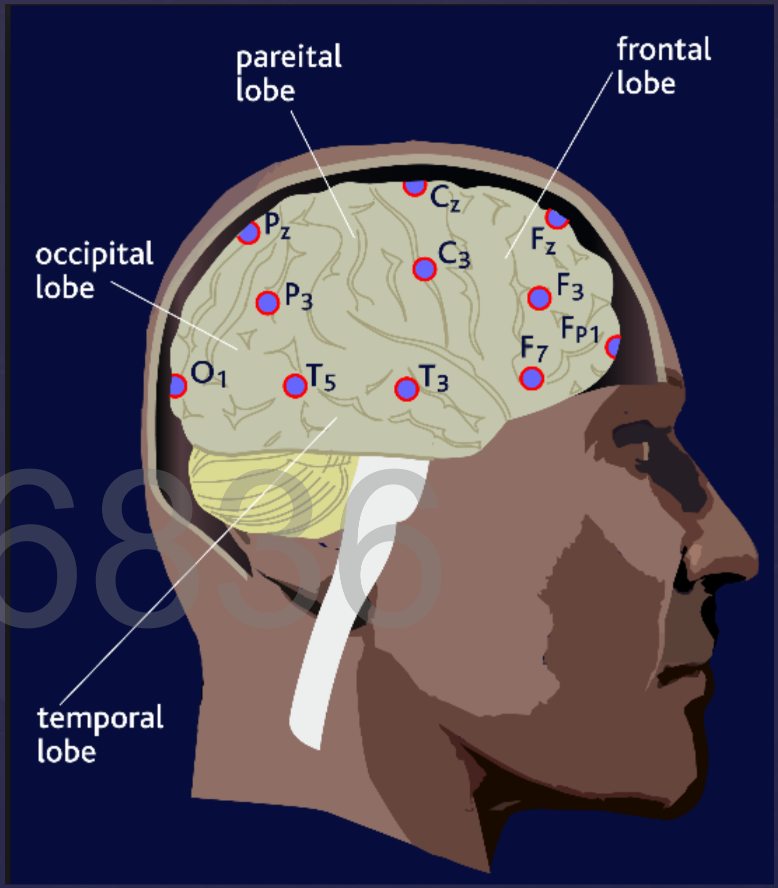
- It is based on anatomical locations and on percentage of distance among these points giving the 10 or 20% in the system name.
- The original 10-20 system has only 19 electrodes but has been extended to accommodate more than 200 electrodes.





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.



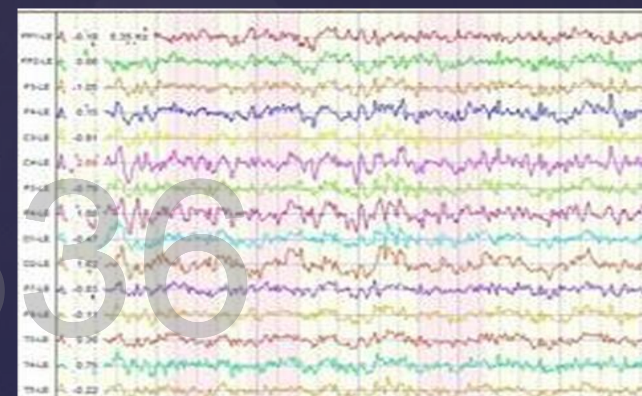
- The raw plot of one live electrode vs. reference (referential montage) can be always transformed into another representation to show the voltage difference of two specific live electrodes (bipolar montage). This allows personalizing the analysis without the need of repeating the recordings.

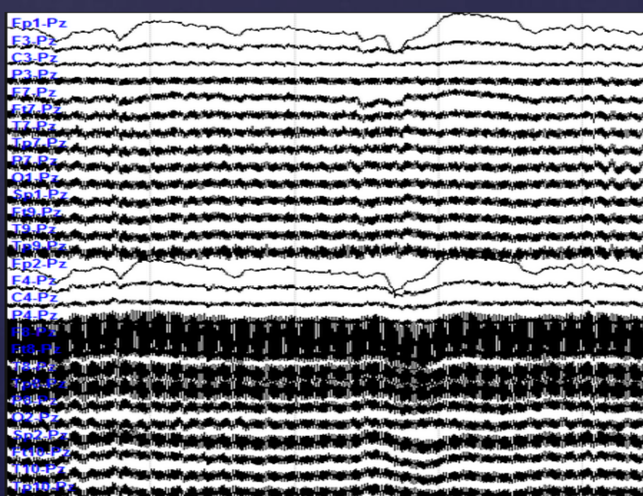
EEG Cap

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

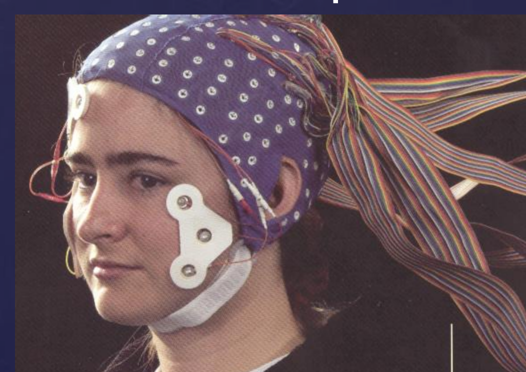
Sliver electrodes

Individual Electrodes



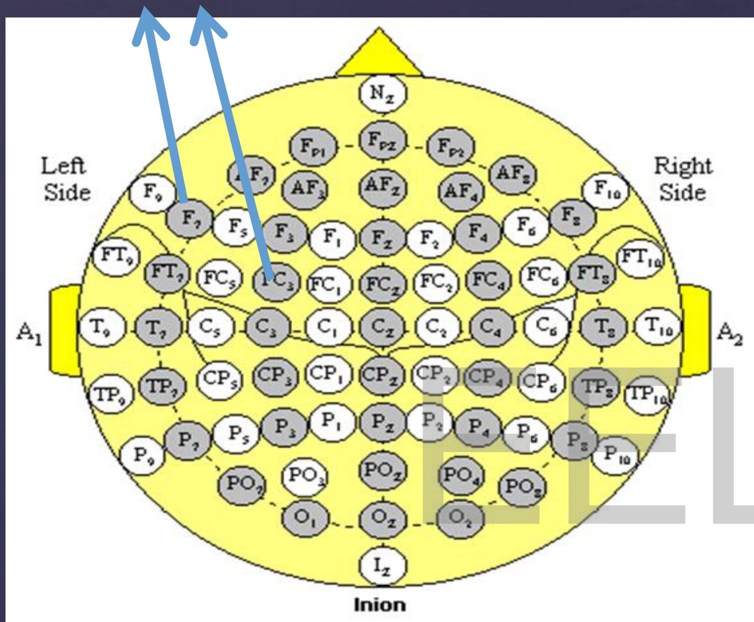


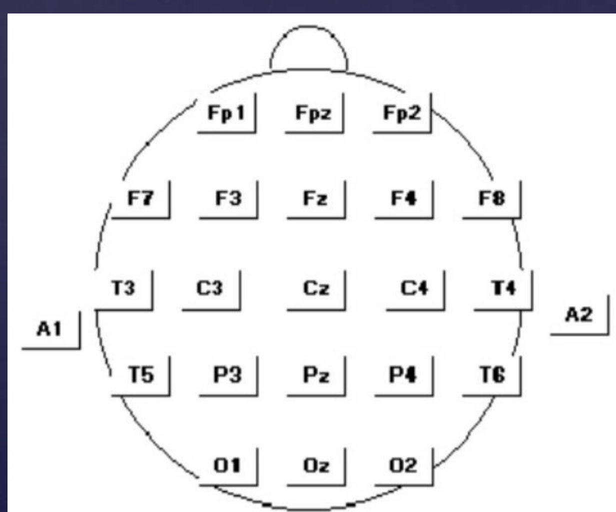
EEG cap



Modified Combinatorial Nomenclature

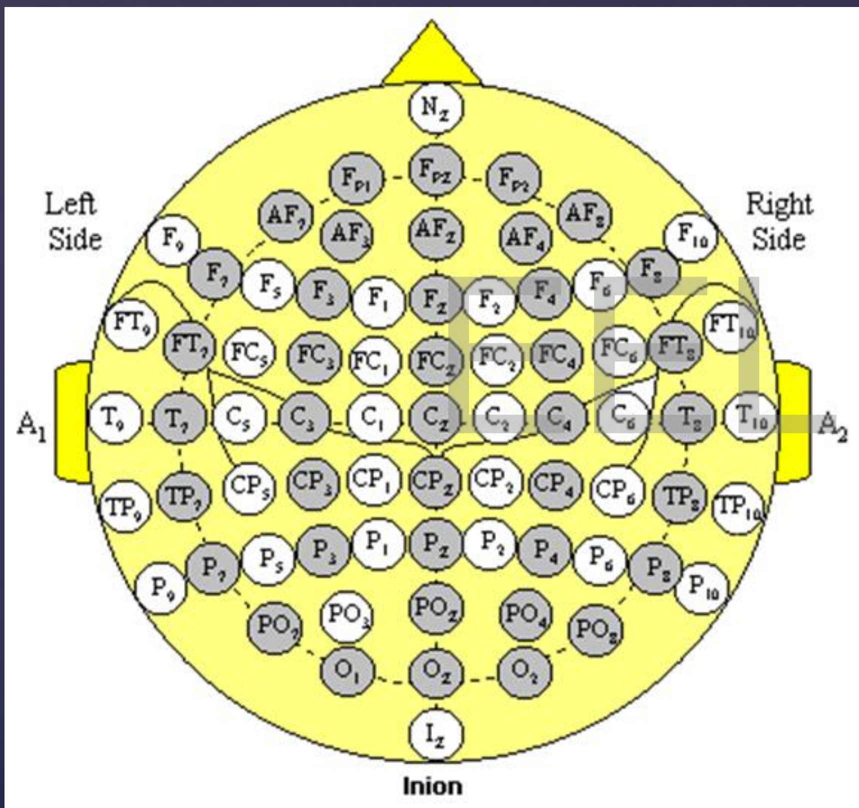
Electrodes between 2 10-20-system





- 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.

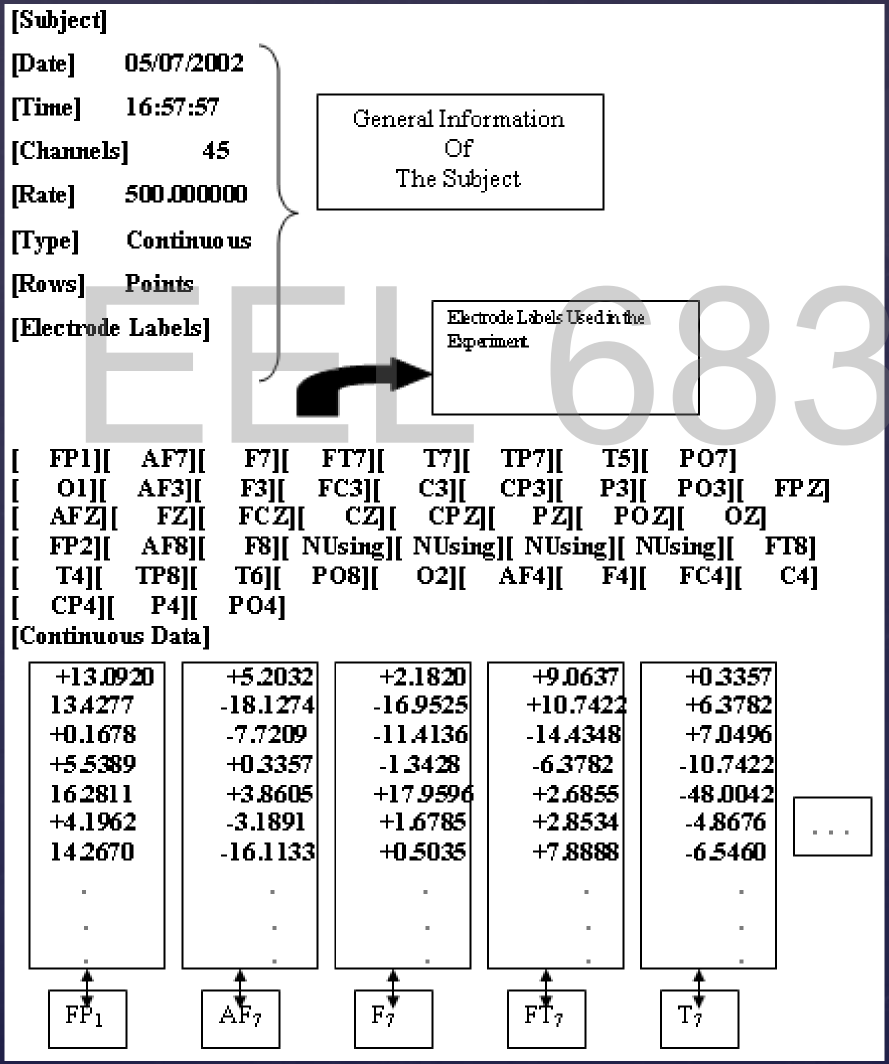
For example:
"FP" as the Front-polar or prefrontal lobe, "F" as Frontal lobe, "T" as Temporal lobe, "C" as Central lobe, "P" as Parietal lobe, and "O" as Occipital lobe.

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.

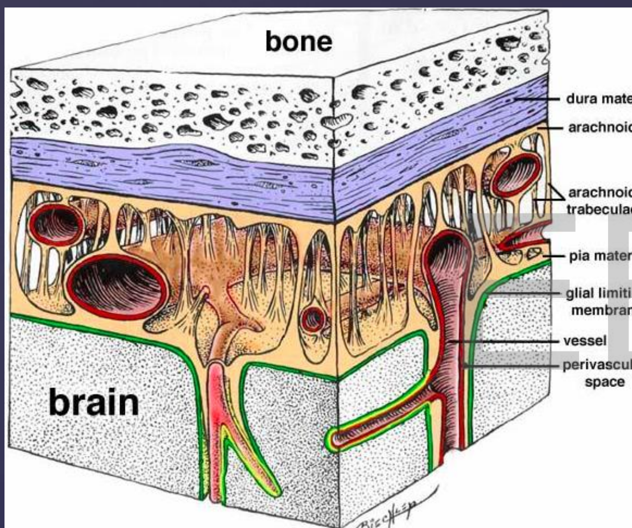
Example of an ASCII file

- 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.**

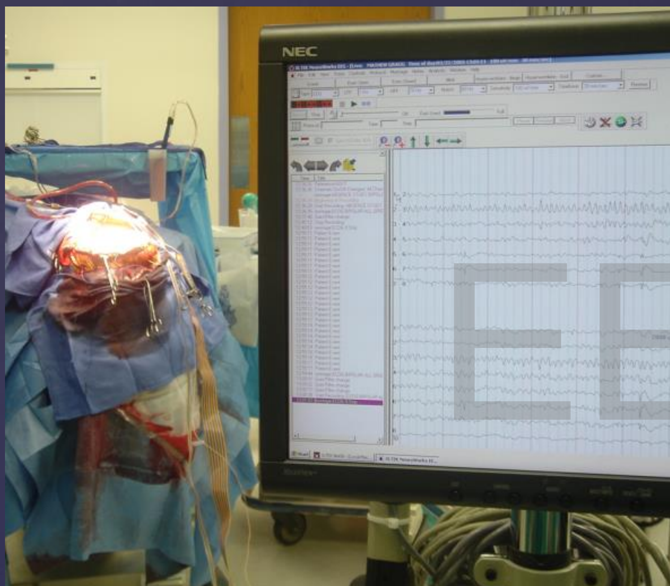
- **Scalp recording is not obviously invasive, but it provides a distorted signal because of the effects of intervening skull, tissue and cerebrospinal fluid.**

- **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

- 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.

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.

Digital Filtering 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:

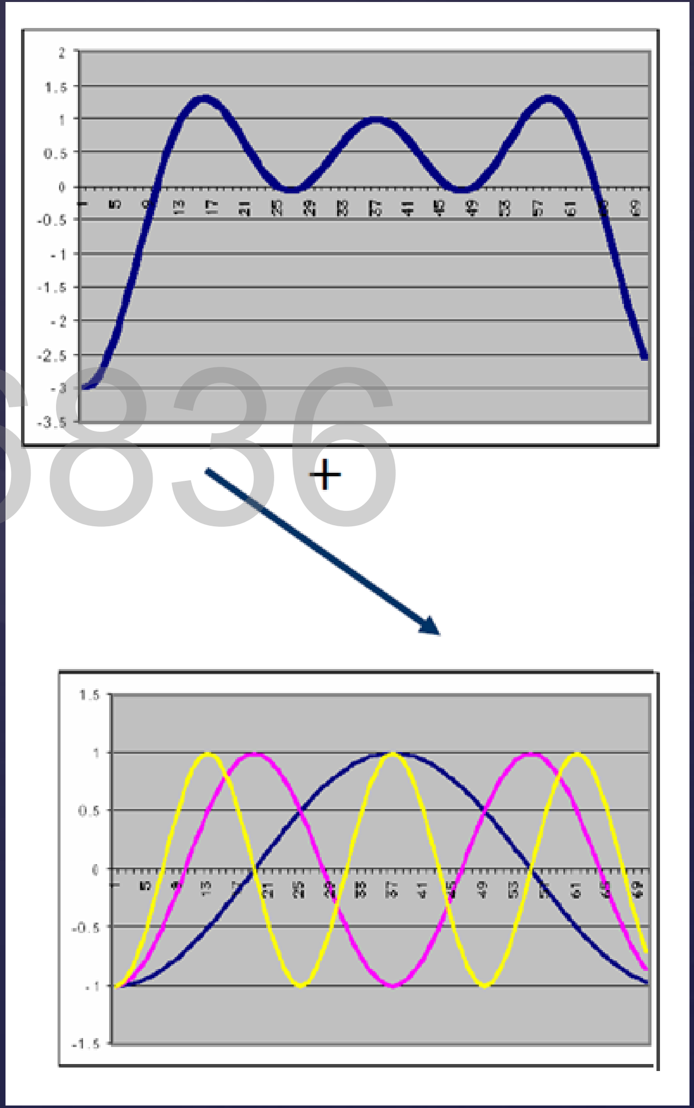
– Infinite Impulse Response (IIR) filters. They are fast but result in distortions similar to those generated by analog filters.

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

EEG Filtering

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

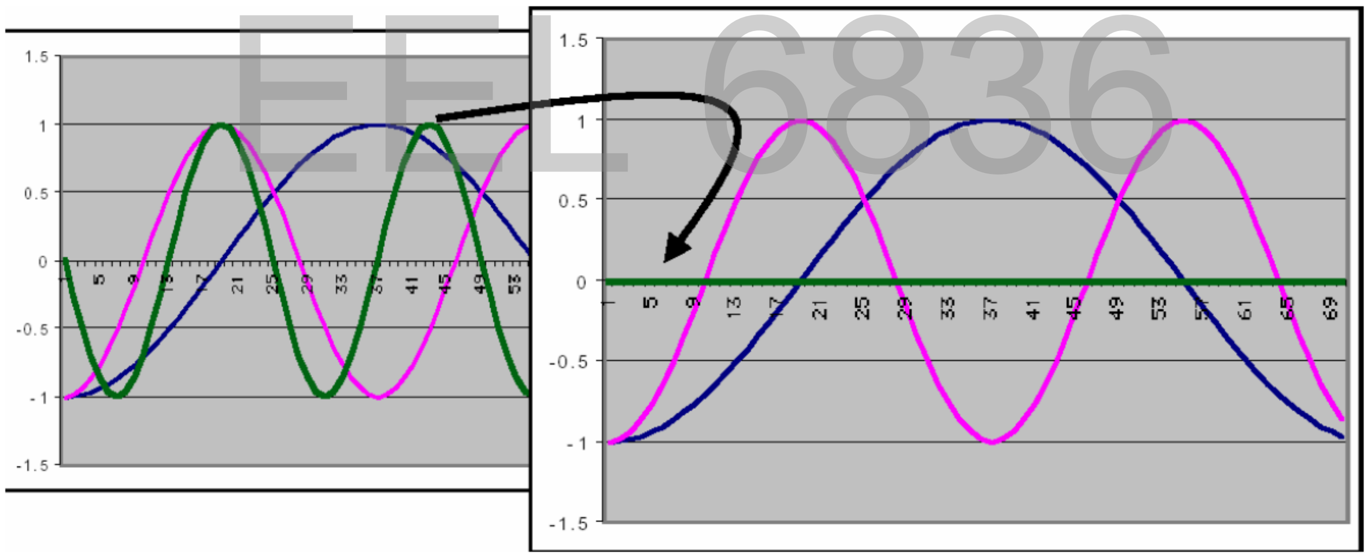
- <u>Any wave can</u> be thought of <u>decomposed of a number of sinusoidal waveforms</u> that vary in <u>amplitude, frequency and phase.</u>



EEG Filtering

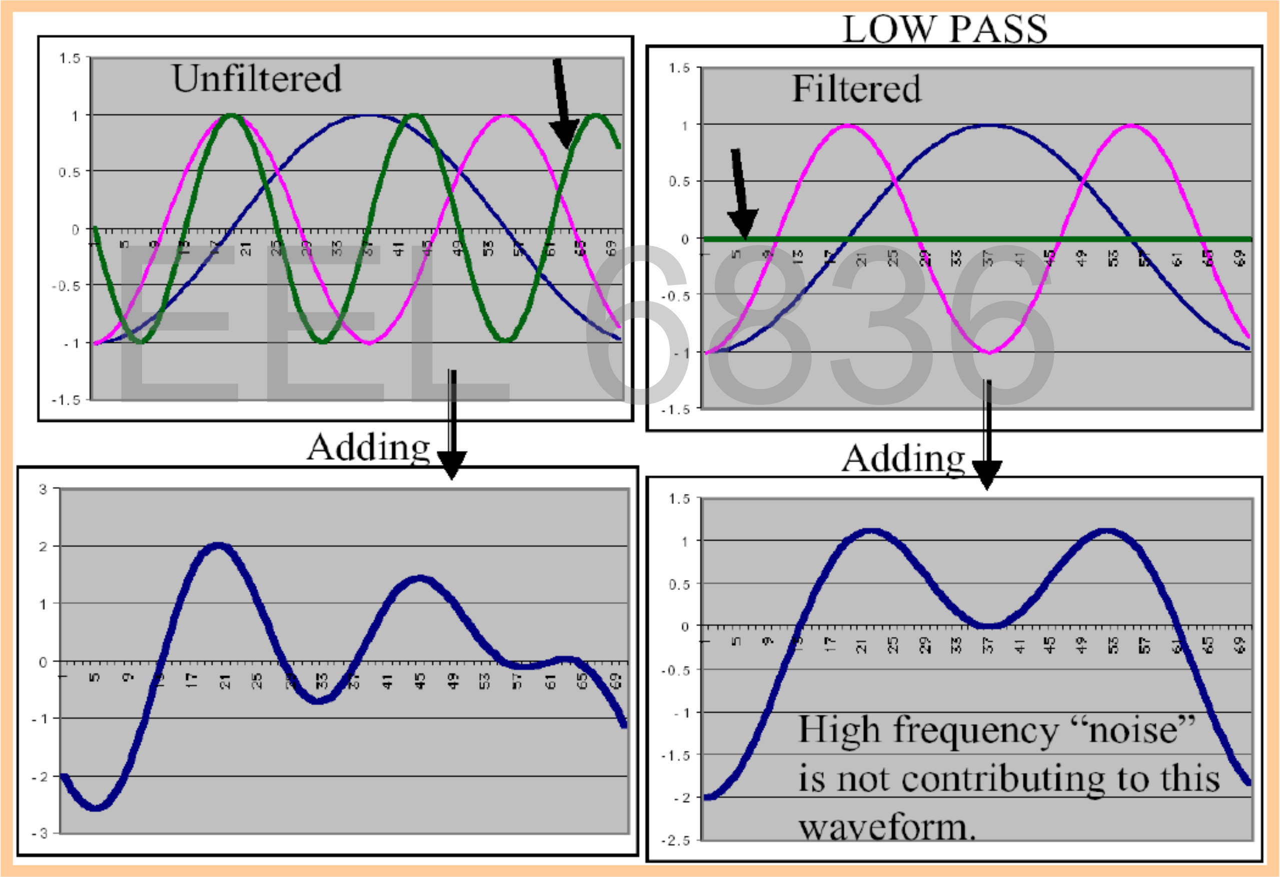
Function of a filter

Filtering is the operation that results in zero amplitude for the waves at frequencies that we don't want to contribute to our final waveform.



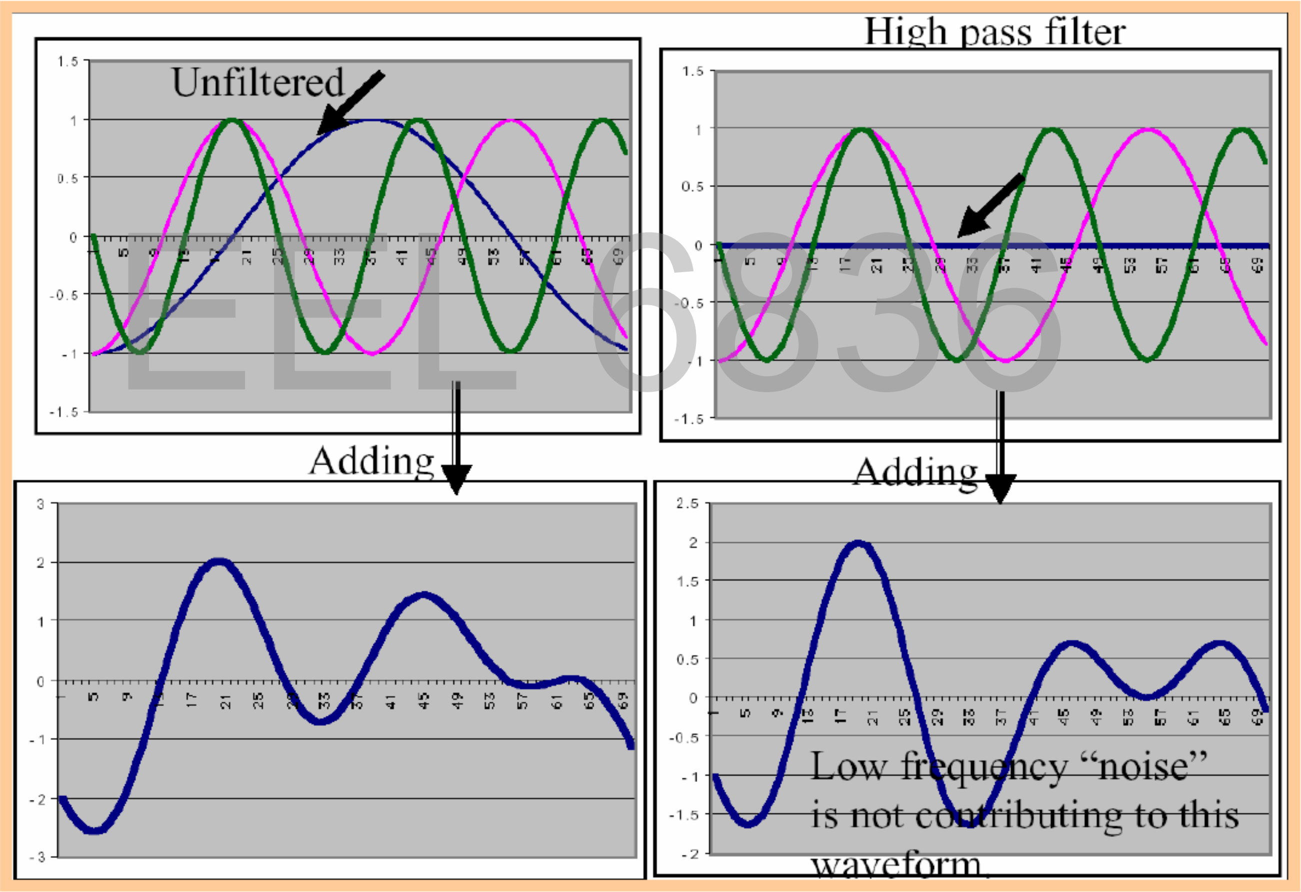
EEG Filtering

Low Pass Filter



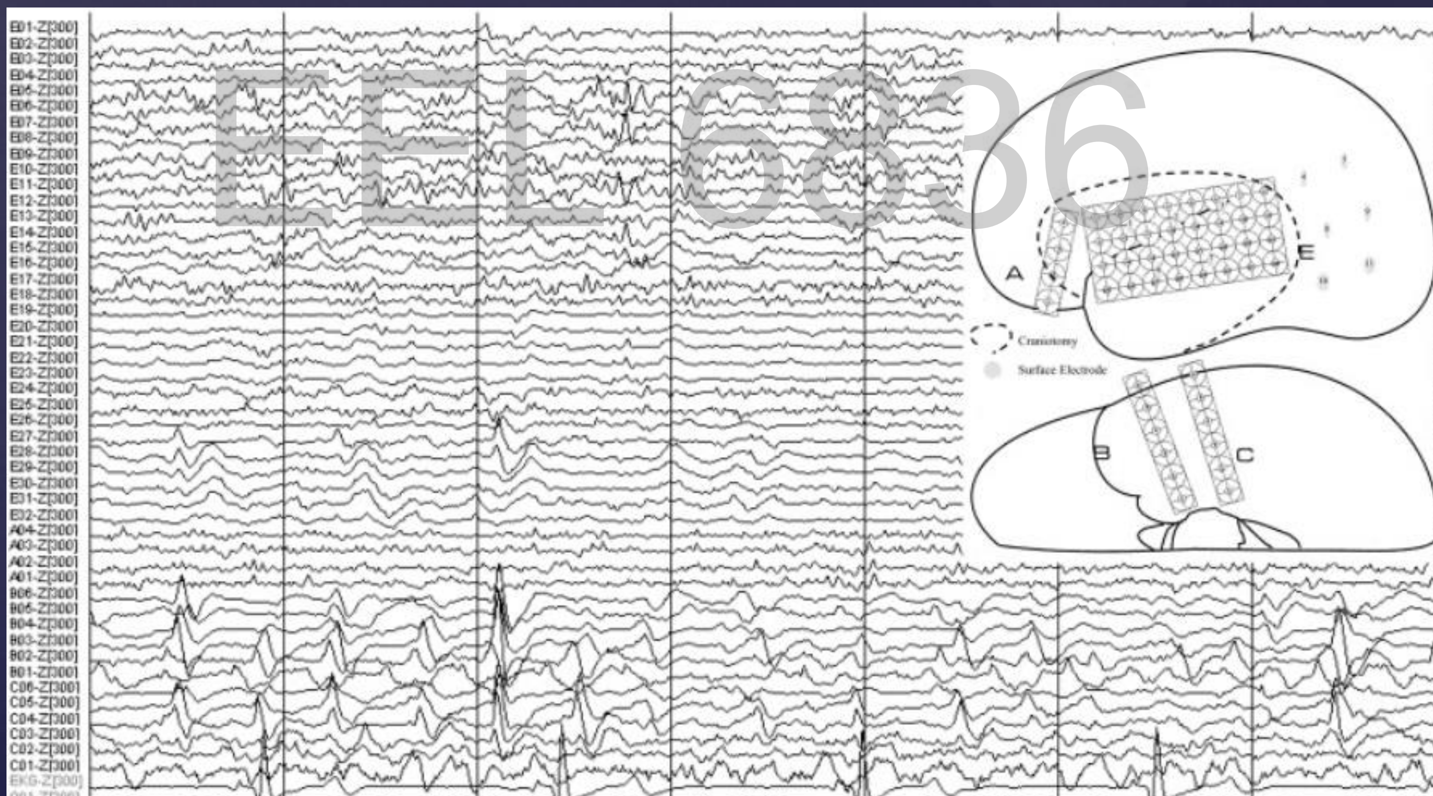
EEG Filtering

High Pass Filter



EEG and ECoG

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



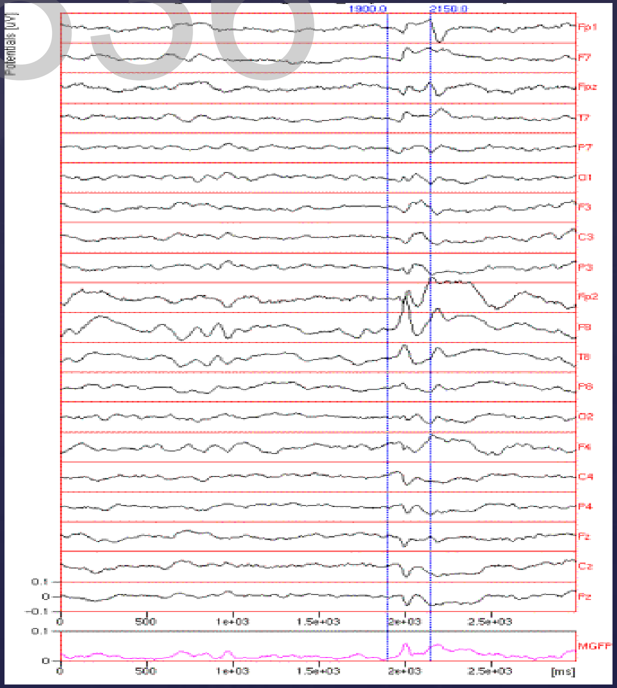
Epileptiform Activity

- 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.

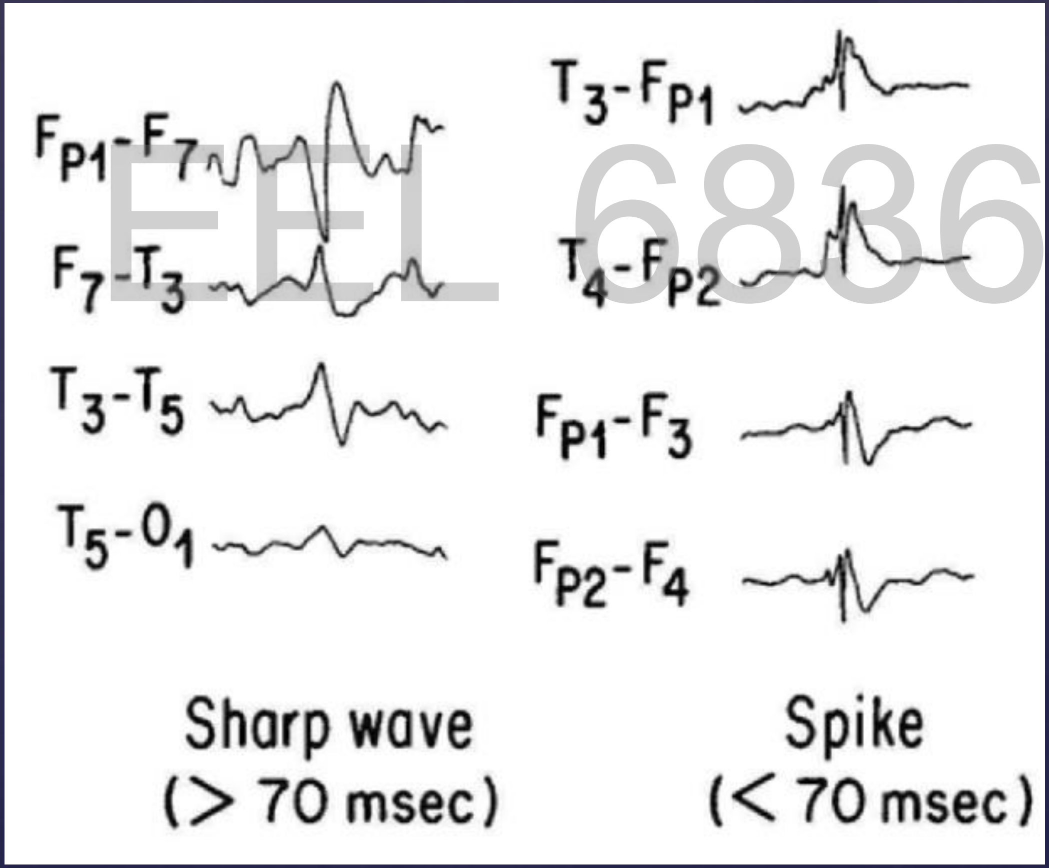
Epileptiform activity can be divided in:

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



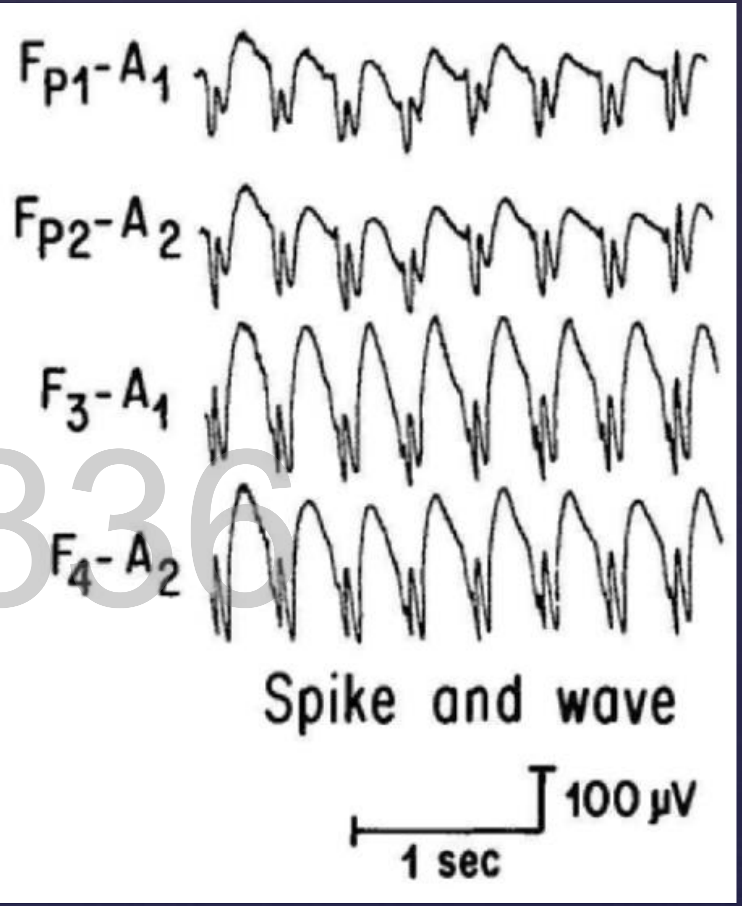
Epileptiform Activity

- 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.



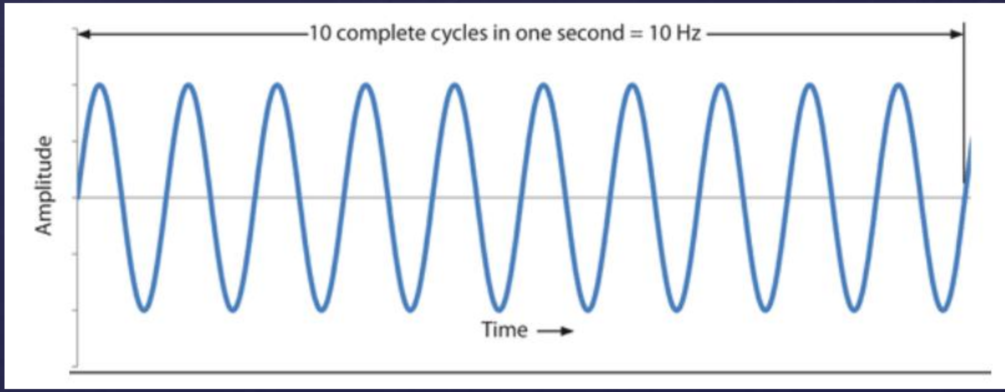
* In practice, however, it is more important to distinguish them from the background activity than to detect their morphological distinctions.

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.

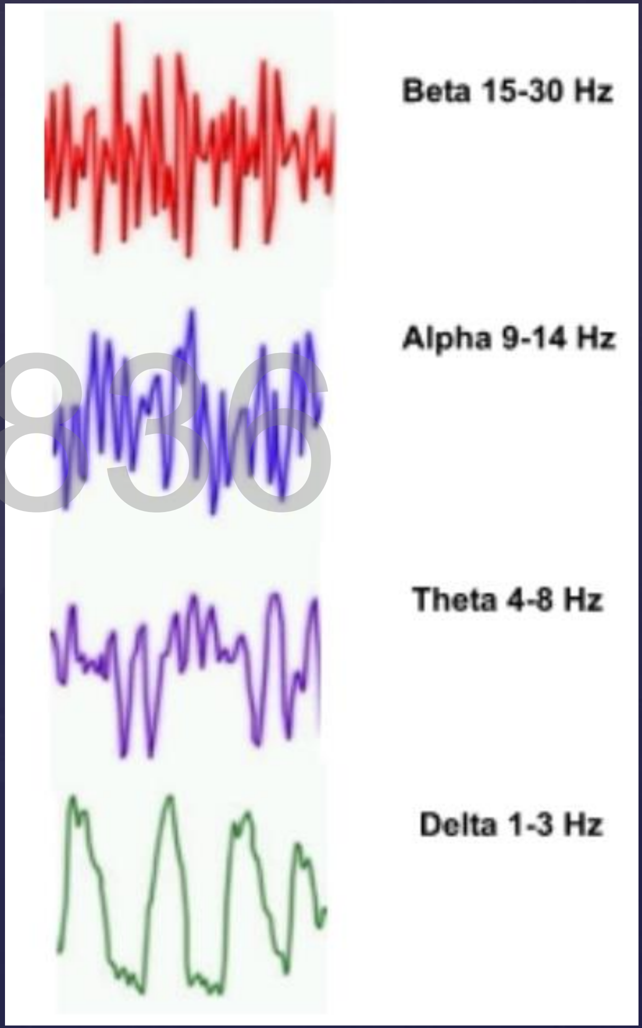
- When "f" is the frequency, we have:
- f = 1/T
  f is in Hertz (Hz)
  T is in seconds (sec)



Frequency Contents of the EEG

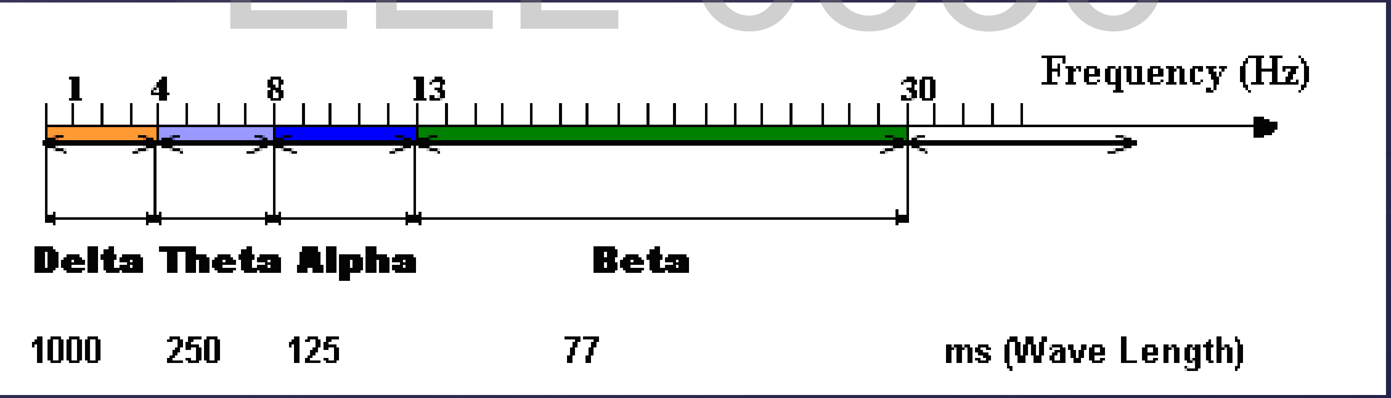
- Electrical activity emanates from the brain in the form of brainwaves. There are **4** brainwave states that range from the low amplitude/high frequency **Beta** to the high amplitude/low frequency **Delta**.

- 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

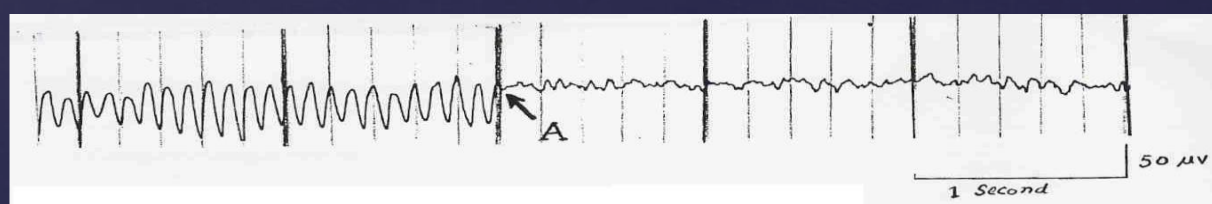
- There are 4 broad spectral bands of clinical interest: **delta (0-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), and beta (12-30 Hz).**



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).



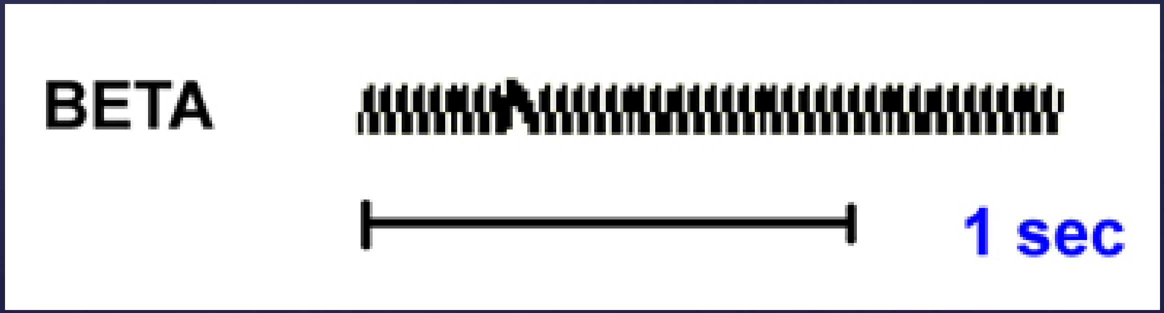
Alpha rhythm changes to beta on eye opening (desynchronization)

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.

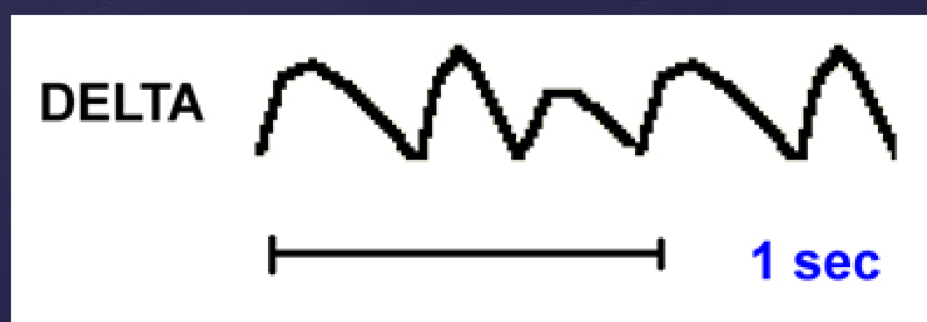
Location: most evident frontally, both sides, symmetrical distribution, low amplitude wave. Also on temporal lobe.



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.



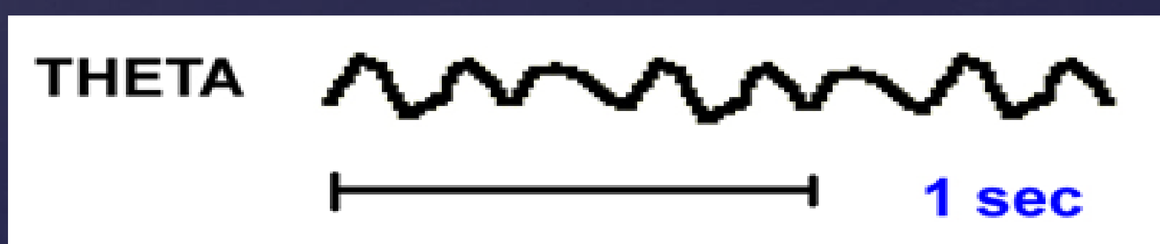
Theta (4-8 Hz)

- 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 is observed in those channels where seizures originate.

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