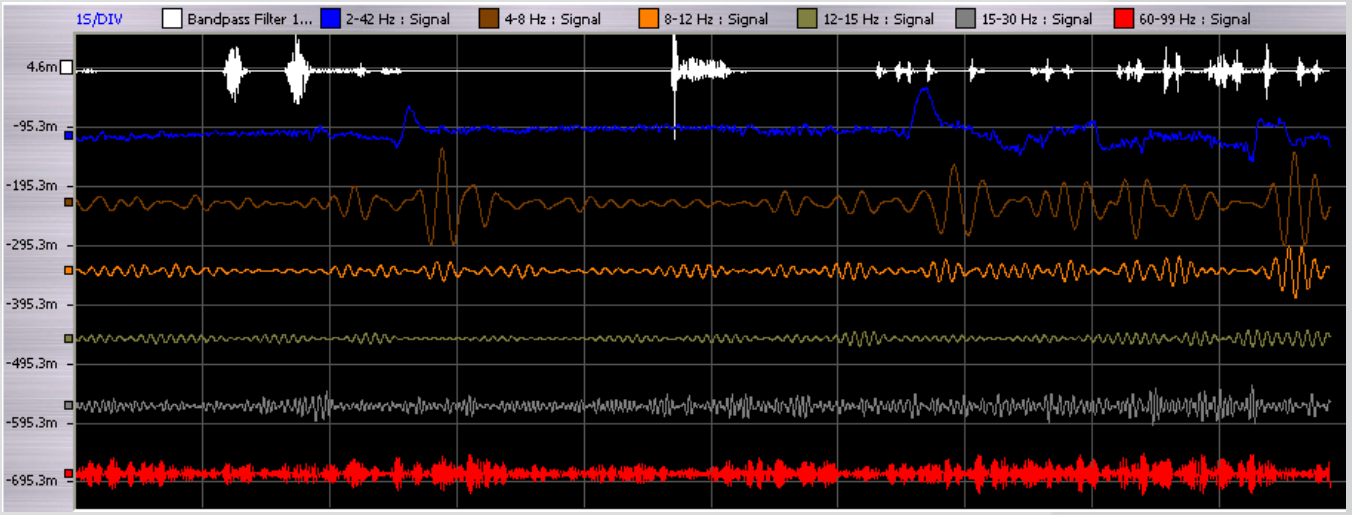
Real-life Neurofeedback

Part I: an introduction in electroencephalography (EEG)



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Presentation contents

- Anatomy of the brain
- Neurophysiology
- Measurement techniques
- EEG frequency bands
- Artefacts

Lobes of the brain

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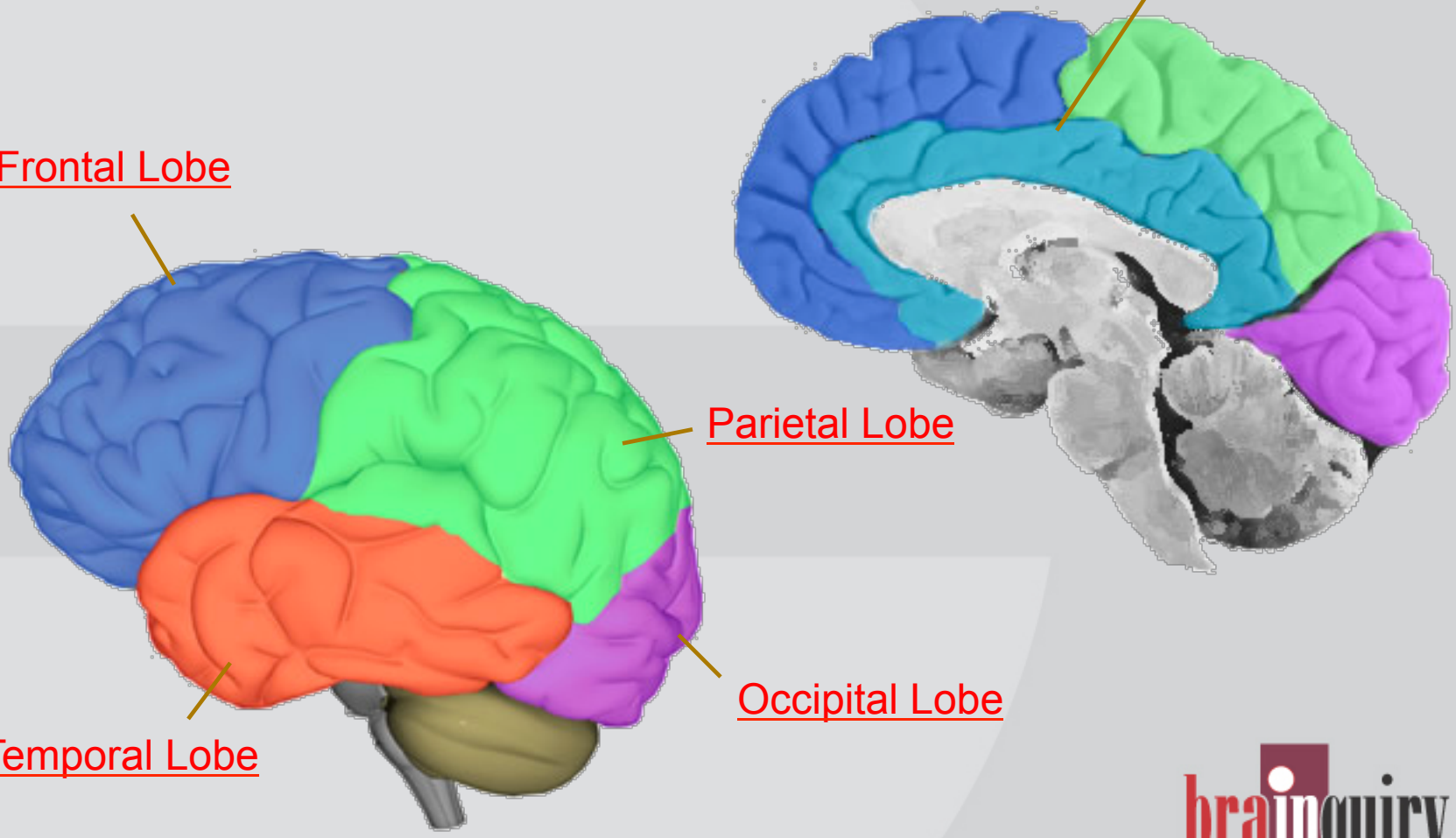
Source: http://www.idealu.com/add/brain/Brain.ppt



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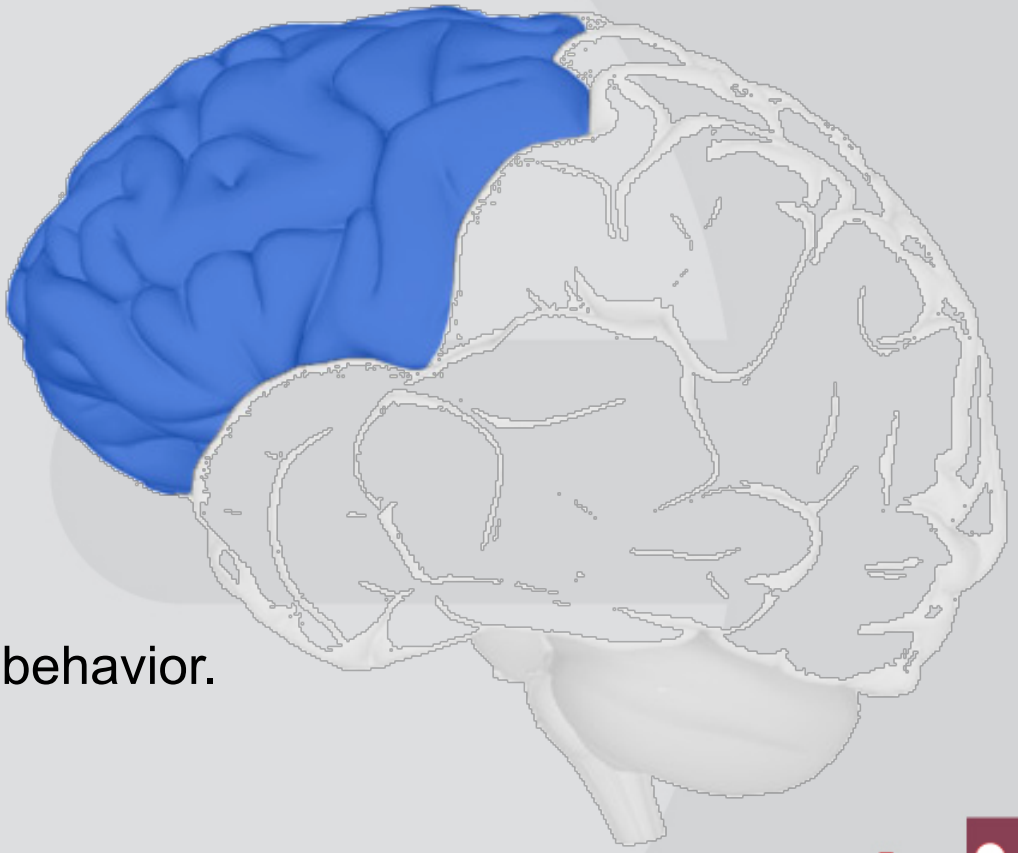
Frontal lobe

The frontal lobe is the area of the brain responsible for higher cognitive functions.

These include:

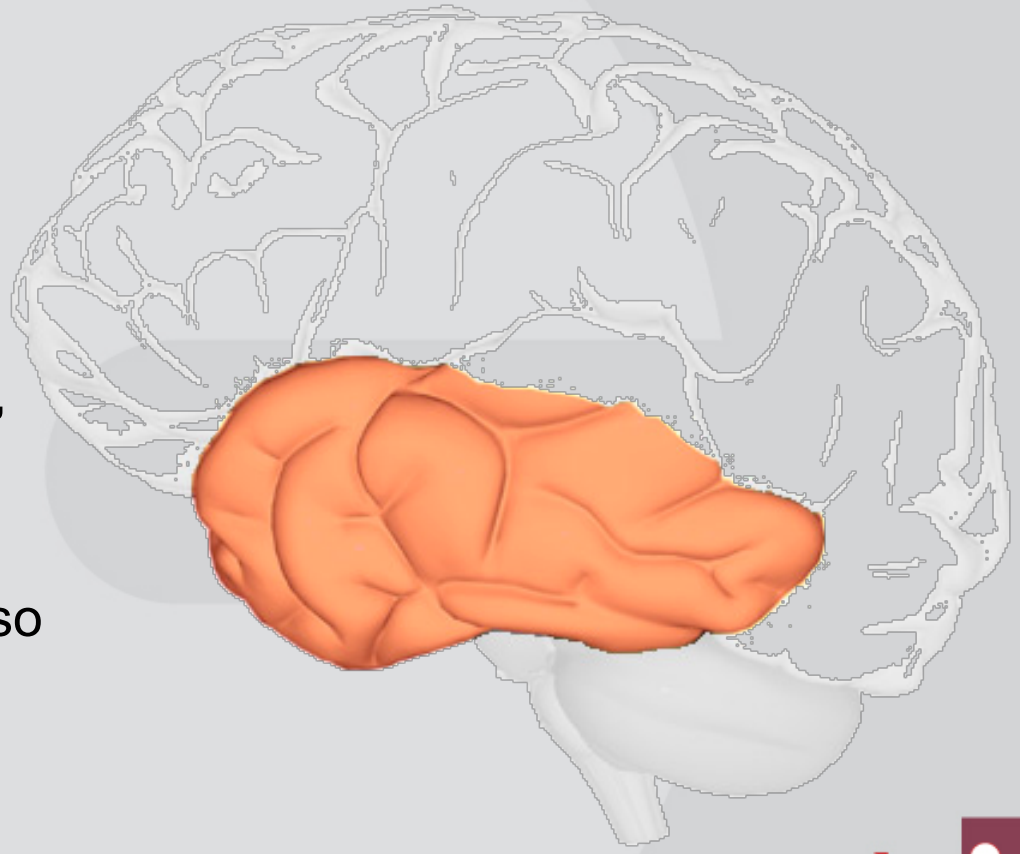
- Problem solving
- Spontaneity
- Memory
- Language
- Motivation
- Judgement
- Impulse control
- Social and sexual behavior.



Temporal lobe

The temporal lobe plays a role in emotions, and is also responsible for smelling, tasting, perception, memory, understanding music, aggressiveness, and sexual behavior.

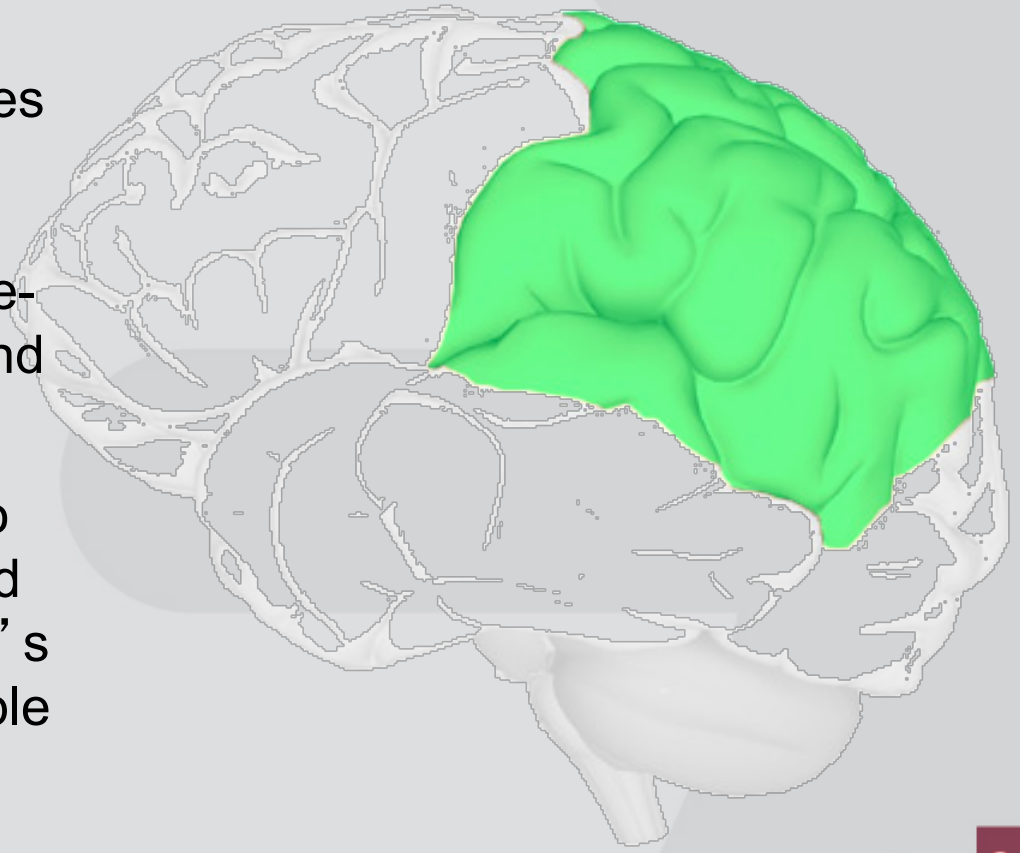
The temporal lobe also contains the language area of the brain.



Parietal lobe

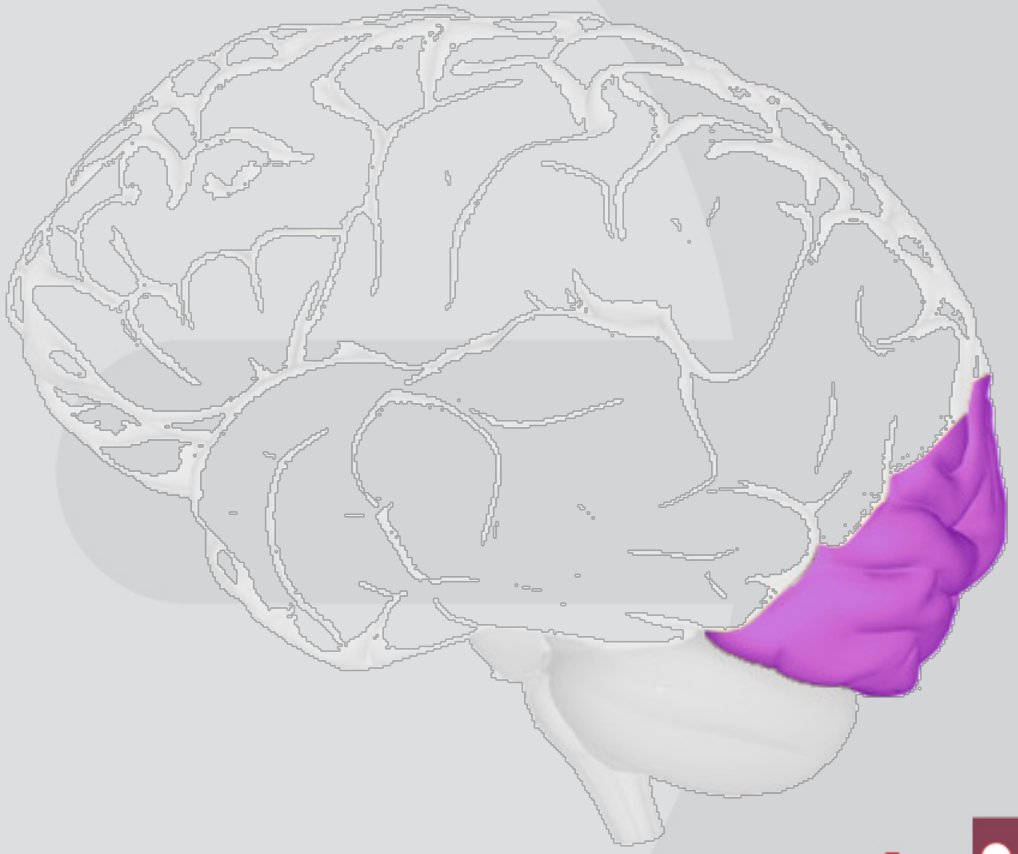
The parietal lobe plays a role in our sensations of touch, smell, and taste. It also processes sensory and spatial awareness, and is a key component in eye-hand co-ordination and arm movement.

The parietal lobe also contains a specialized area called Wernicke's area that is responsible for matching written words with the sound of spoken speech.



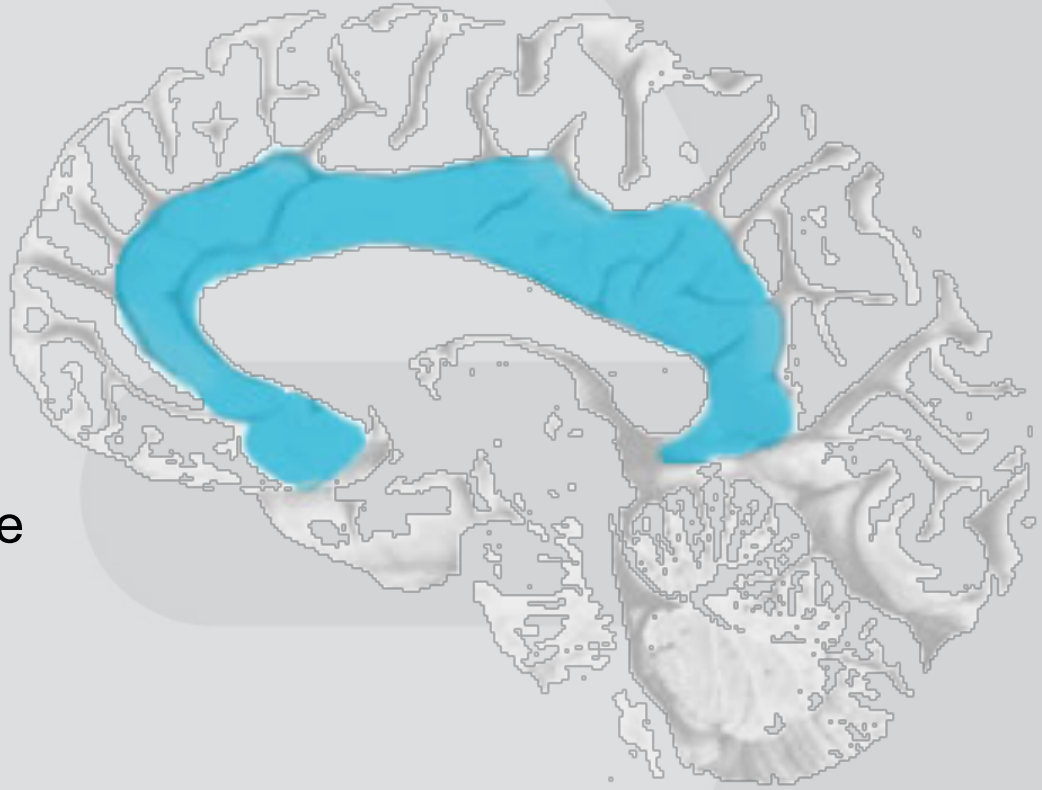
Occipital lobe

The occipital lobe is at the rear of the brain and controls vision and recognition.



Limbic lobe

The limbic lobe is located deep in the brain, and makes up the limbic system.

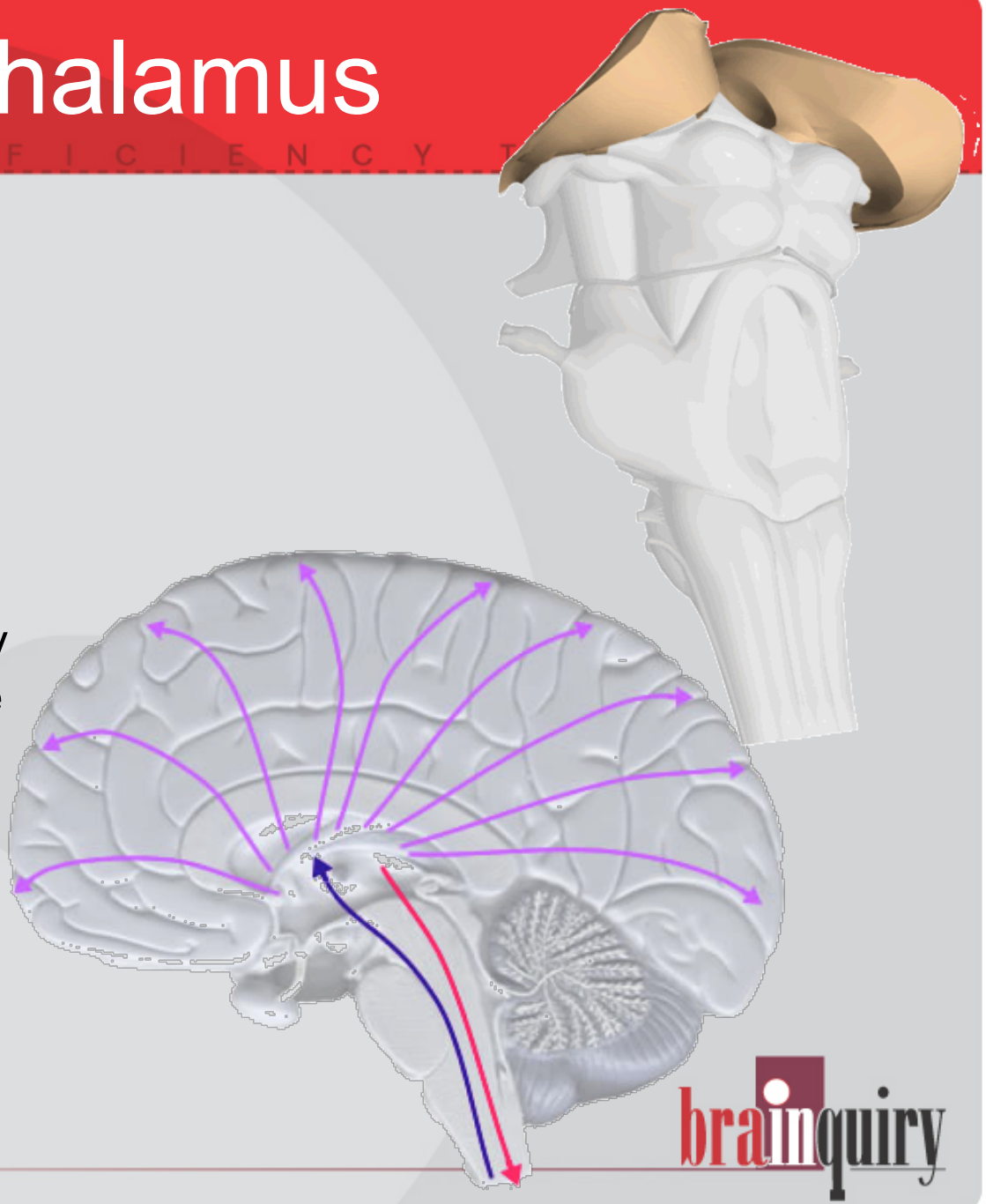


The limbic system is the area of the brain that regulates emotion and memory. It directly connects the lower and higher brain functions.

Thalamus

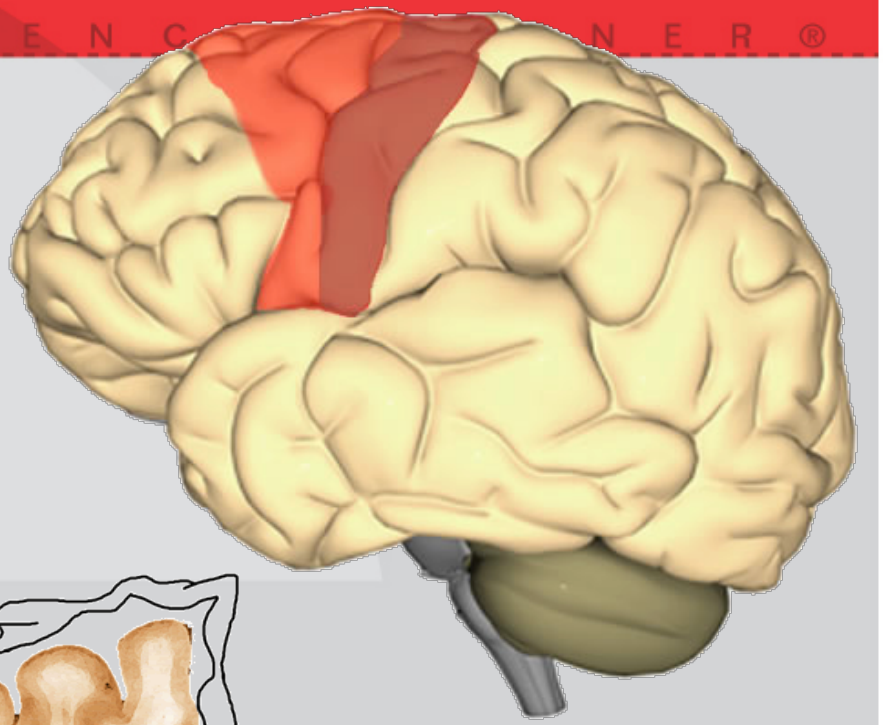
Thalamus means “inner room” in Greek, as it sits deep in the brain at the top of the brainstem.

The thalamus is called the gateway to the cerebral cortex, as nearly all sensory inputs pass through it to the higher levels of the brain.



Motor cortex

The motor portion of the cerebrum is illustrated here. The light red area is the premotor cortex, which is responsible for repetitive motions of learned motor skills. The dark red area is the primary motor area, and is responsible for control of skeletal muscles.



Different areas of the brain are associated with different parts of the body.

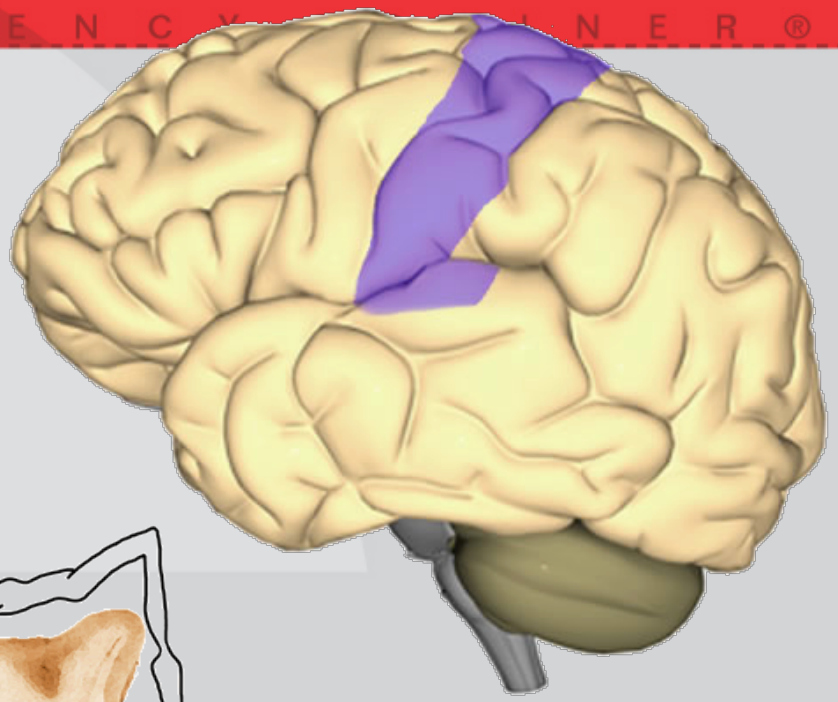
Injury to the motor cortex can result in motor disturbance in the associated body part.

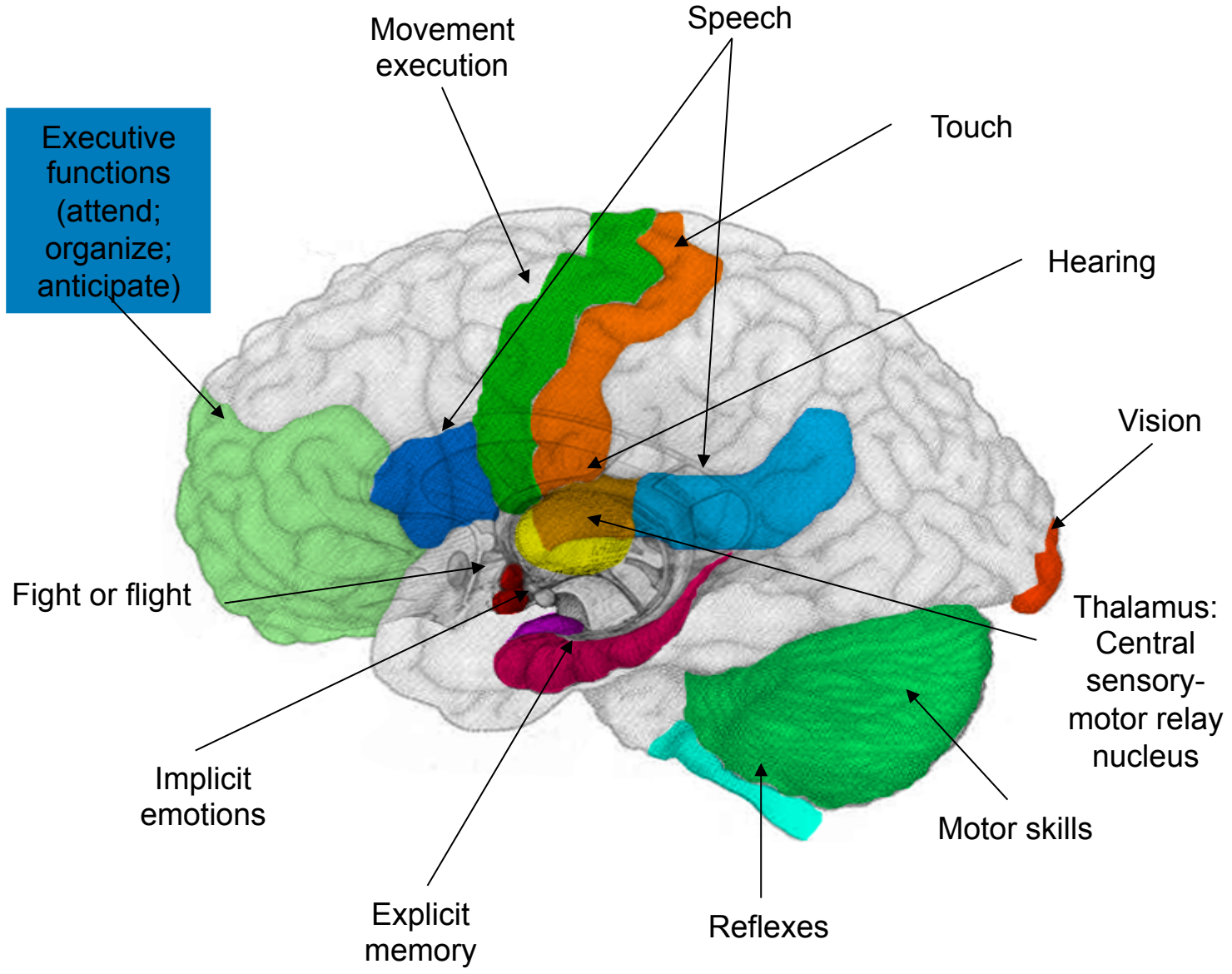
Sensory cortex

The sensory portion of the cerebrum is illustrated here.

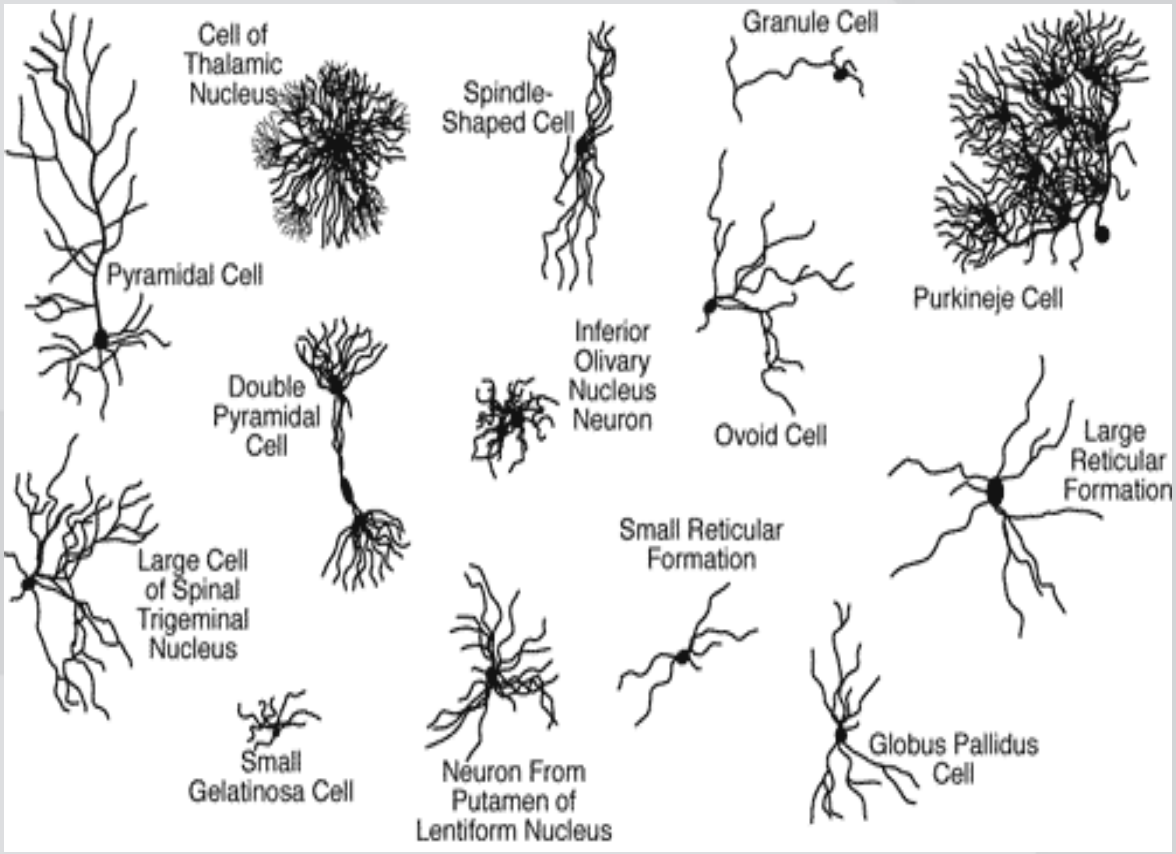
Different areas of the brain are associated with different parts of the body, as can be seen below.

Injury to the sensory cortex can result in sensory disturbance in the associated body part.

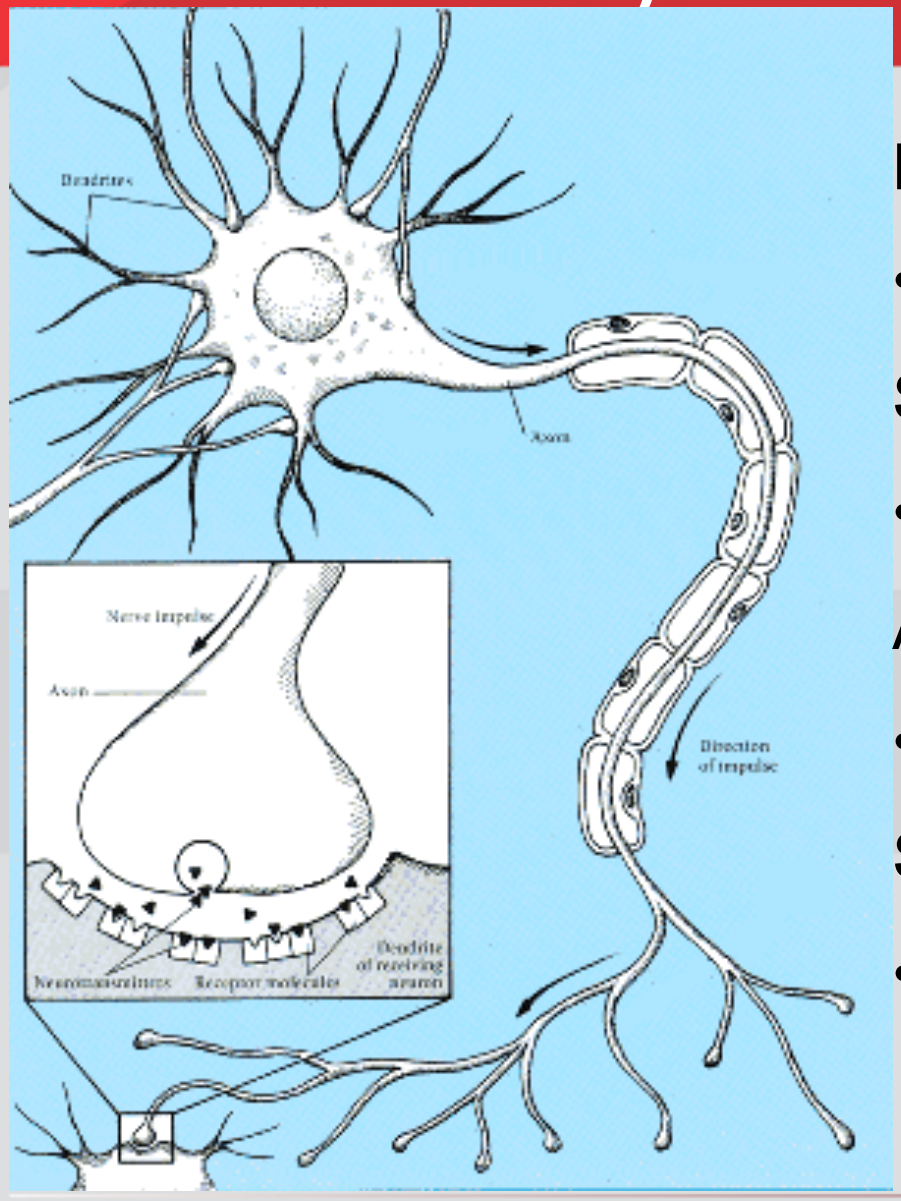



Movement execution
Speech
Executive functions (attend; organize; anticipate)
Touch
Hearing
Vision
Fight or flight
Thalamus: Central sensory-motor relay nucleus
Implicit emotions
Motor skills
Explicit memory
Reflexes

Neuron types



Pyramidal cell



Dendrites

•reception of information

Soma

•cell body

Axon

•sending of information

Synaps

•information terminal

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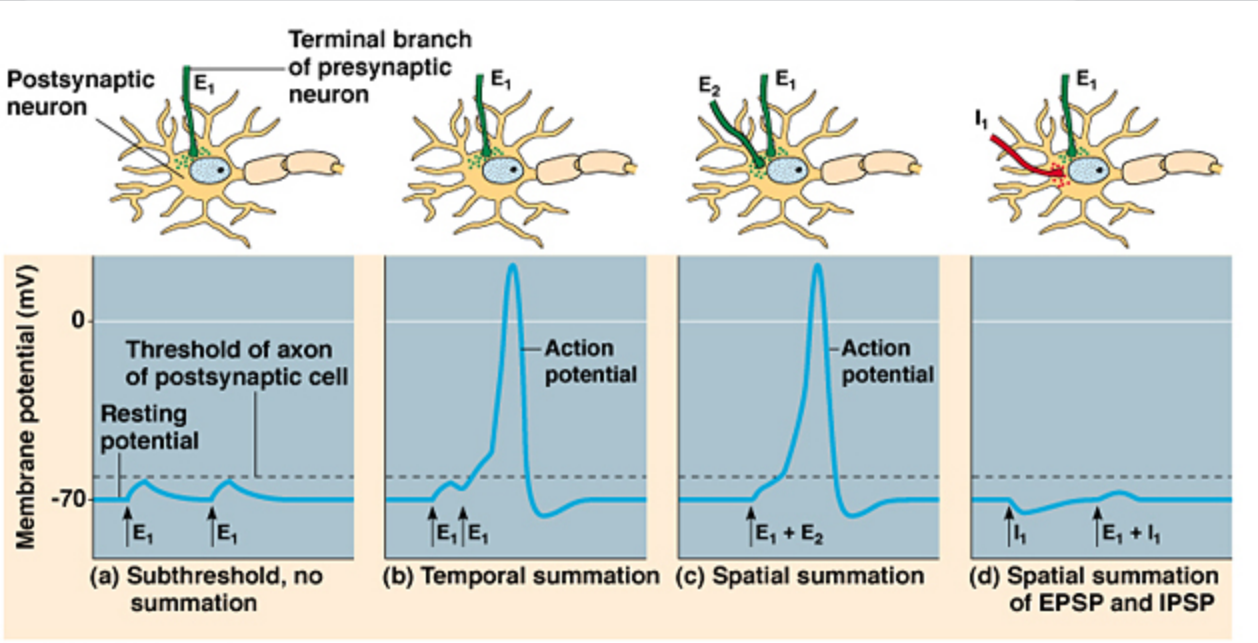
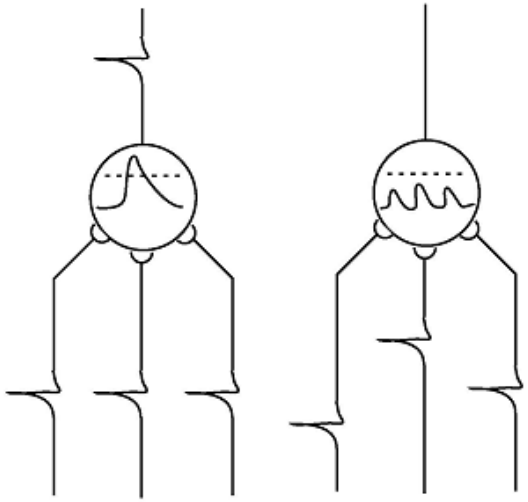
PSPs



Excitatory/Inhibitory Post Synaptic Potentials (EPSPs/IPSPs)

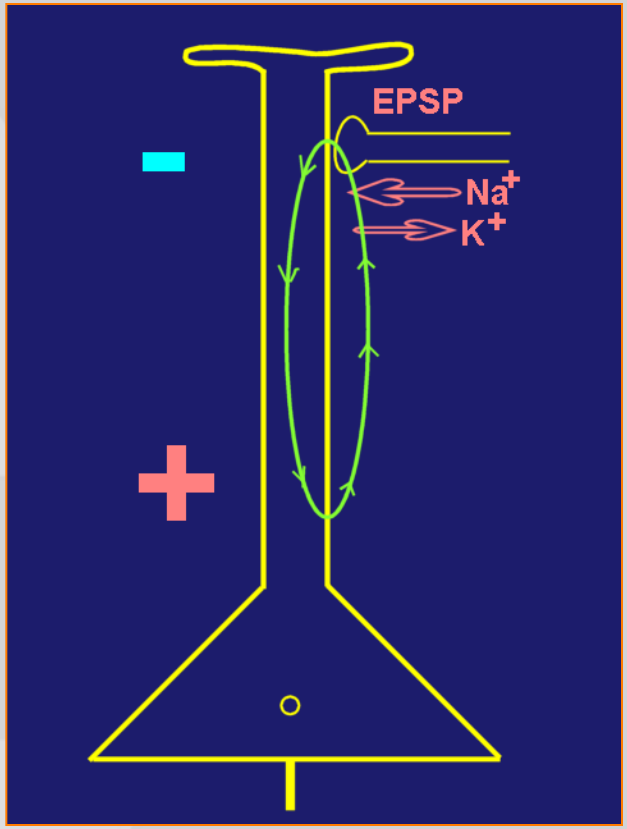
➔ Action potential



Synchronization might be an ideal mechanism to modulate effective synaptic gain flexibly and dynamically.

Equivalent current dipole

- Neurotransmitter release leads to selective movements of ions through postsynaptic membrane, local changes in ionic concentrations, intra- and extracellularly.
- Causing dipoles: separation of positive and negative discharges. Extracellular and intracellular ionic currents flow between the dipoles, (brain liquids are excellent conductors). The extracellular currents give rise to the surface recorded EEG.



EEG!

Post Synaptic Potential produces ohmic current flow throughout the head (and body). The ohmic current flow produces electric potential differences on the scalp (actually, everywhere) ⇒ EEG.

Neuron orientation

BUT: One neuron is not enough to produce EEG.

If the pyramidal cells on the cortex are randomly oriented, then there is no EEG. For example:

In such a case, the contribution of all cells adds up to zero (or nearly so).

Pyramidal cell orientation

Pyramidal cells tend to have an orientation perpendicular to the cortical surface:

Desynchronization

BUT: The perpendicular orientation of the pyramidal cells is not enough to produce EEG.

If neighboring neurons are not synchronously stimulated , then there is no EEG. For example:

In such a case, the contribution of all cells adds up to zero (or nearly so).

Synchronization

Similarly oriented, synchronized assemblies of neurons produce EEG

- Action potentials in axons do not contribute to the ongoing EEG activity: too short, course in to many directions relative to the surface, not synchronized

- Synaptic activity of cortical neurons (IPSP and EPSP) (PSP´s in TC-cells last 10-30 times longer than axonal AP´s, this increases the probability of overlapping in time, allowing summation)

- Changes in membrane potential of glial cells

Conclusion

- Individual PSP are too small to be detected, however, up to 40K synapses on a single pyramidal cell
- If PSP occur random in time net effect on the potential of the surface electrode would be zero.
- Potentials recorded at the surface are the algebraic sum of somewhat synchronous contributions by neuronal synapses which change rapidly in either direction (pos and neg),and glial cells which operate slowly) mainly DC.
- Pyramidal cells in the cerebral cortex most important neuronal source of the EEG.

  Long and in parallel, large dipoles

  Granular cells in cortex are small, dentritic trees radially around cell bodies, small dipoles

History

1874: Richard Caton

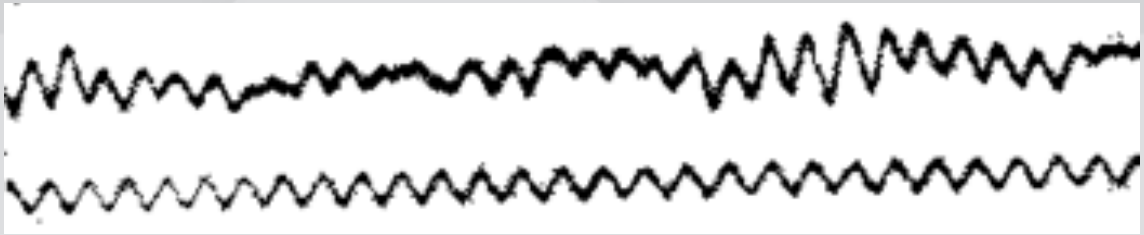
- rabbits and monkeys

1913: Pravdich-Neminsky

- mammalian (dog)

1920: Hans Berger

- human



Equipment

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Two electrodes and a measurement system

EEG measurement

Measurement of potential difference between two electrodes

Potential difference => current flow through electrodes

BUT: Current flow is resisted by boundary between skin and electrode => IMPEDANCE

Impedance

- Prepare electrode sites (alcohol, Nuprep)
- Electrolyte is applied
- Offset potentials

Impedance should be as low as possible

Unipolar vs. bipolar

Unipolar:

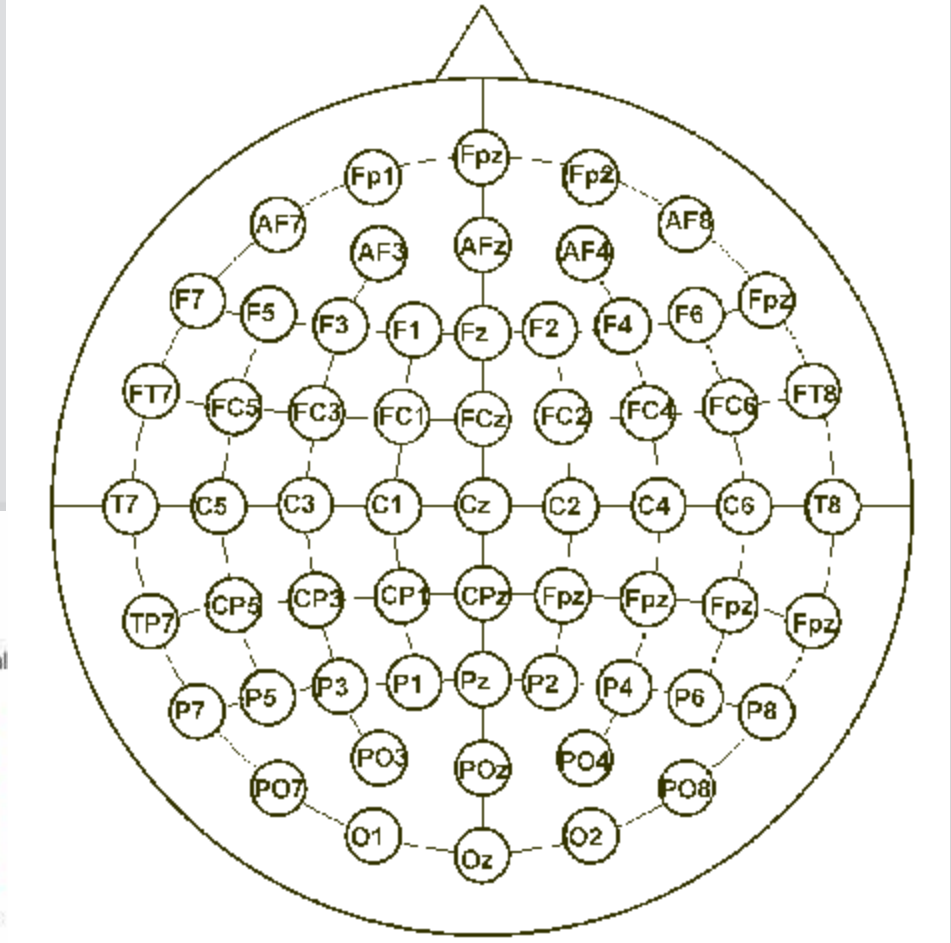
measurement between a site of interest and a ‘neutral’ site (mastoid- or earlobe reference)

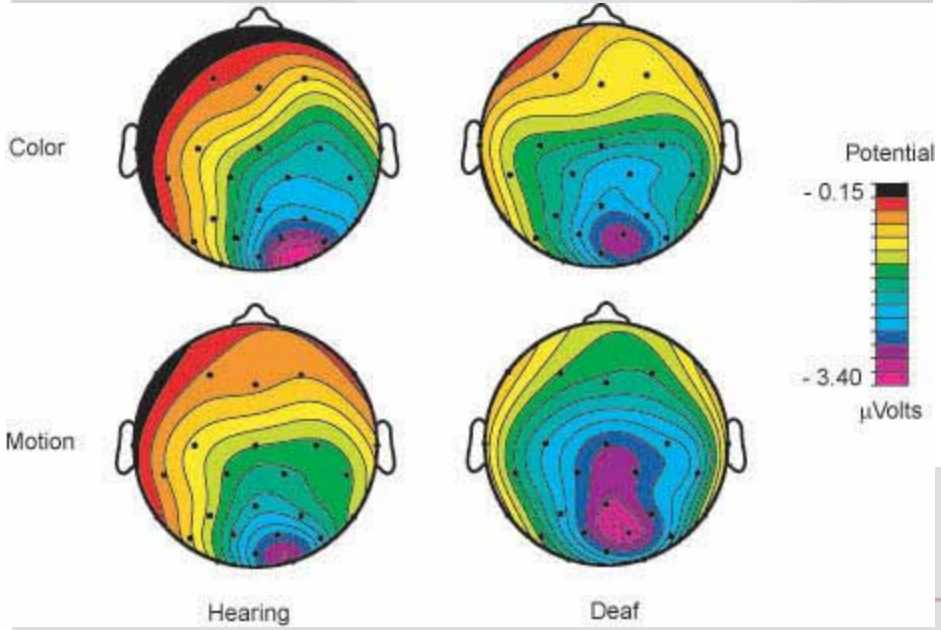
Bipolar:

measurement between two brain sites

10-20 system

International convention of placement of EEG electrodes





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Montages

Re-referencing of EEG data

Linked ears vs. Laplacian montage

Figure 16: Linked ear reference with EKG artifact

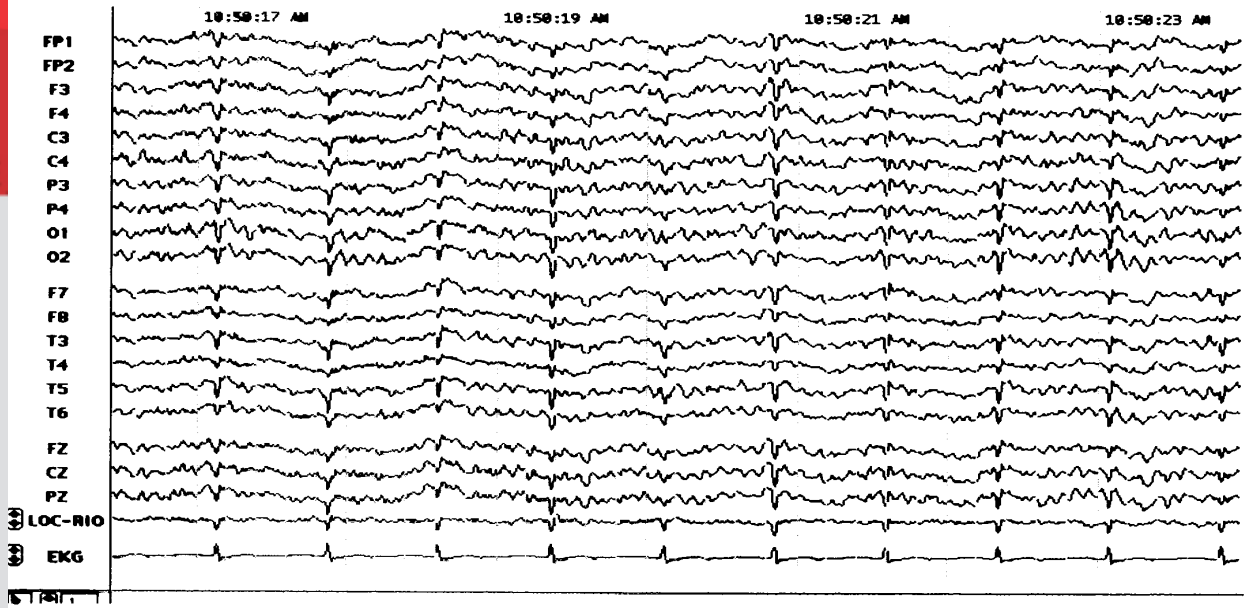
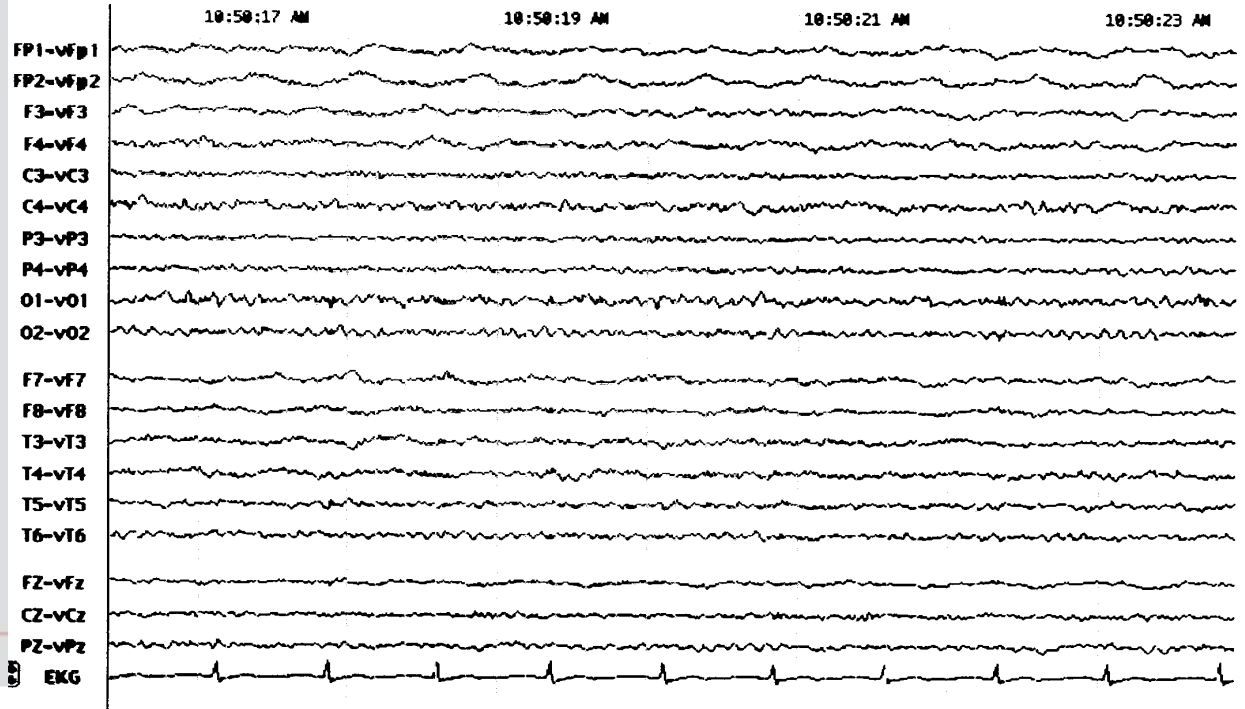
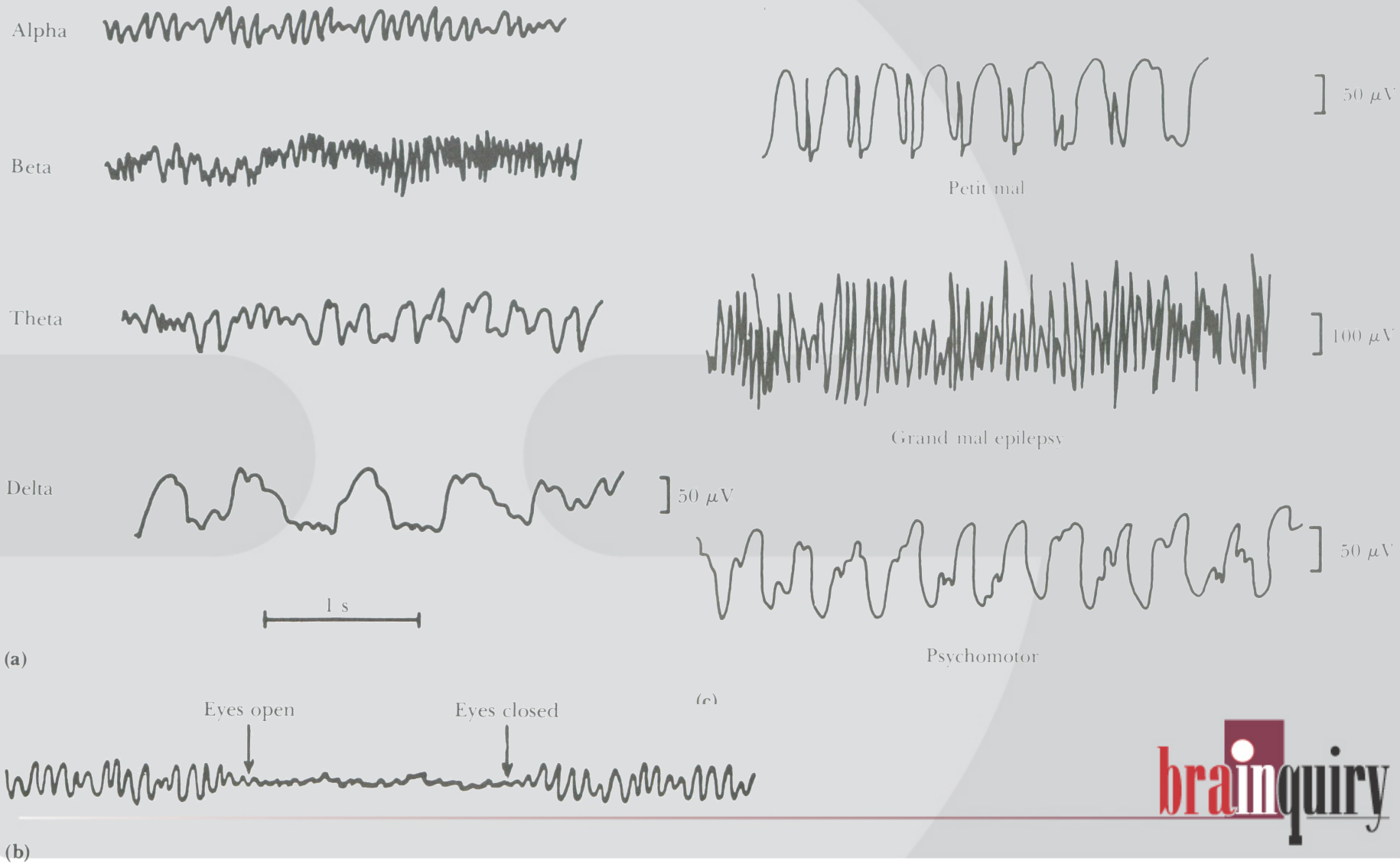


Figure 17: Hjorth referencing of the same data

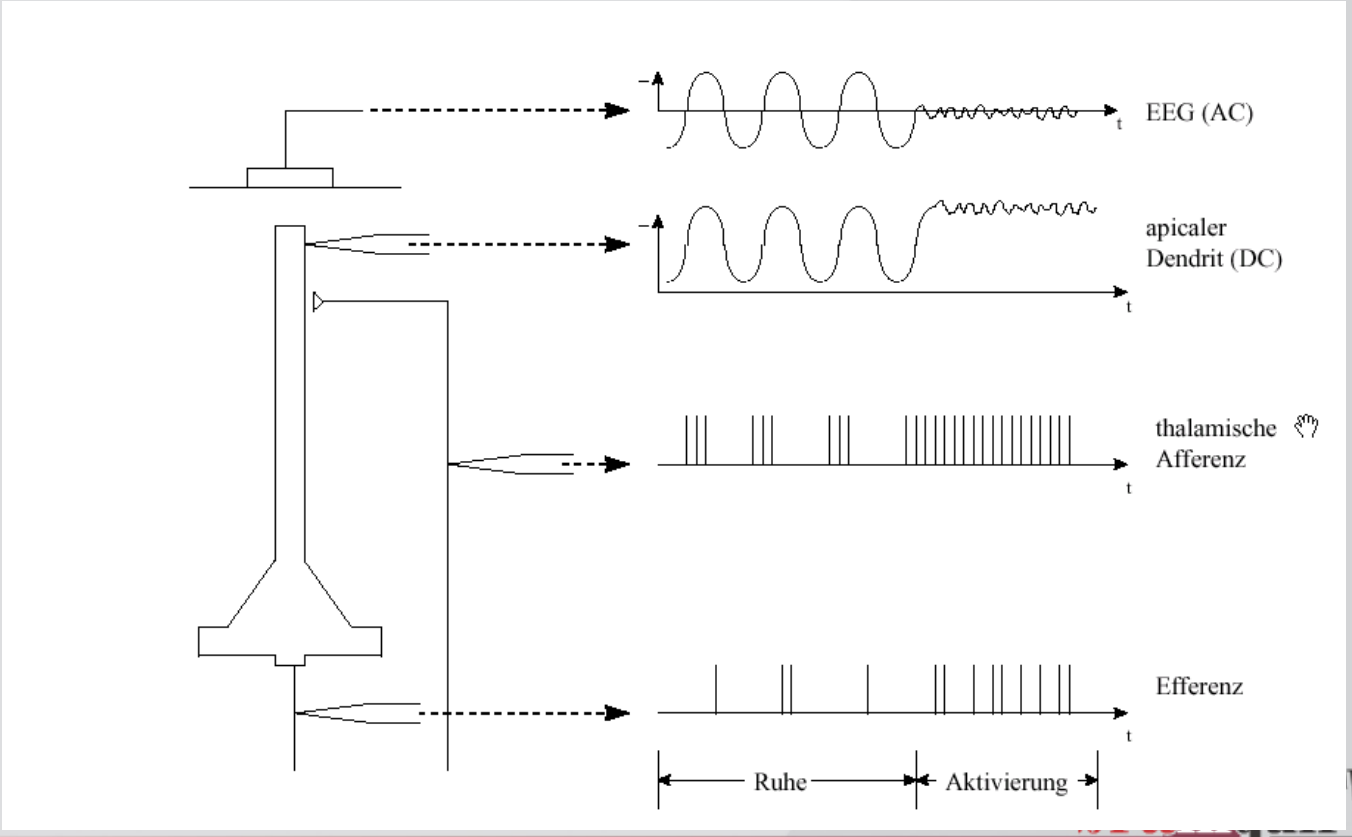


EEG rythms



Thalamic rythm

EEG frequencies correlate with firing rythms originating at the thalamic level



SCPs

Negative: Initiation of behaviour

Positive: Inactive states

0-2 Hz

Delta

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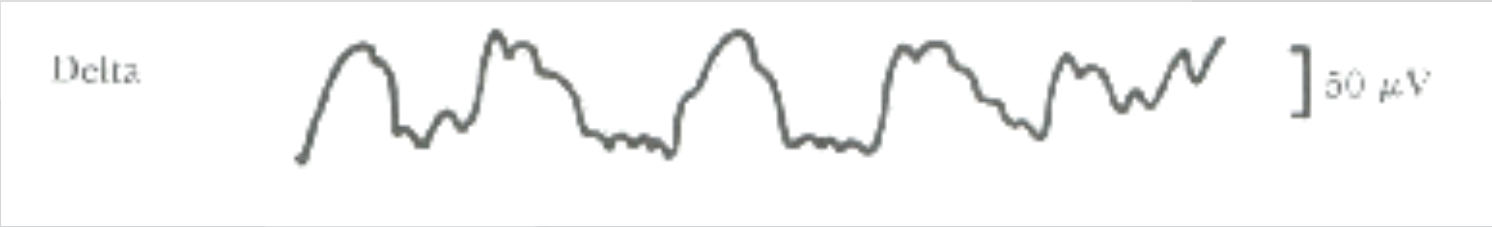
Slow wave sleep



1-4 Hz

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Theta

phase I sleep, memory, attention

4-7.5 Hz

Alpha

Cortical idling (stand-by mode)

8-13 Hz

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SMR

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Sensorimotor rhythm: movement related (on sensorimotor cortex)

12-15 Hz

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Beta

Cognitive functioning

Rythmic beta: pathology

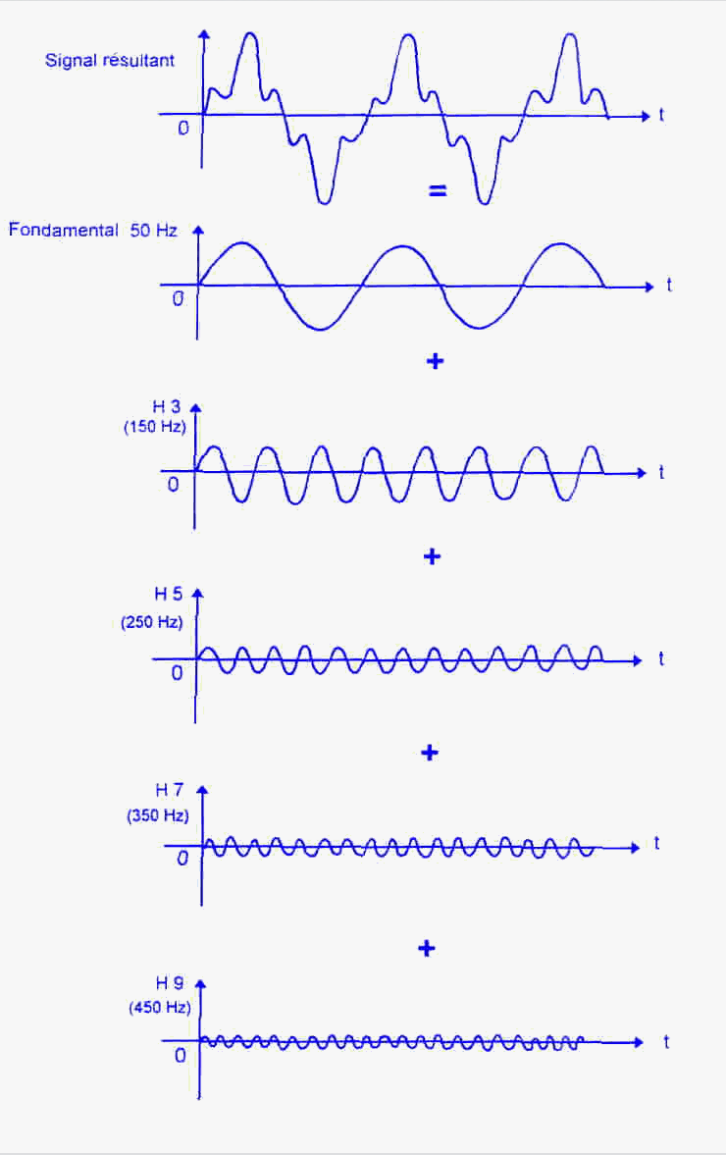
12-30 Hz

Gamma

Synchronization of activity in cortical networks

>30 Hz

Fourier



Every signal can be thought as being build up from sine-waves

Filtering

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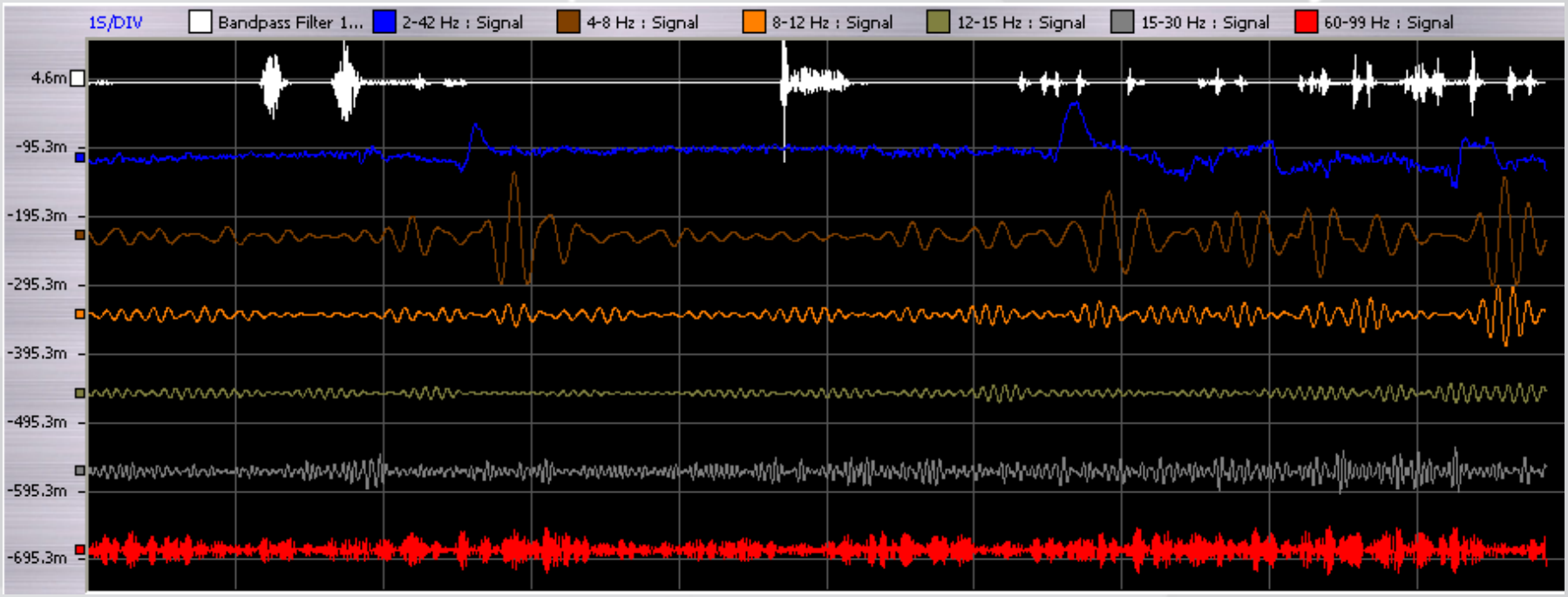
The EEG is build up from the different EEG rythms



The EEG rythms can be extracted from the measured EEG by filtering the EEG signal

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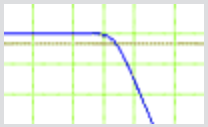
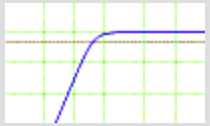
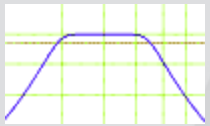
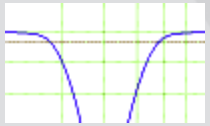
Filter types

- Lowpass 
- Highpass 
- Bandpass 
- Bandstop 

- Characteristics can be modified by choosing different cut-off frequencies and different filter families:
  - FIR
  - Butterworth
  - Chebyshev
  - Elliptic

Filter effects

ECG data filtered with different filters

Artefacts

A number of phenomena can distort the EEG measurement

Approaches to counter the disturbances:

- avoid disturbance
- control for disturbance
- reject disturbances

EOG

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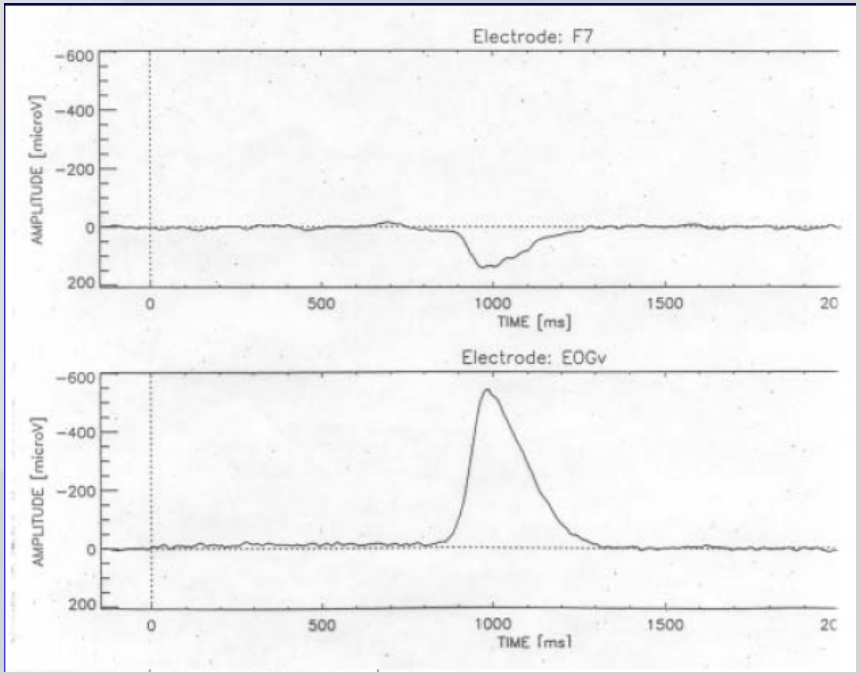
- EOG = electro-oculogram
- An electric field is generated when the eyelid moves along the eyeball
- This electric field is measured by EEG electrodes, where the electrodes closest to the eyes are most affected



- The EOG artefact concerns the lower EEG frequencies (delta & theta)

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EMG

Electric activity of facial or neck muscles can be picked up by EEG electrodes

EMG activity is high frequency activity and therefore primarily distorts high frequency EEG activity (beta & gamma)

Movement

Because EEG is a very sensitive measurement, it can be degraded by (head) movement of the subject; movement of the subject leads to movement of the electrodes

Electrode movement causes the skin-electrolyte interface to be unstable, which causes large potential shifts (low frequency)

Additionally, movement can cause EMG artefacts

End of part I