Electroencephalography - An Introduction

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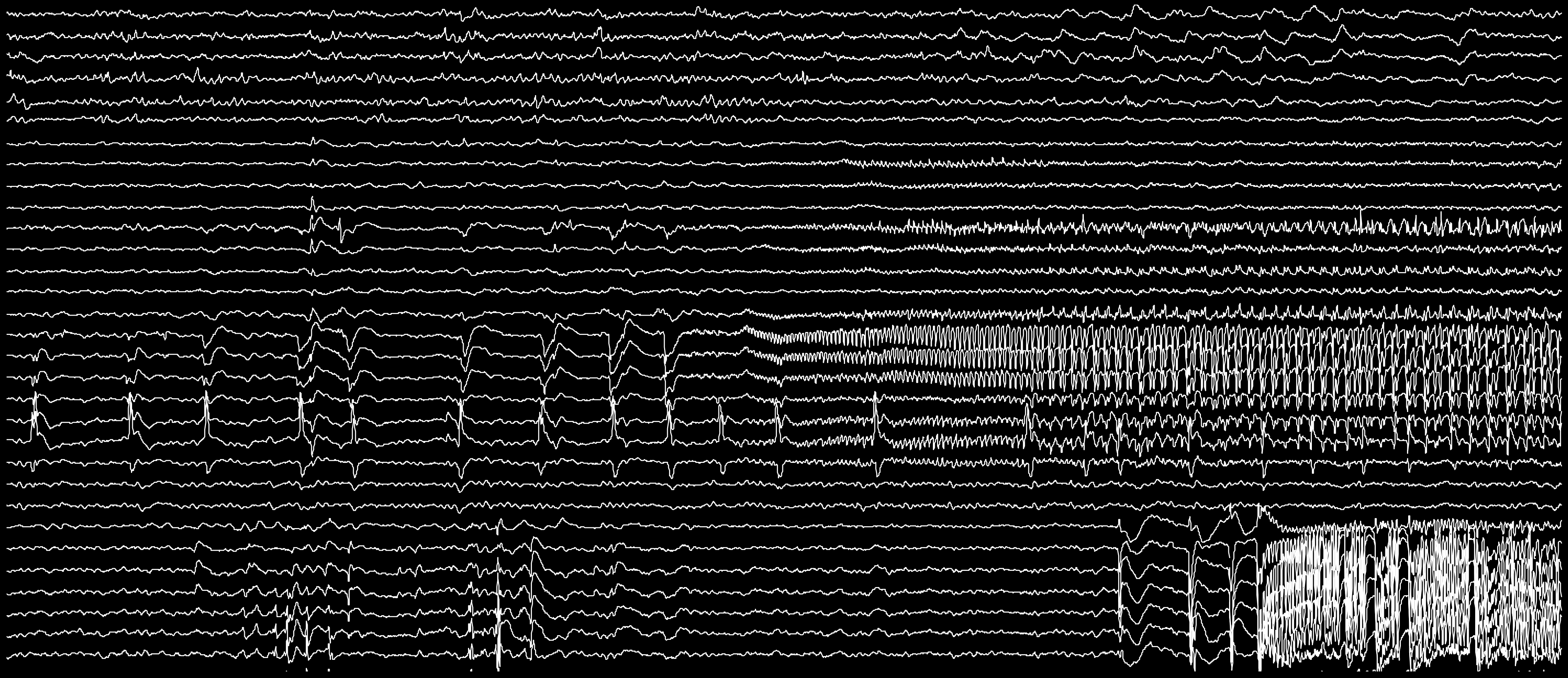
(Summer Term)



Nomenclature

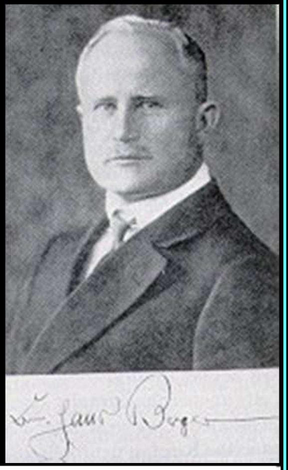
Electroencephalography (EEG)

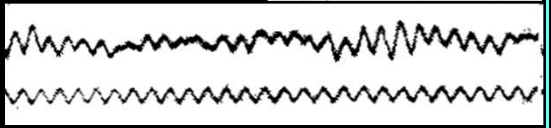
“the recording of electrical activity along the scalp produced by the firing of neurons within the brain”

in clinical context:
“the recording of the brain's spontaneous electrical activity over a short (sometimes long) period of time as recorded from multiple electrodes placed on the scalp”

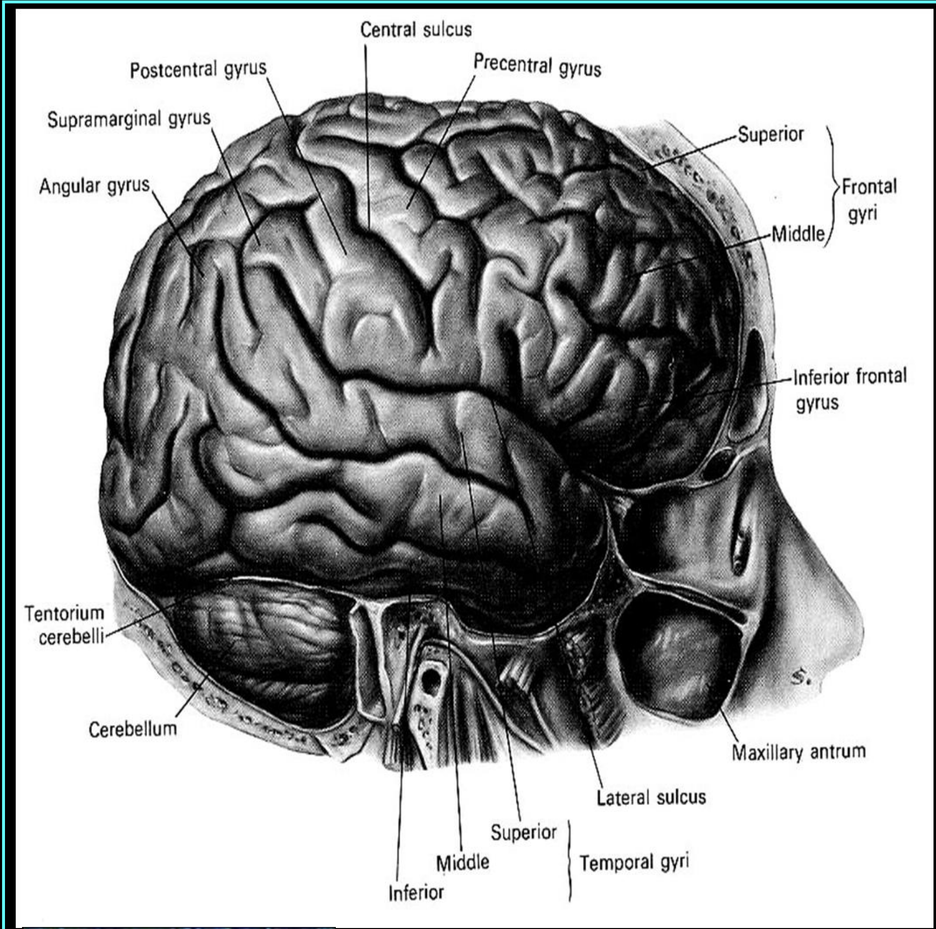
Some Historical Milestones

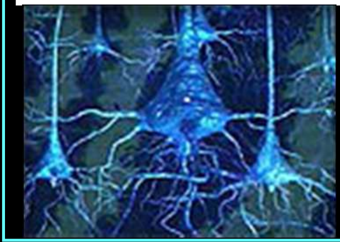
1791 - Luigi Galvani: electrical stimulation of frog nerves
1849 - Hermann von Helmholtz: speed of frog nerve impulses
1850 - Emil Du Bois-Reymond: nerve galvanometer
1868 - Julius Bernstein: time course of action potential
1870 - Eduard Hitzig and Gustav Fritsch discover cortical motor area of dog using electrical stimulation
1874 - Roberts Bartholow: electrical stimulation of human cortical tissue
1875 - Richard Caton: recordings of electrical activity from an animal brain
1906 - Sir Charles Scott Sherrington publishes *The Integrative Action of the Nervous System* that describes the synapse and motor cortex
1913 - Edgar Douglas Adrian: all-or-none principle in nerve
1929 - Hans Berger: first human electroencephalogram
1932 - Jan Friedrich Toennies: multichannel ink-writing EEG machine
1932 – Nobel Prize to E. D. Adrian and C. S. Sherrington for work on the function of neurons
1932 - Jan Friedrich Toennies and Brian Matthews: differential amplifier
1991 - Nobel Prize to Erwin Neher and Bert Sakmann for work on the function of single ion channels





Some Useful Facts about the Brain

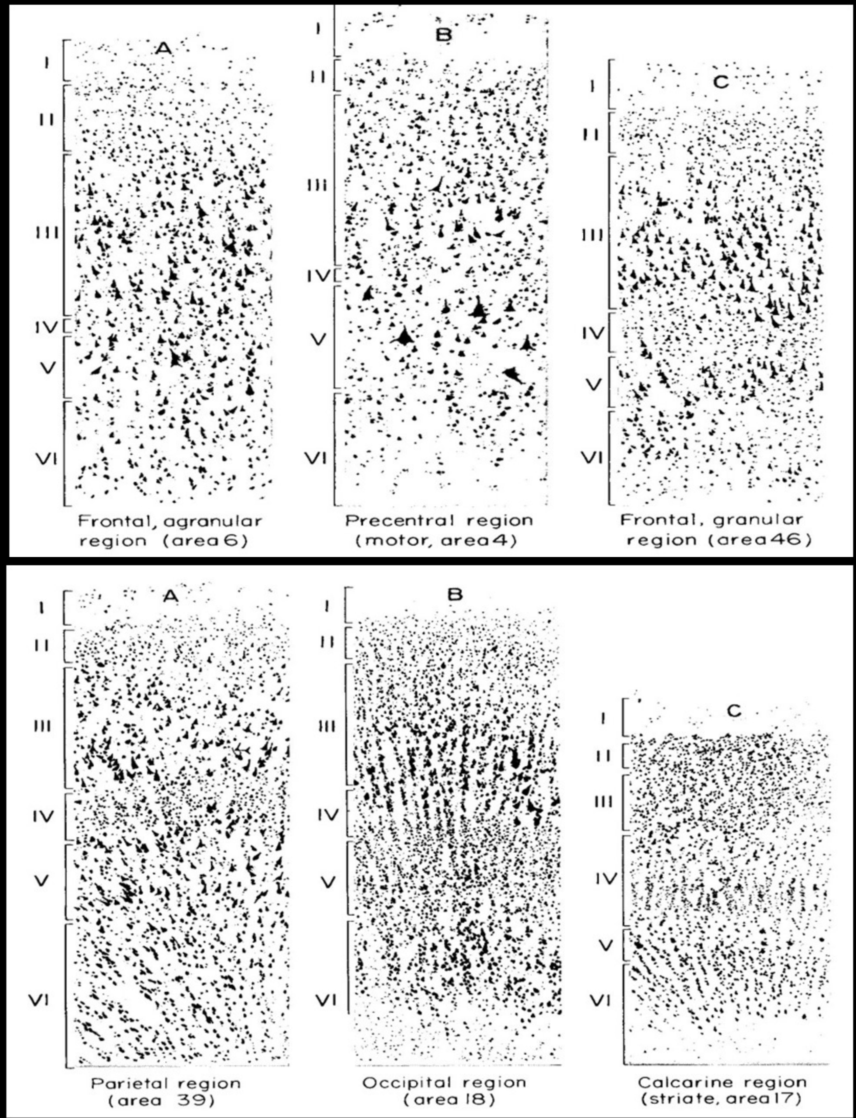




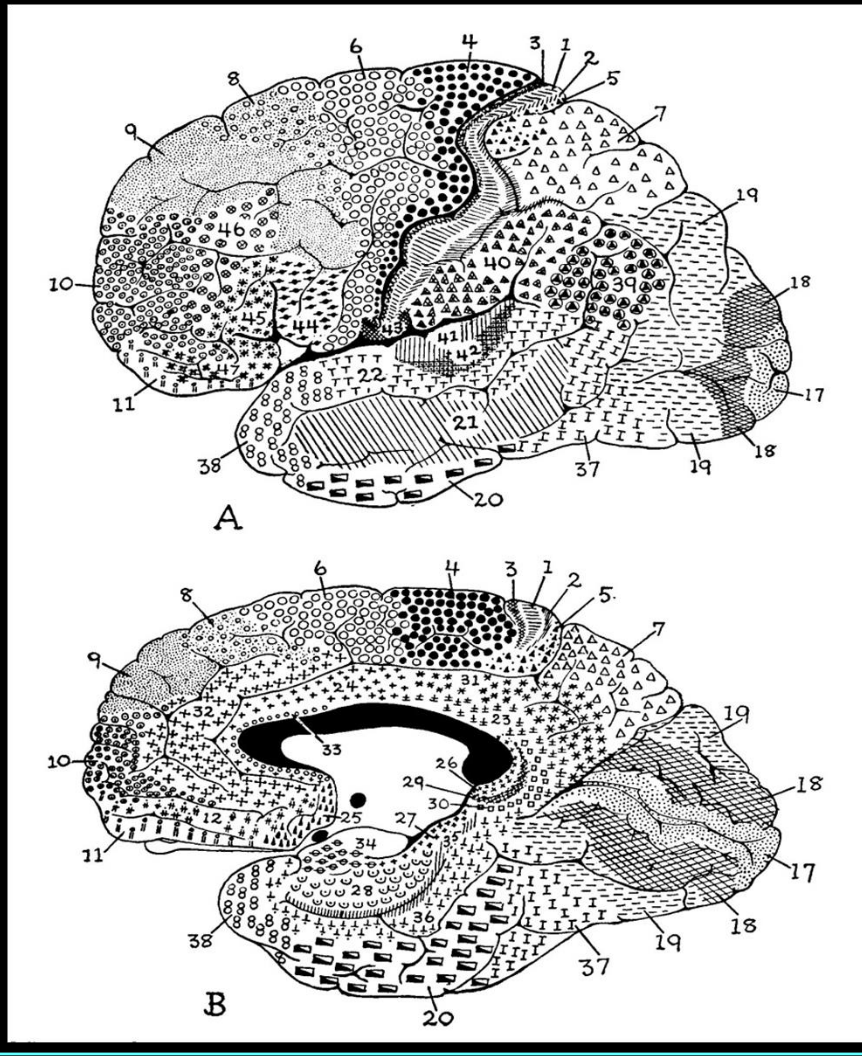
Cortex:

thickness: 1.5 - 4.5 mm
total area: 2200 cm^2 (2/3 in sulci)
neurons: ~ 10^{10} (75 % excitatory)
synapses / neuron: ~ 10^3 - 10^4
length of connections: ~ 10^7- 10^9 m
(~ 2.5 x distance earth - moon)
ion channels / neuron: ~ 10^2 – 10^3
exchange of information: electromagnetic, chemical
neurotransmitter & other active substances: ~ 50
glia cells: x3 # neurons

Cyto-architectural Map of Human Cerebral Cortex

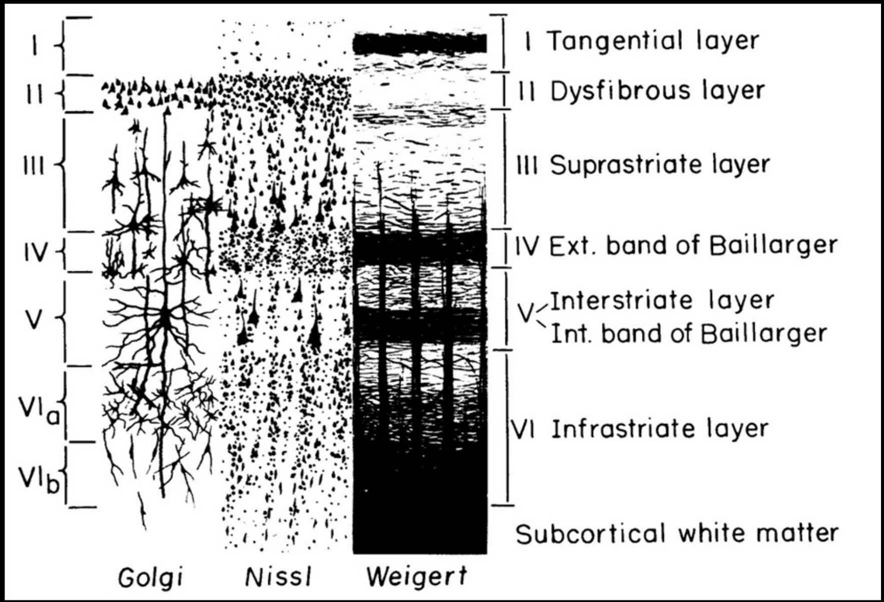


Brodman areas

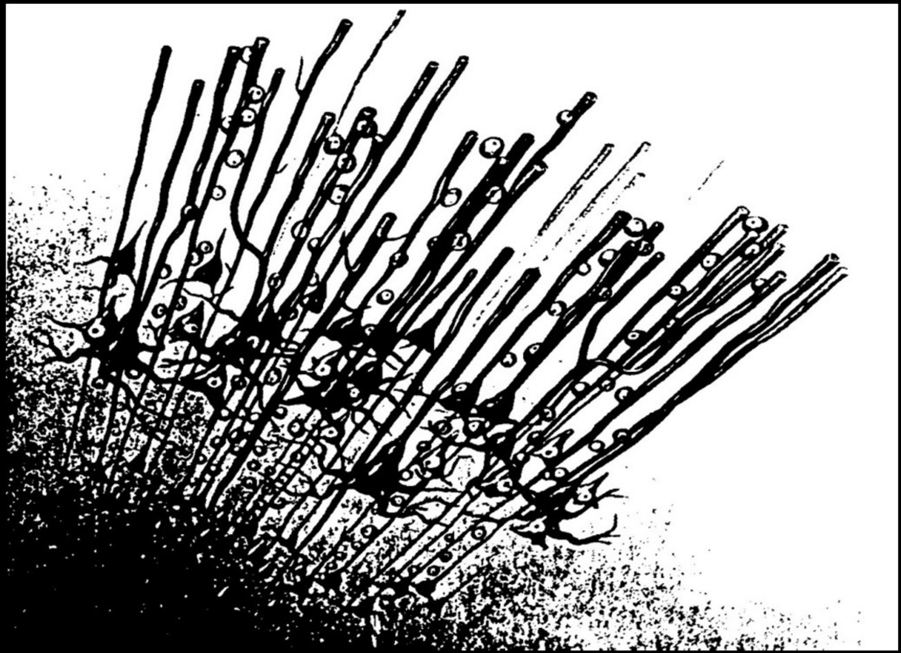


Important organizational features of cortex

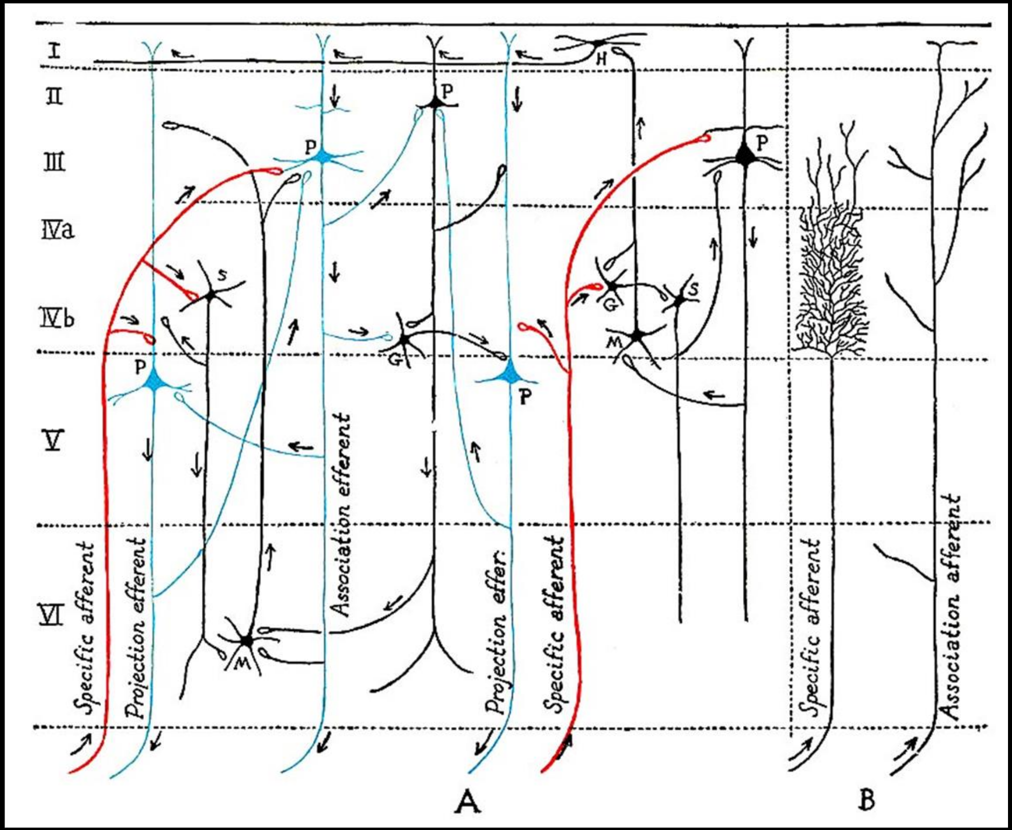
horizontal lamination

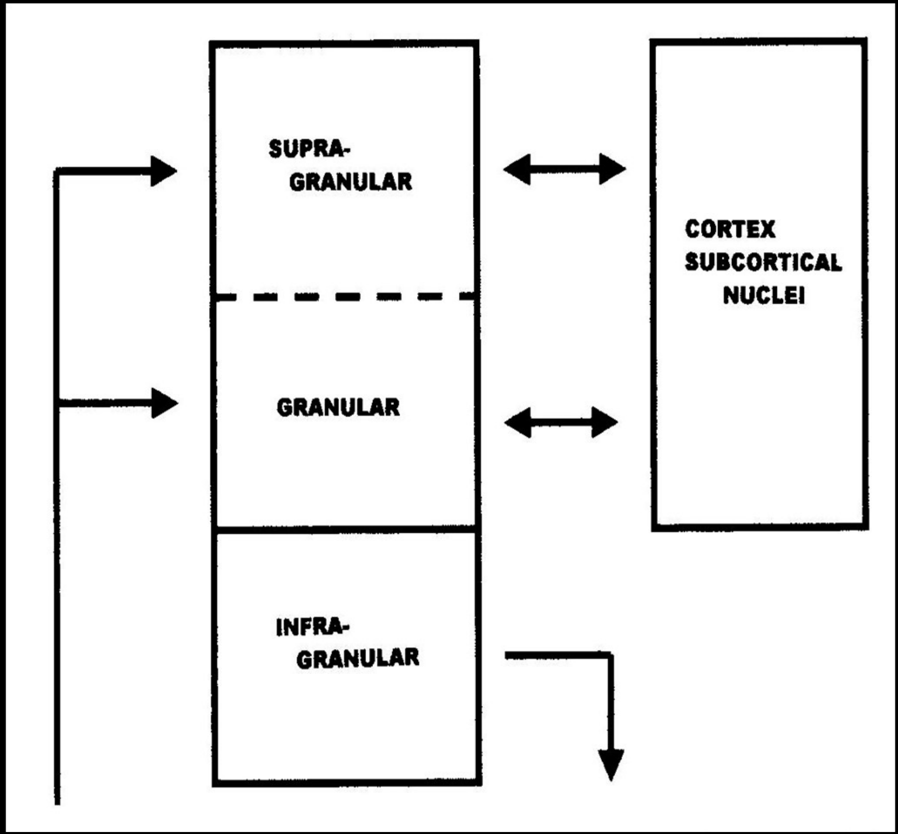


vertical columnation

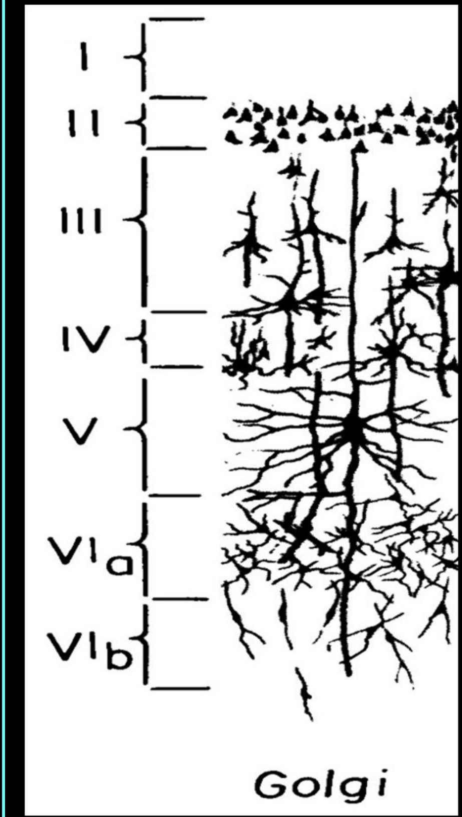


Inputs-outputs to Different Layers are Different





EEG is Generated by Large Pyramidal-shaped Neurons in Layers II, III, IV



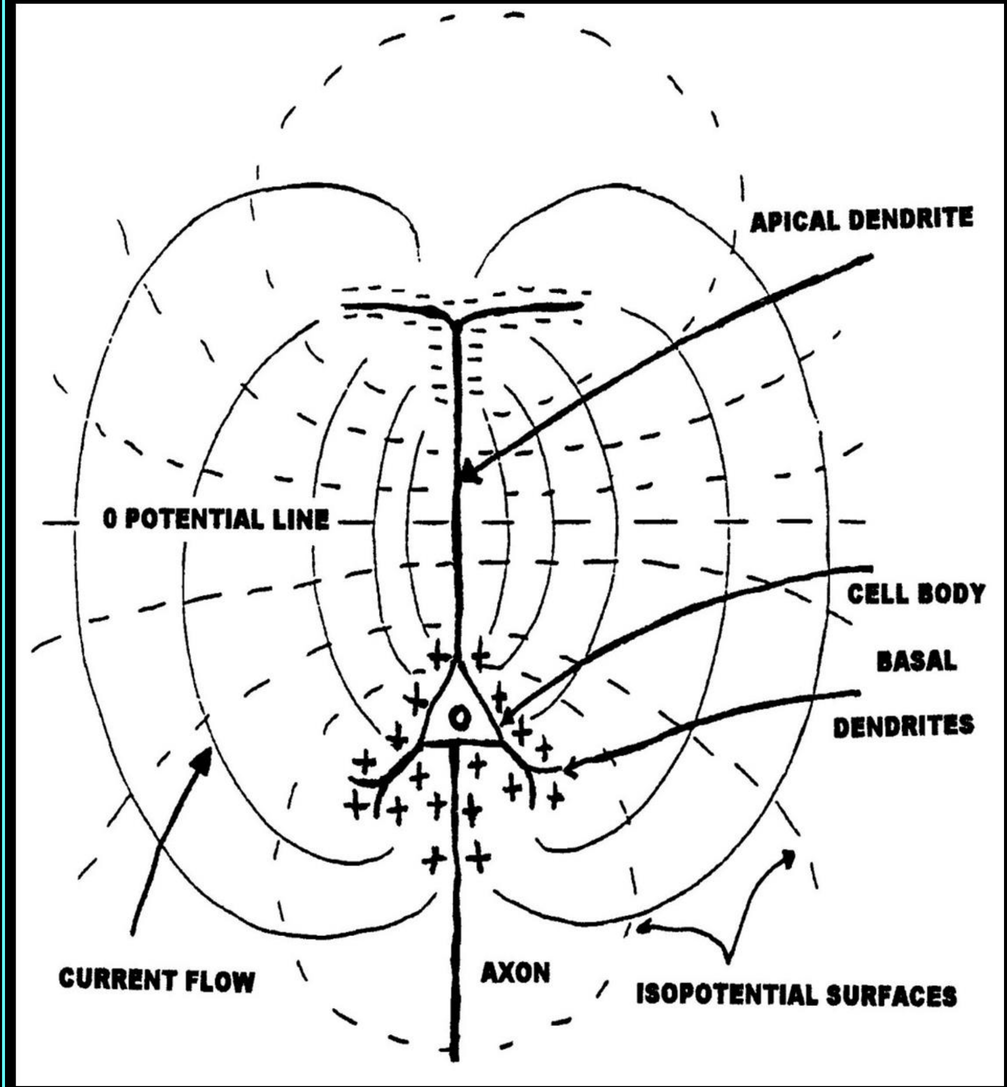
Important features:

- oriented vertical to cortical surface
- inhibitory and excitatory inputs are spatially segregated over the surface of these neurons

  soma: inhibitory inputs only
  dendrites: excitatory and inhibitory inputs
  (excitatory : inhibitory ~ 6.5 : 1)

  inhibitory inputs to dendrites and soma not generally the same

How Charge Separation arises in Cortical Neurons?

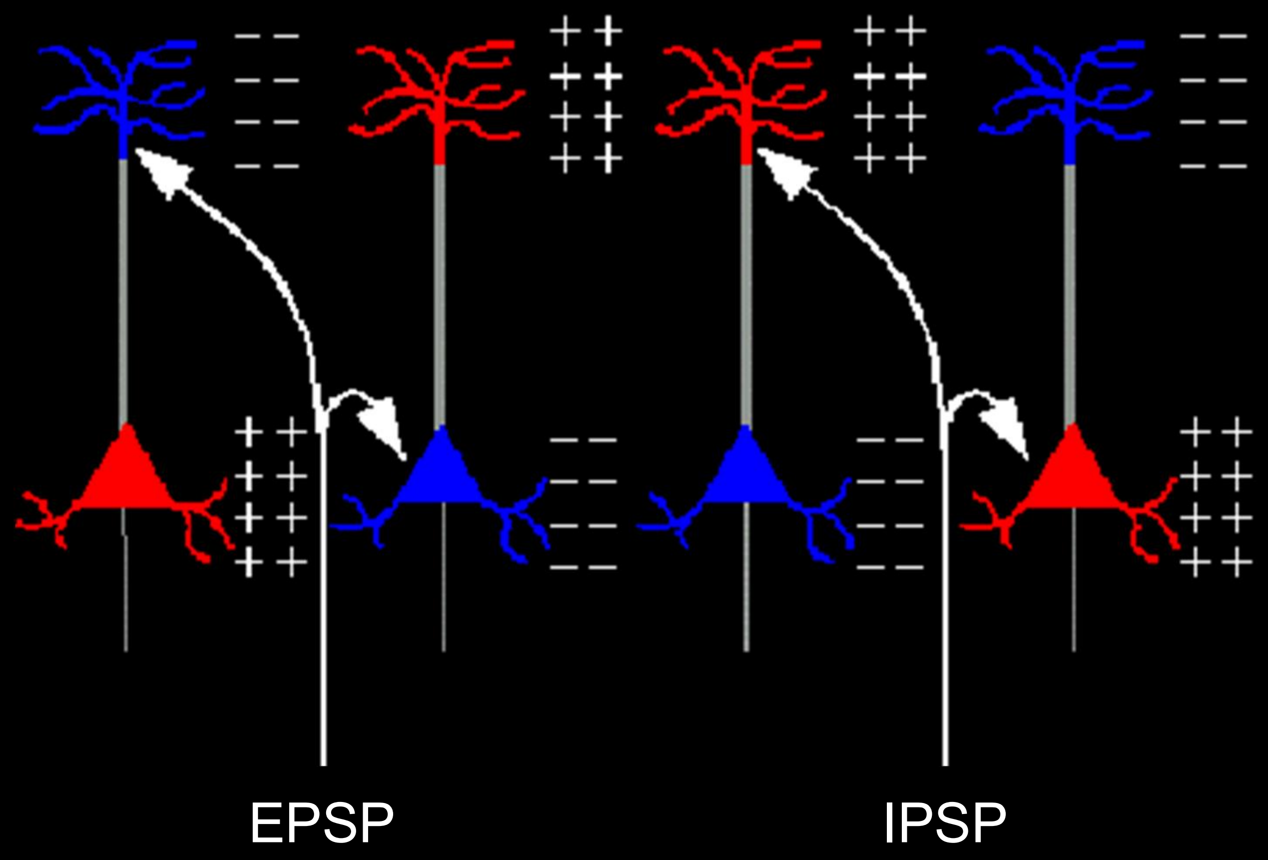


Assumption:
excitation is increased in dendrites
(other choices are possible)

Generators of EEG are excitatory and inhibitory post-synaptic potentials
(not action potentials !!)

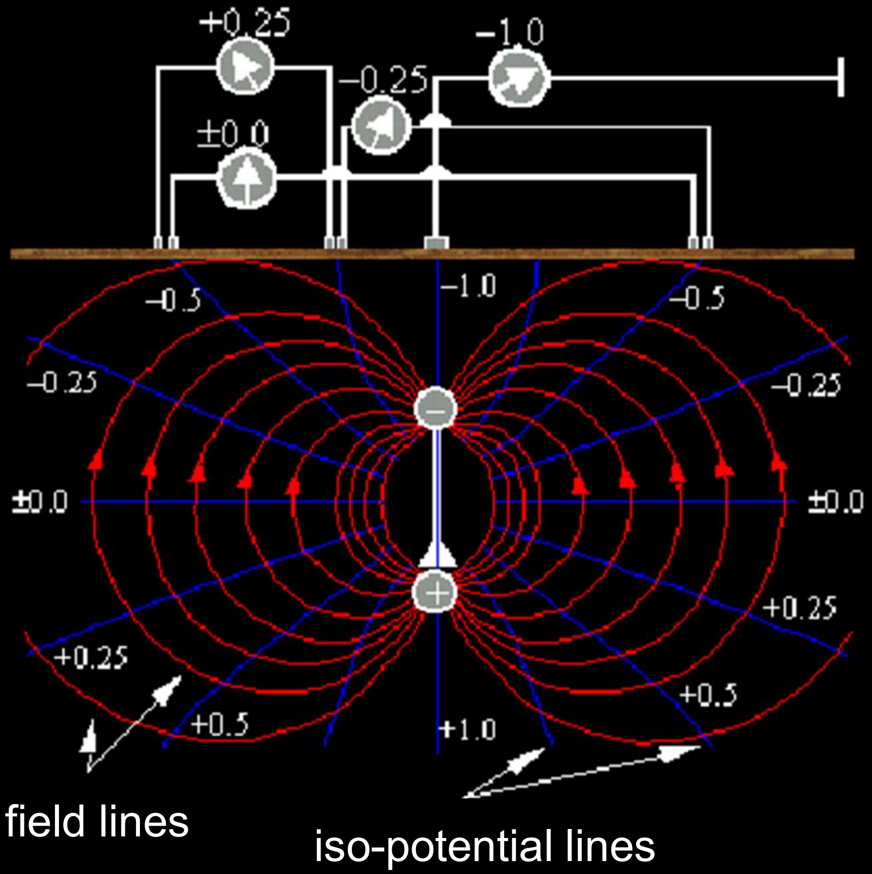
Convention:
current flow is the direction that the positive ions flow

Current flow due to EPSP and IPSP



direction of current flow reflects polarization due to EPSP or IPSP

Field potentials and EEG



neuron as ***current dipole***
(current flow between soma and apical dendrites)

de- or hyperpolarization of postsynaptic membrane

cell body differentially polarized

polarization *travels* to cell body

-> field potential

potential difference can be measured between electrodes located at different iso-potential lines

EEG is a Measure of Neuronal Synchrony (1)

- potential produced by a single neuron is too small to be measured by an electrode on the scalp

- since the EEG-important neurons are vertically arranged, they can summate

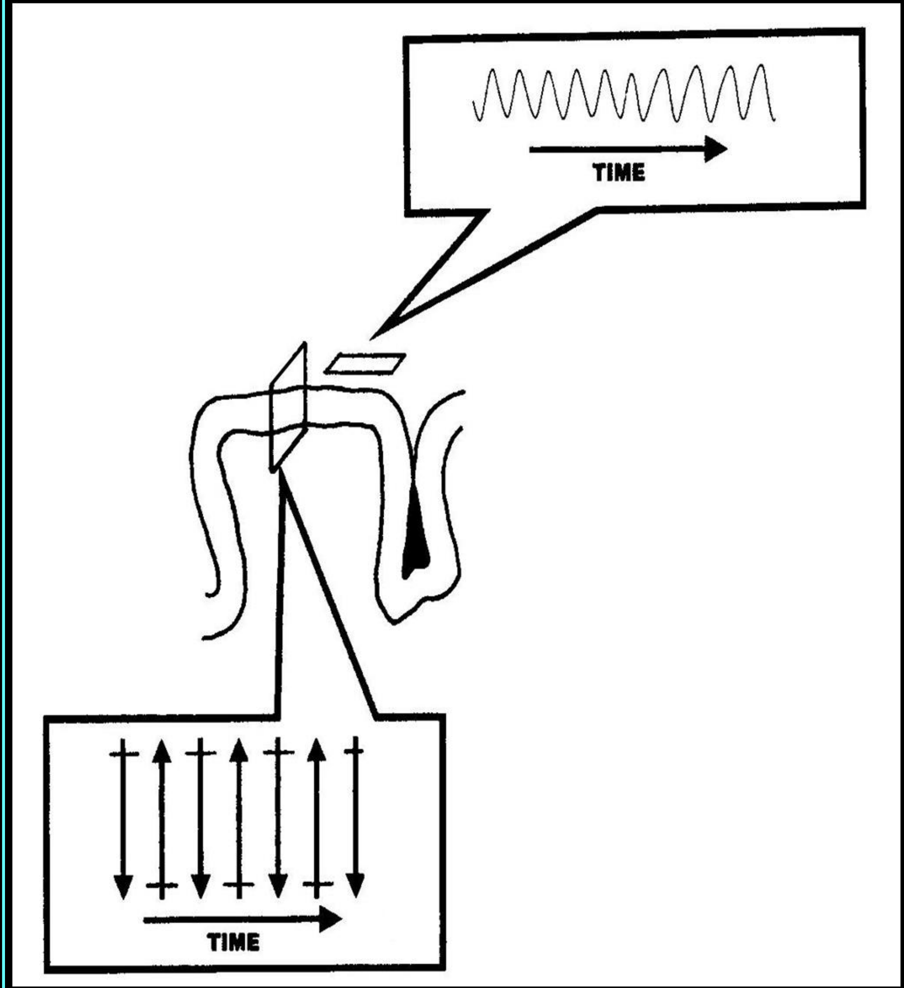
- hence EEG is generated by a huge population of neurons:

  cortical area required to produce a potential measured by a scalp electrode: ~ 6 cm^2

  ~ 10^5 neurons per 0.008 cm^2

  so the measured signal is from ~ 10^8 neurons !!!

EEG is a Measure of Neuronal Synchrony (2)



<u>Time averaged potential</u> P_t

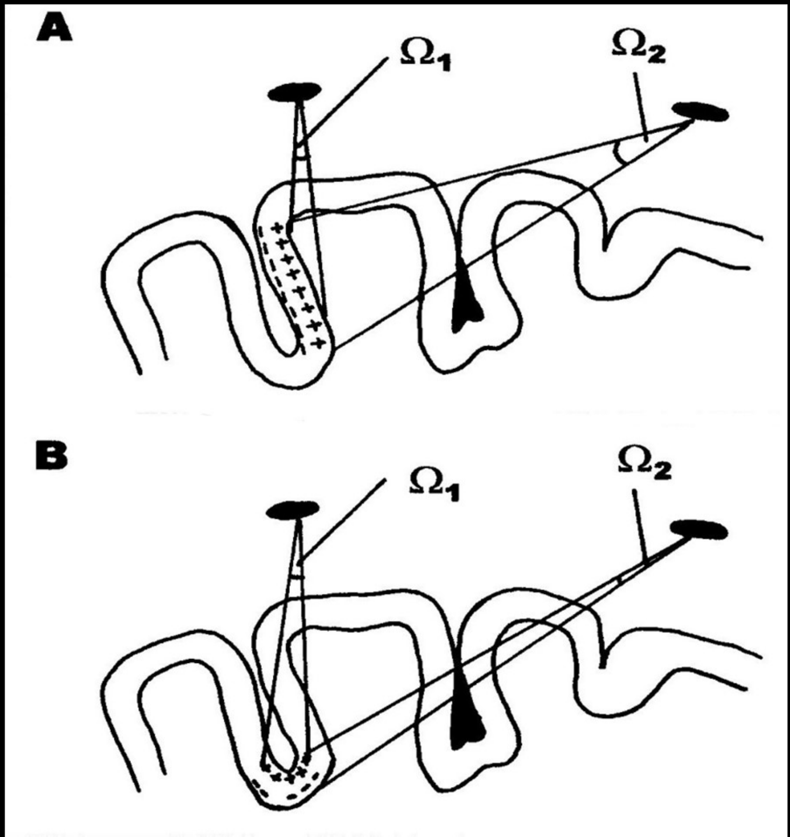
if *m* dipoles oscillate in synchrony:

$$P_t \approx m$$

if *m* dipoles oscillate non-synchronously:

$$P_t \approx \sqrt{m}$$

EEG and Cortical Anatomy

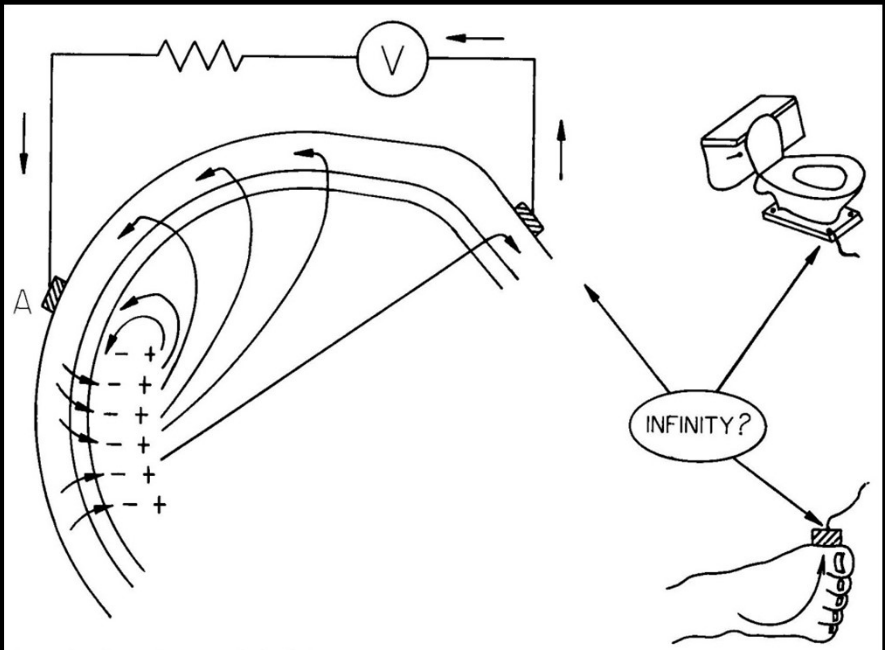


vertical-parallel arrangement of cortical pyramidal neurons is not always present (e.g. amygdala)

dipoles will tend to cancel each other out and hence the potential will approach zero for a large enough neuronal population

gyral surfaces contribute most !!

What does the EEG measure?



current flow through wires vs. aqueous solutions:

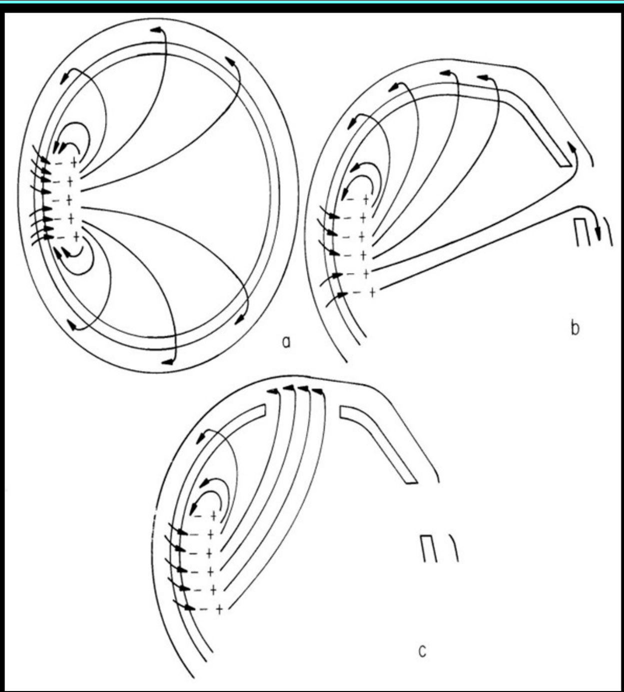
wires

- negatively charged
- electrons move towards the positive charges

aqueous solutions

- the ions do the flowing

How do we know that Brain Generates the EEG?



- current flow follows the path of least resistance
- thus expect that current over skull defect will be greater than in a person with no skull defect

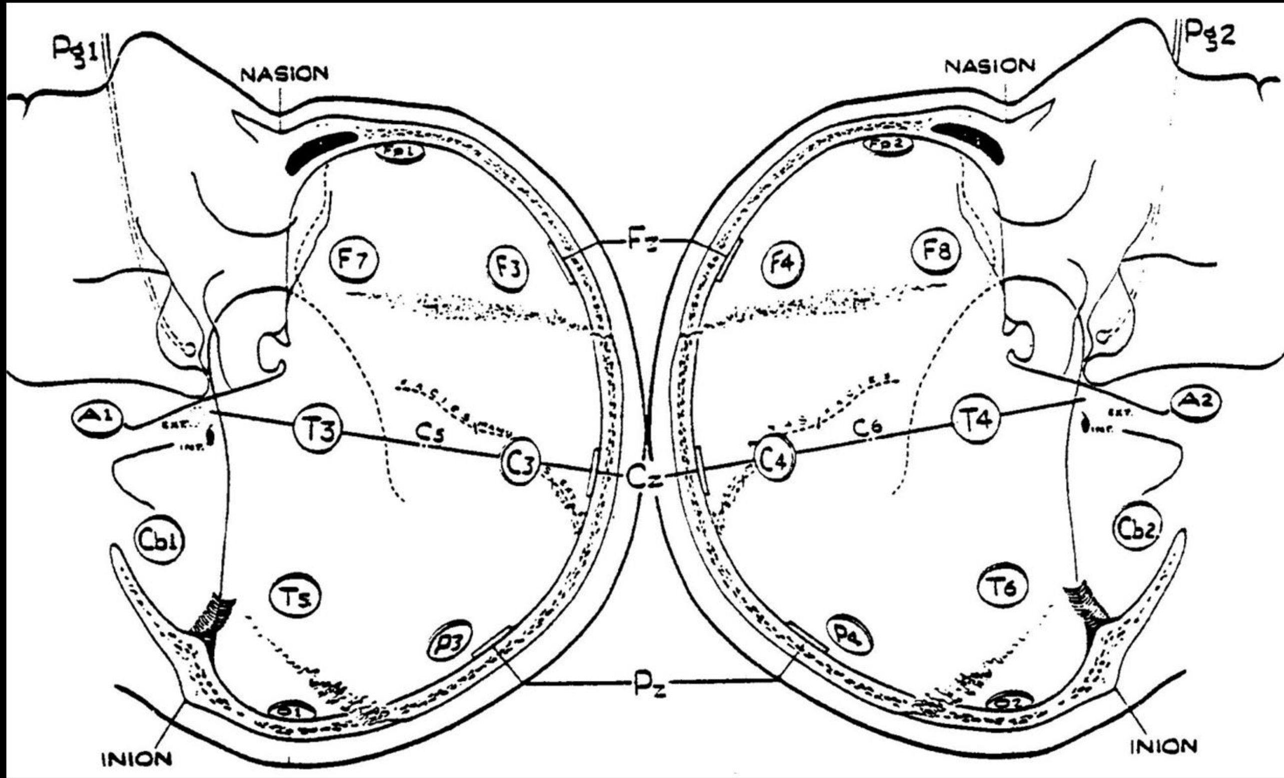
Adrian and Matthews (1934) “*alpha-EEG*”

Observation 1: alpha current density above skull defect is higher than in person with no defect (if alpha is generated outside the skull, this would not be observed)

Observation 2: less alpha current flows into frontal regions (if alpha is generated by eye muscles, this effect would not occur)

Non-invasive measurements of EEG

International
10/20 System:
- consistent naming
- reproducible placement



Reference points:

nasion (between forehead and nose)
inion (bump at the back of the skull)
left + right pre-auricular points (between lower jaw & cheek bone)

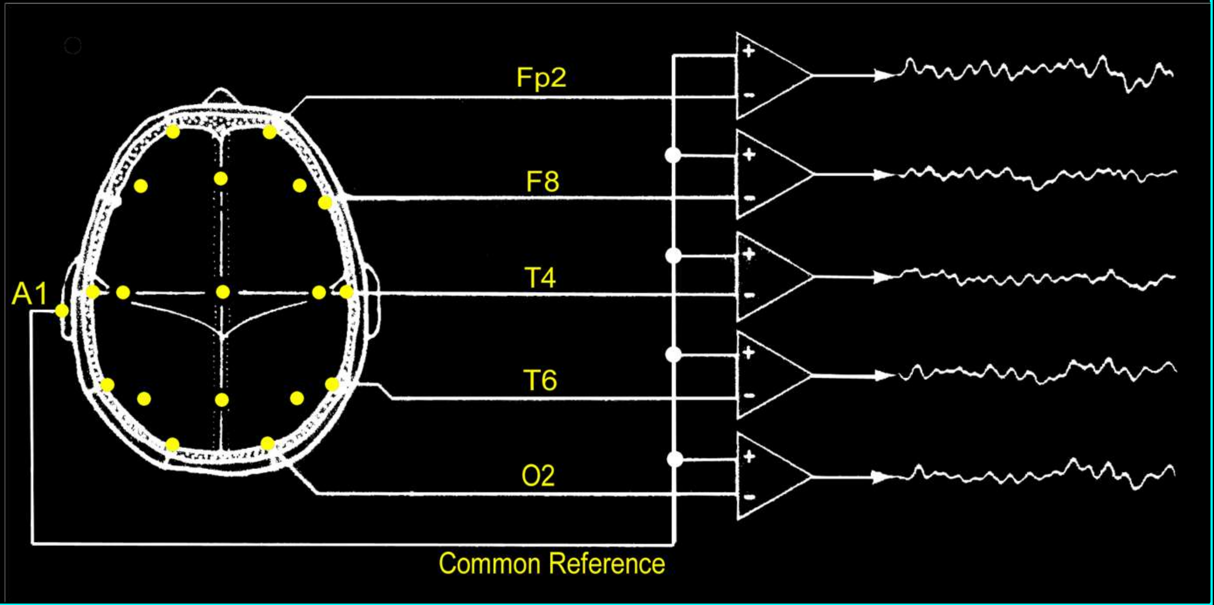
location: **F**_rontal, **T**_emporal, **P**_arietal, **O**_ccipital, **C**_entral, **z** (central line)

numbers: even: right side, odd: left side

Non-invasive measurements of EEG

prepare scalp area (light abrasion to reduce impedance due to dead skin cells)
place electrodes on scalp with a conductive gel or paste

place ground electrode (electrically zero?) and choose reference electrode(s)
connect each electrode to one input of **differential amplifier**
connect reference electrode(s) to other input of differential amplifier
Amplification: x 10^3-10^5; EEG has small amplitude: ~ 10-50 µV (AP: 60-100 mV)
anti-aliasing filtering
A-D conversion (typically 16 bit)
low-pass: 35 – 70 Hz
high-pass: 0.5 – 1 Hz
sampling rate: 200 Hz (20 kHz)
digital storage
representation on screen



Representation of EEG: the Choice of a Montage

EEG signal represents a difference between the voltages at two electrodes

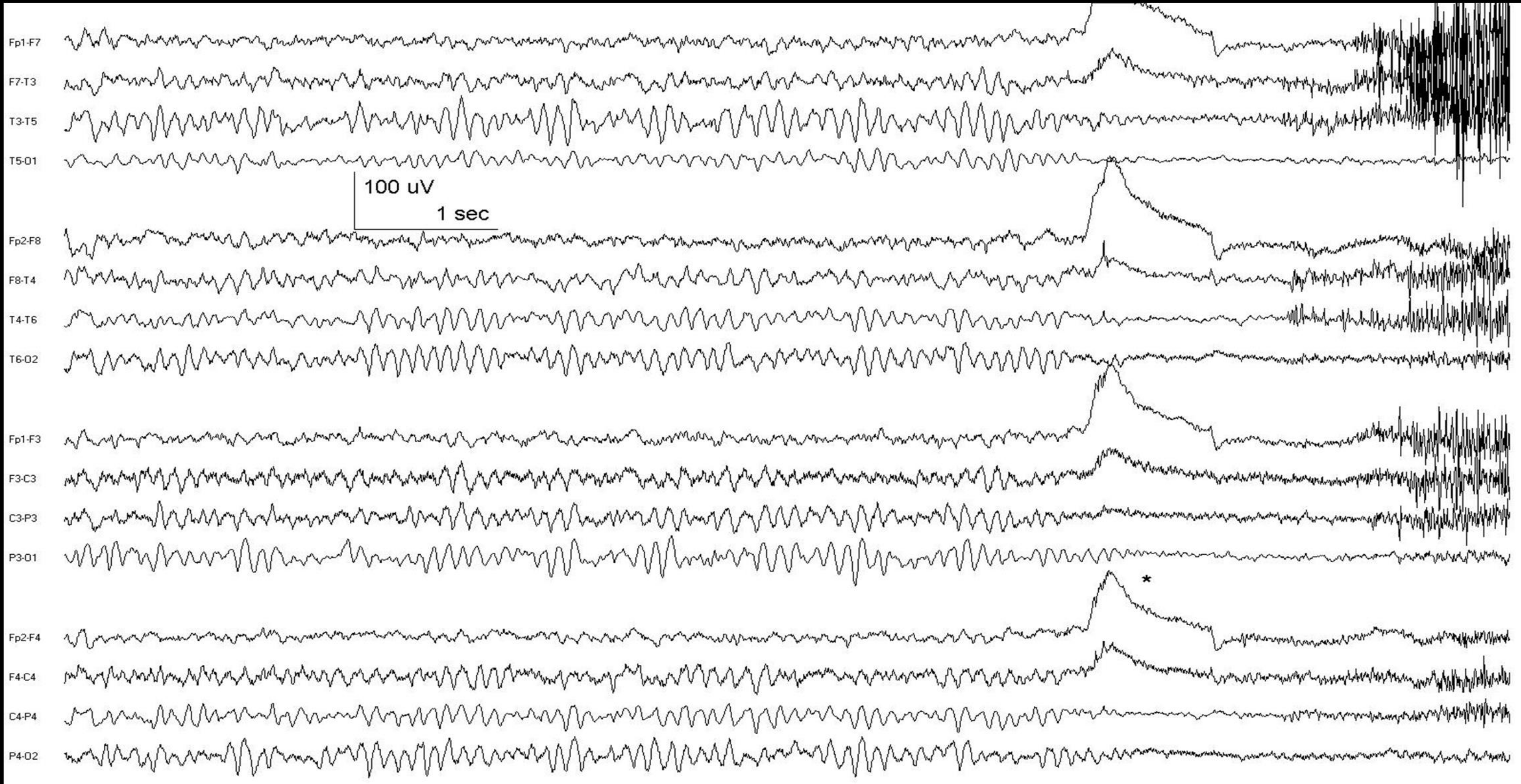
Bipolar montage
difference between two adjacent electrodes (e.g. Fp1-F3)

Referential montage
difference between a certain electrode and a designated reference electrode
- midline positions (they do not amplify the signal in one hemisphere vs. the other)
- linked ears (physical or mathematical average of electrodes at both earlobes or mastoids)

Average reference montage
outputs of all of amplifiers are summed and averaged
averaged signal is used as the common reference for each channel

Laplacian montage
difference between an electrode and a weighted average of the surrounding electrodes

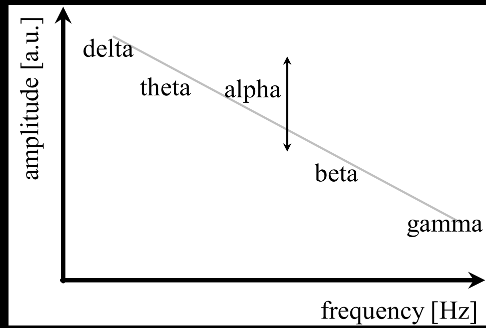
An EEG Example



awake, resting; normal posterior alpha rhythm disappears with eye opening (*);
high frequency activity after eye opening is muscle artifact; anterior-posterior bipolar montage; 0.5 - 70 Hz

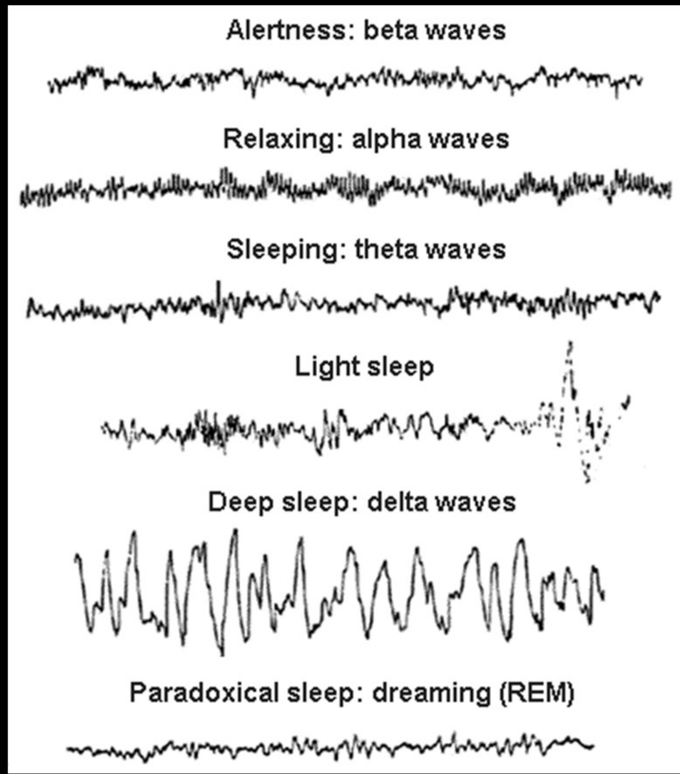
State-dependent Rhythms of the EEG

EEG power spectral density:
- frequency dependent amplitude behavior
- looks like 1/f noise
- long-term correlations



name	f [Hz]	A [µV]	Loc.
δ	0 - 4	20-200	variable
ϑ	4 - 8	5-100	front., temp.
α	8 - 13	5-100	occ., par.
β	13 - 30	2-20	front.
γ	30 - 70	< 10	variable

(higher ??)



functional integration:
from short (γ) to long-range interactions (δ)

Artifacts look more or less like EEG Signals

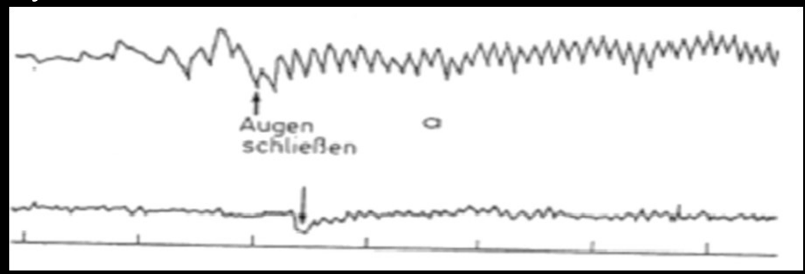
technical artifacts

- power line (incl. higher harmonics)
- broken cable, dirty connectors
- different electrode materials
- poor grounding
- …

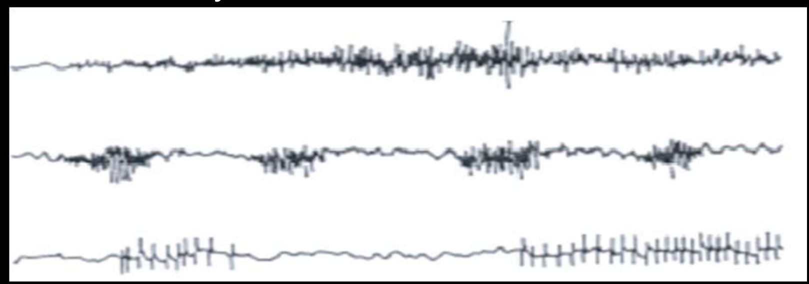
biological artifacts

- eye-induced (blink, movement)
- cardiac-induced (heart beat, pulse)
- muscle-induced (movement, chewing)
- sweating
- …

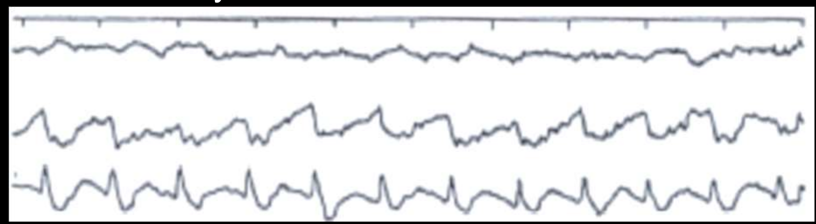
eye blink



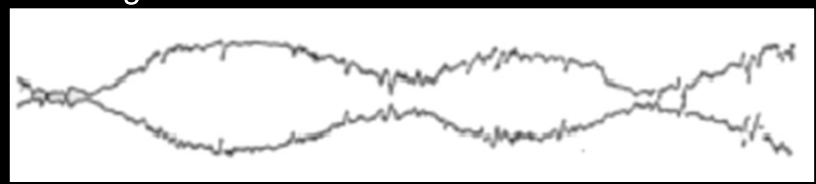
muscle activity



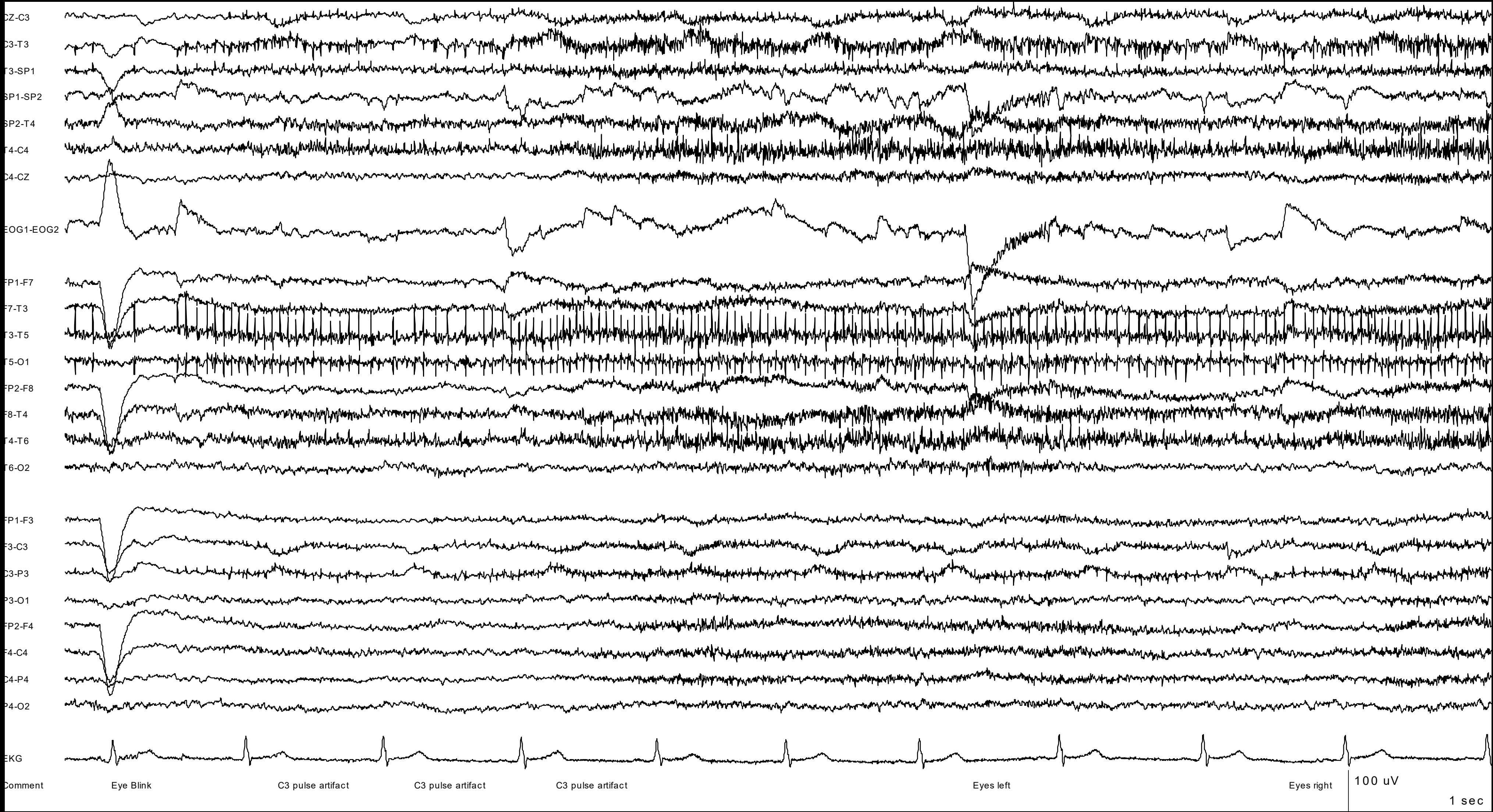
cardiac activity



sweating



Artifacts look more or less like EEG Signals



Eye blink, horizontal eye movements, frontalis and temporalis EMG, lateral rectus EMG, pulse artifacts. Combined circular and anterior-posterior bipolar montage.

Applications of EEG

well-established uses of EEG

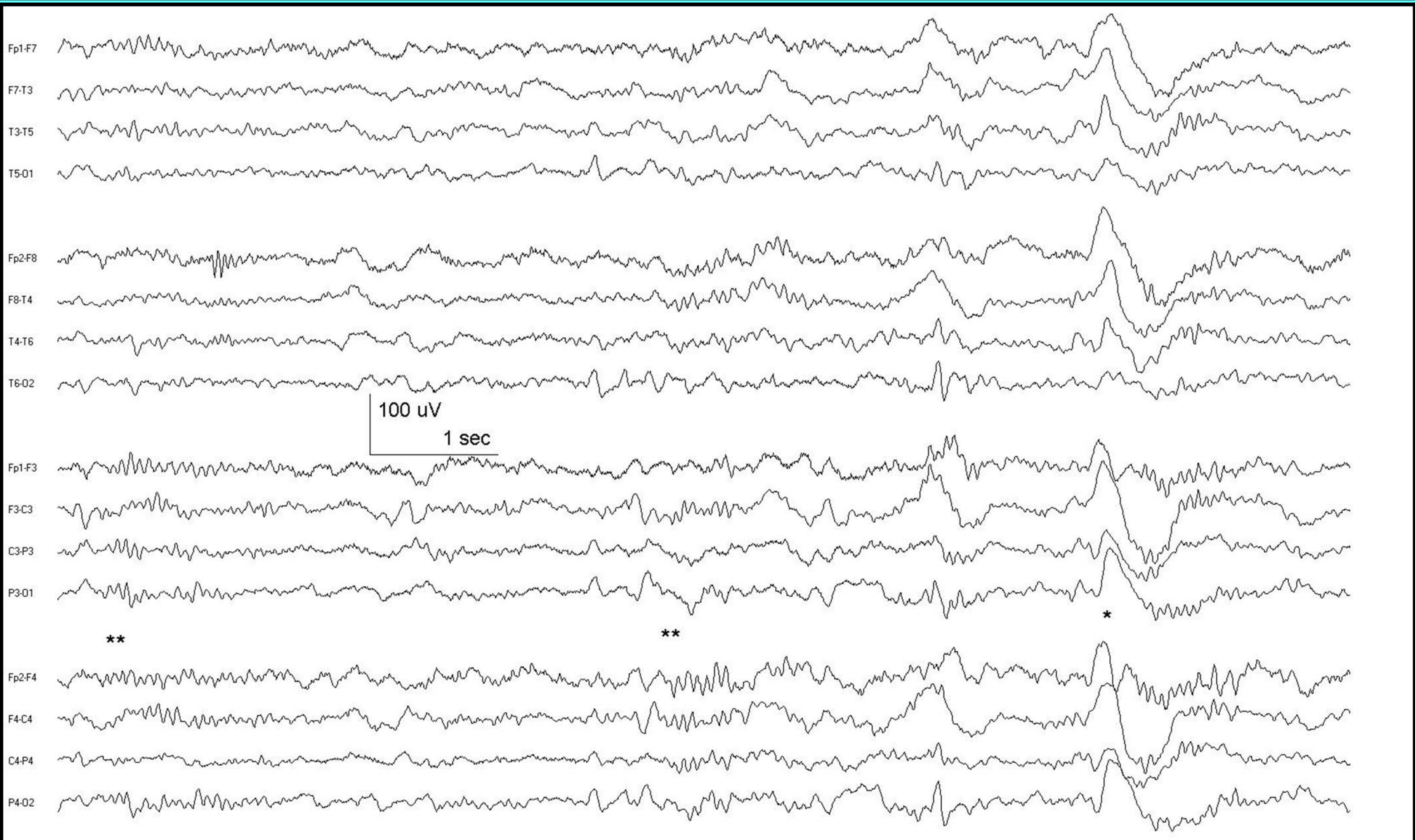
- levels of consciousness (e.g. coma, delirium)
- epilepsy (e.g. diagnosis, epilepsy surgery)
- sleep (e.g. sleep disorders)
- other neurologic diseases, depth of anesthesia
- brain death, intensive care

areas of research

- neuroscience, cognitive science, cognitive psychology,
- psychophysiological research
- brain-computer interfaces

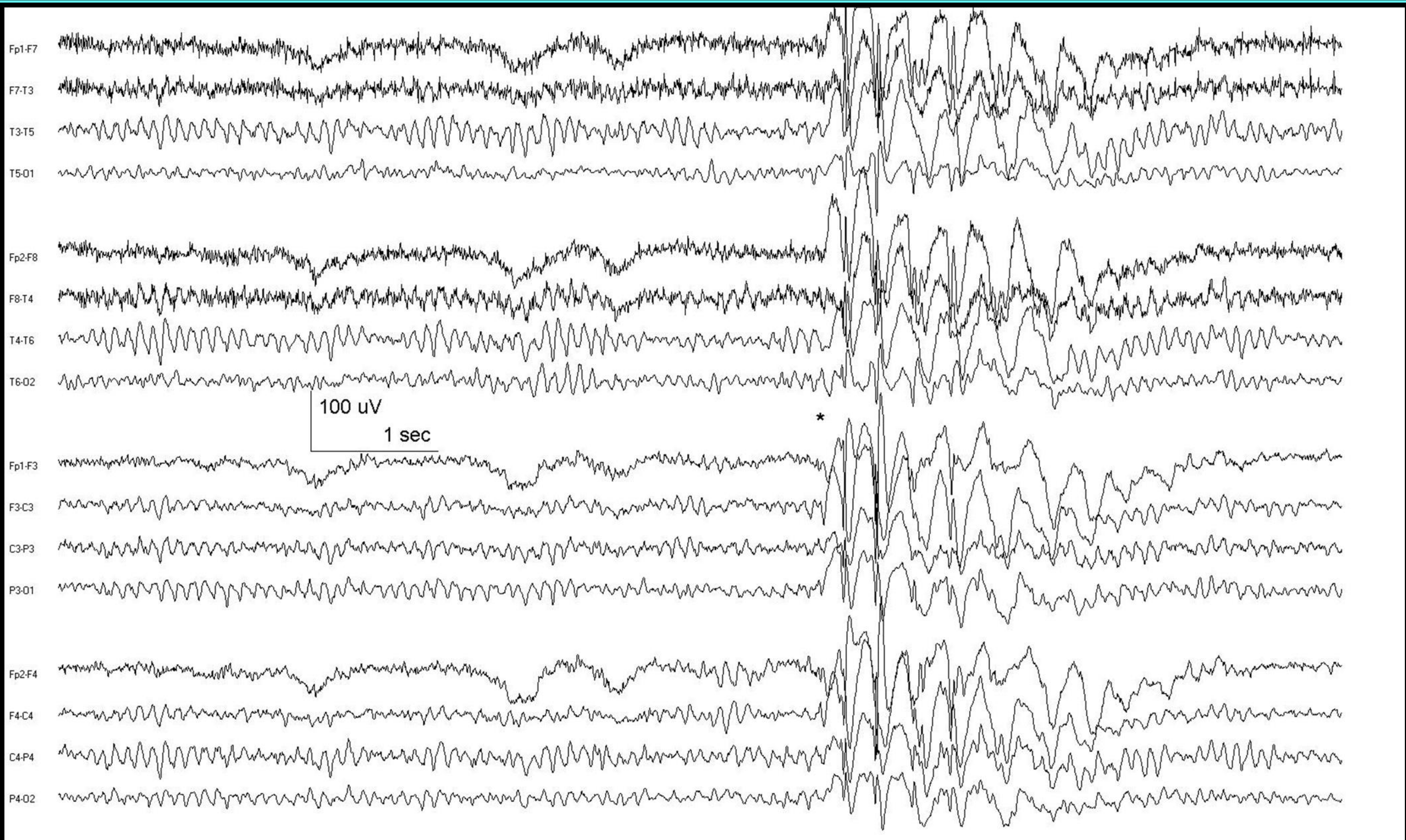
many, many abuses

EEG Examples: Sleep



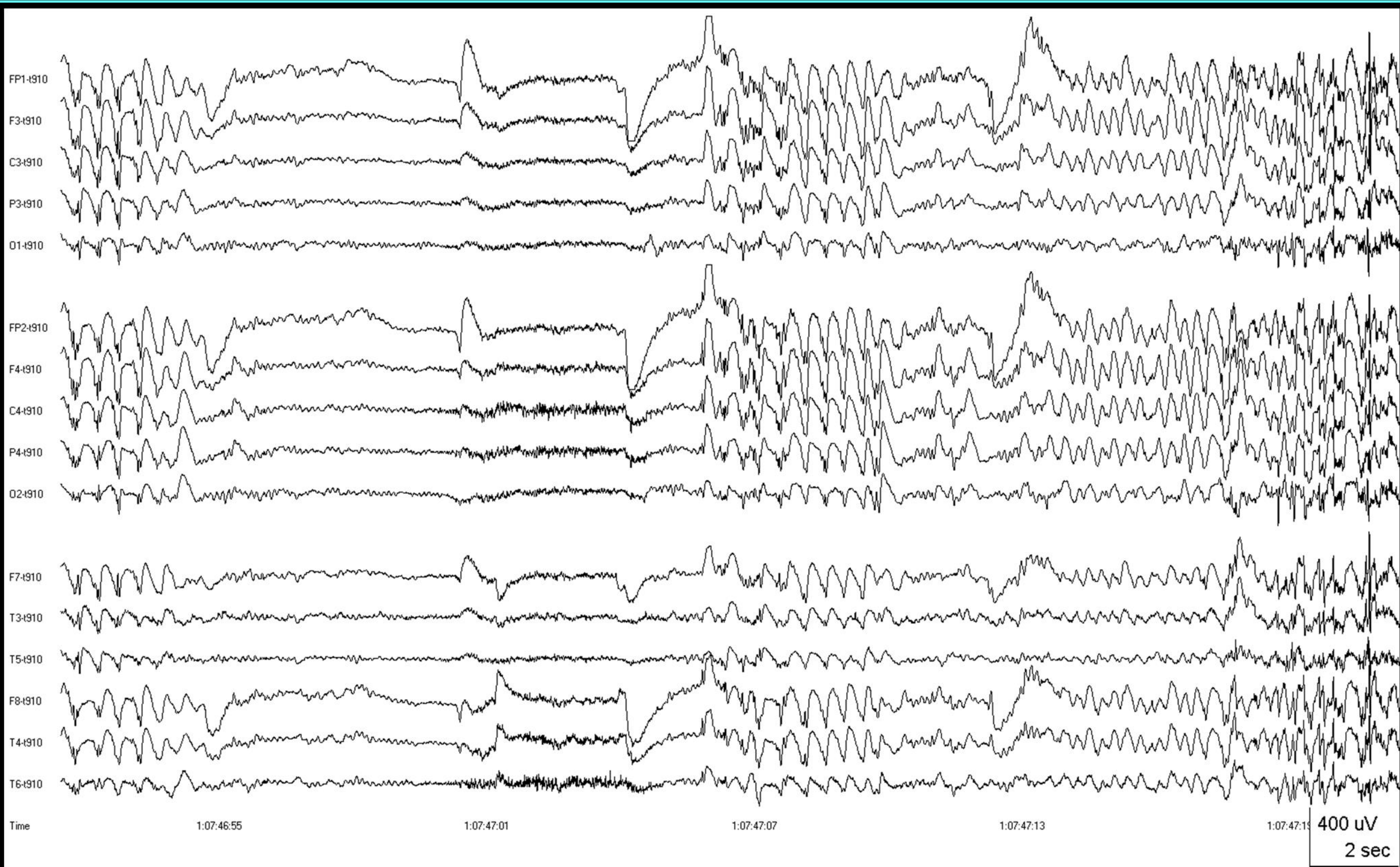
Stage II sleep. K-complex (*); Sleep spindles (**). Anterior-posterior bipolar montage.

EEG Examples: Primary Generalized Epilepsy



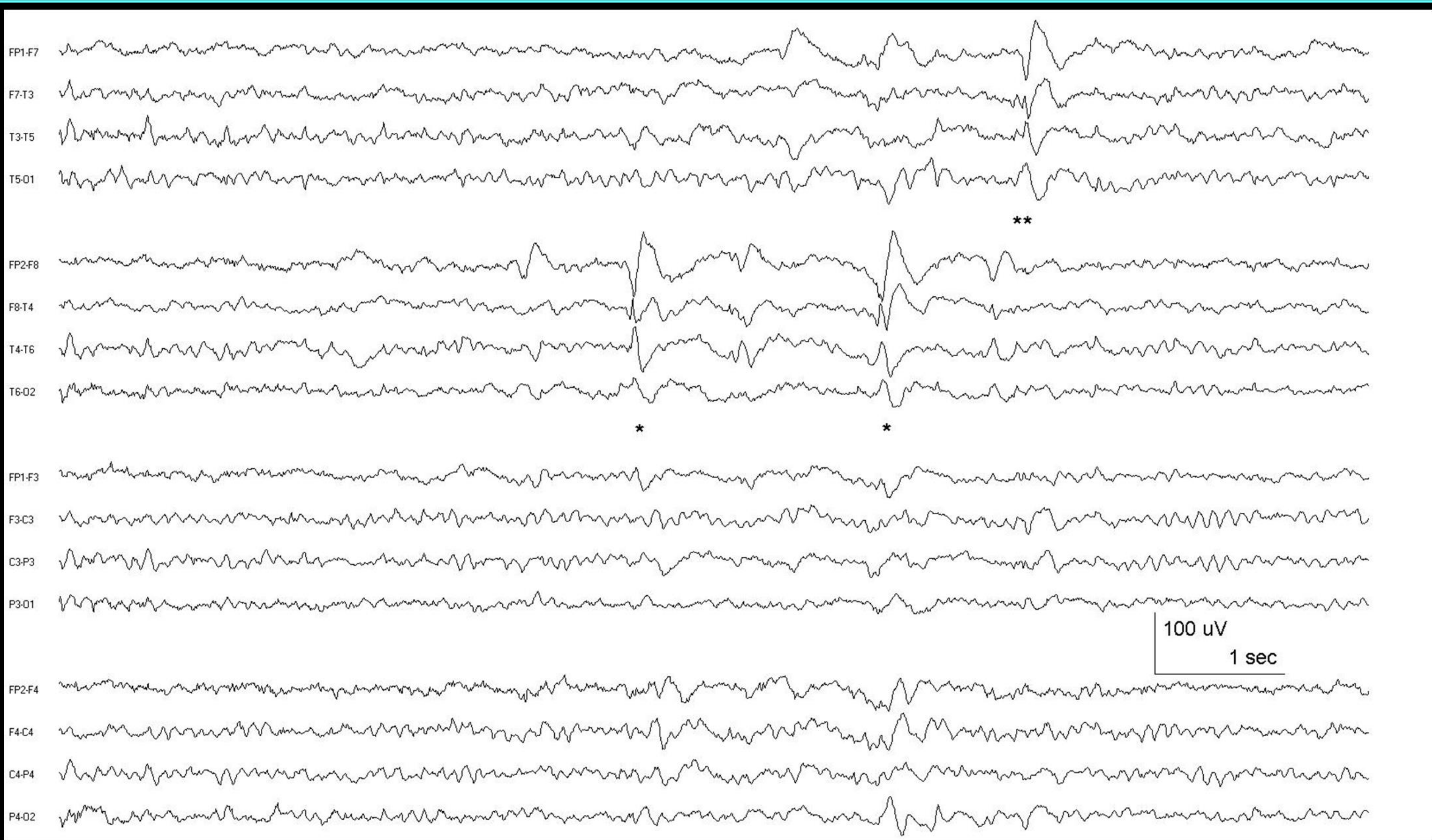
Burst of generalized 3 Hz spike and wave activity (*). Anterior-posterior bipolar montage.

EEG Examples: Primary Generalized Epilepsy



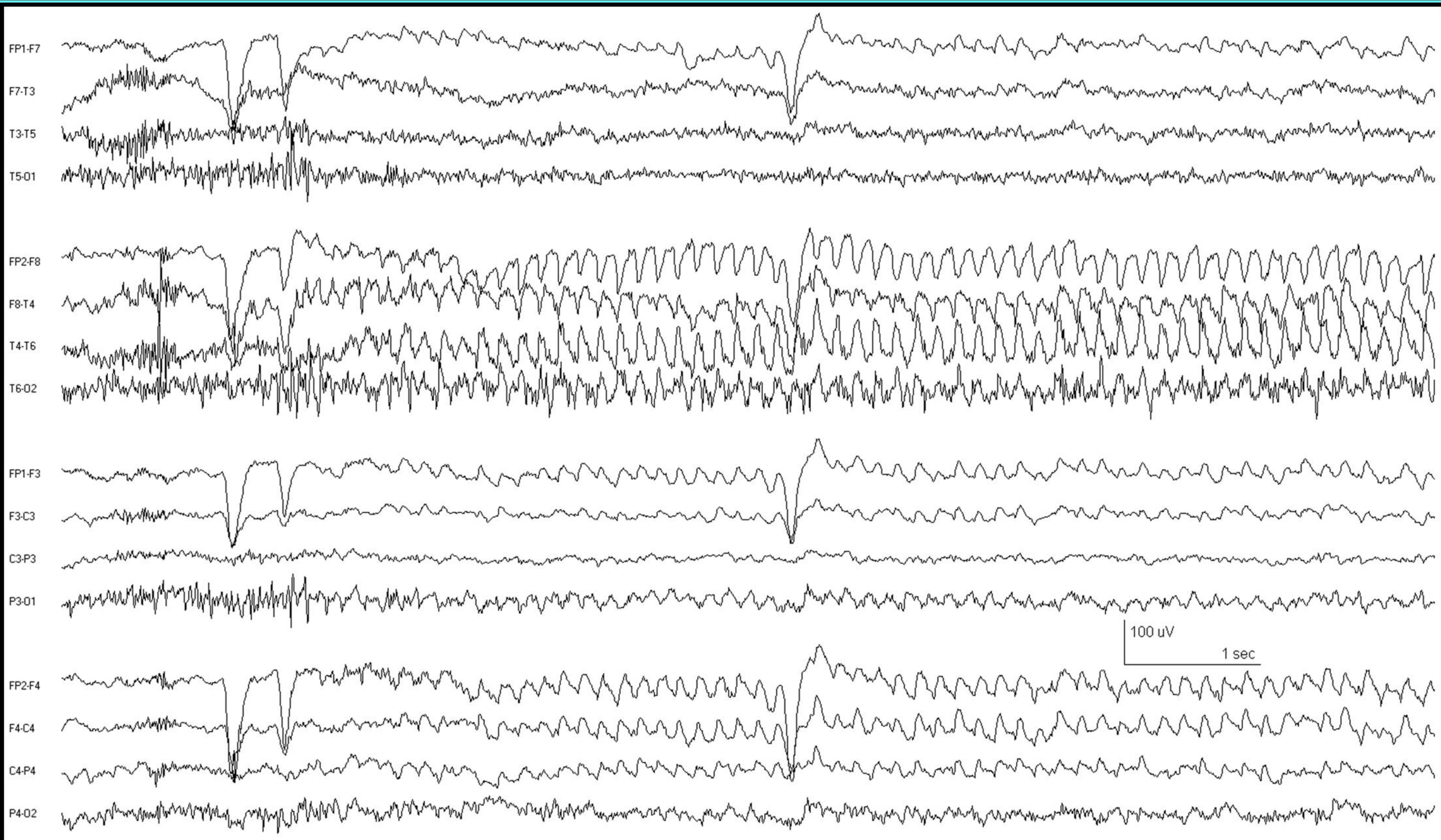
Transition to tonic-clonic seizure. Referential montage; reference = linked ears

EEG Examples: Temporal Lobe Epilepsy



Independent sharp and slow wave complexes over right (*) and left (**) anterior-mid temporal regions. Anterior-posterior bipolar montage.

EEG Examples: Temporal Lobe Epilepsy



Focal rhythmic seizure pattern localized to right temporal region ("equipotentiality" at F8-T4). Anterior-posterior bipolar montage.

Summary

EEG is dominated by activity at the cortical surface (i.e., the gyrus)

only about on-third of cortical surface

EEG cannot “see” deep into the brain

spontaneous activity in, e.g., mesial temporal regions,
interhemispheric frontal lobe structures, thalamus
is NOT apparent on scalp EEG

Note that output of cortical neurons is in direction away from surface

suggests that is more sensitive to afferent (sensory) inputs to cortex
(not proven)

Rhythmic nature of EEG unexplained !!!

Advantages of EEG

- best spatial-temporal resolution
  (compared to all other measurements of cerebral activity)

  temporal resolution: 1 msec (1000 Hz) or better
  spatial resolution: 10 microns (theoretically!)

- can measure while behavioral activities are on-going