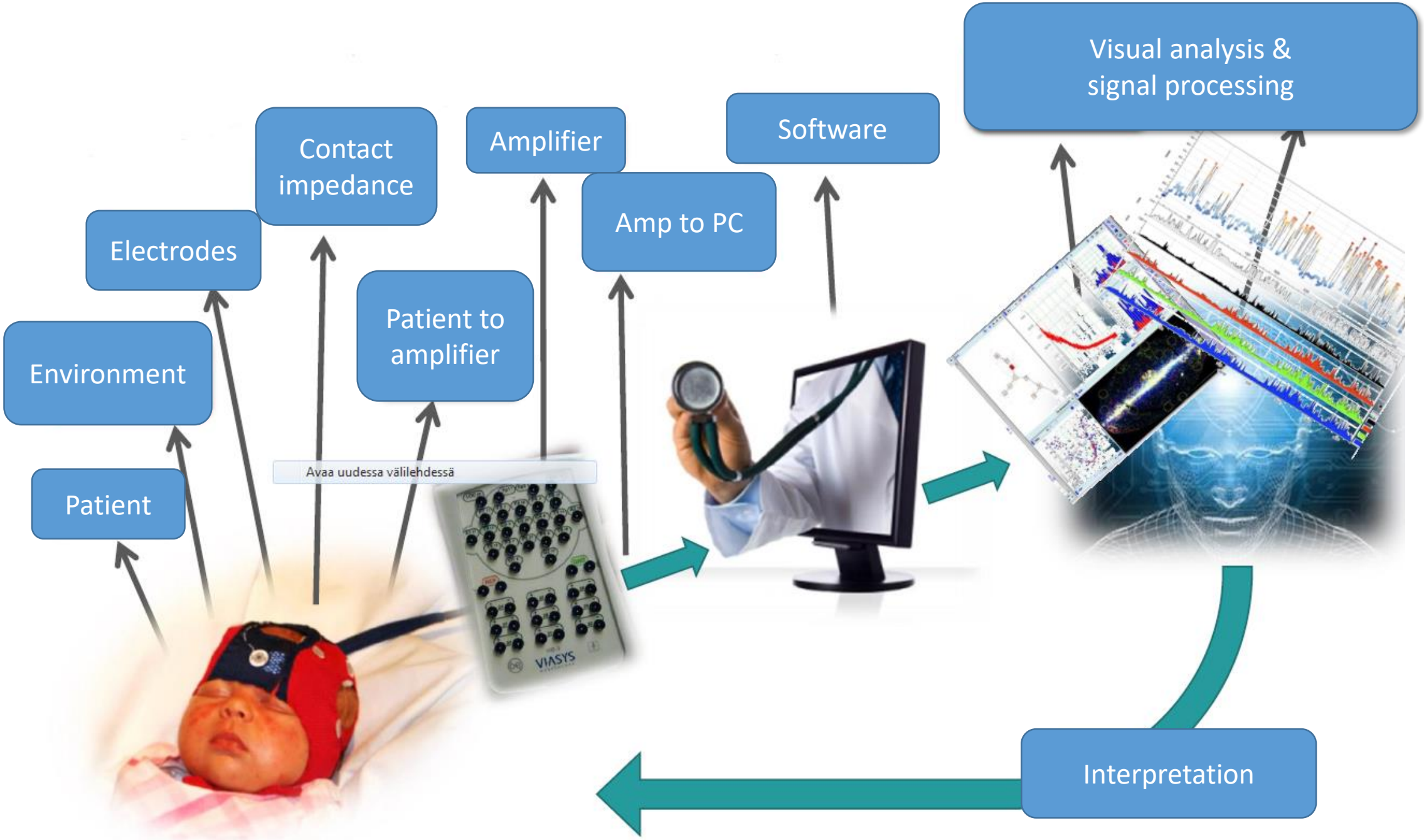
Basics of EEG

Signal and Image Processing Course

2.6.2022

Spelicialist Medical Physicist, PhD Janika Paavola

janika.paavola@tyks.fi


Visual analysis & signal processing
Software
Amplifier
Contact impedance
Amp to PC
Electrodes
Patient to amplifier
Environment
Patient
Interpretation
Avaa uudessa välilehdessä
VIASYS

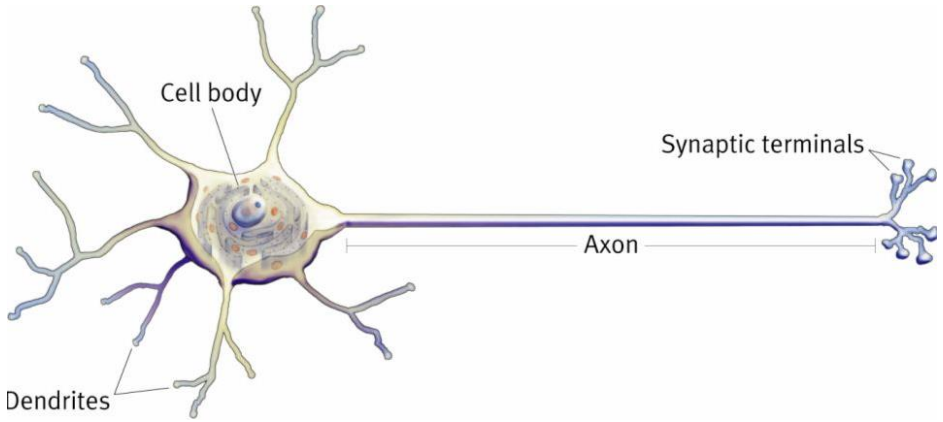
Origins of EEG signal

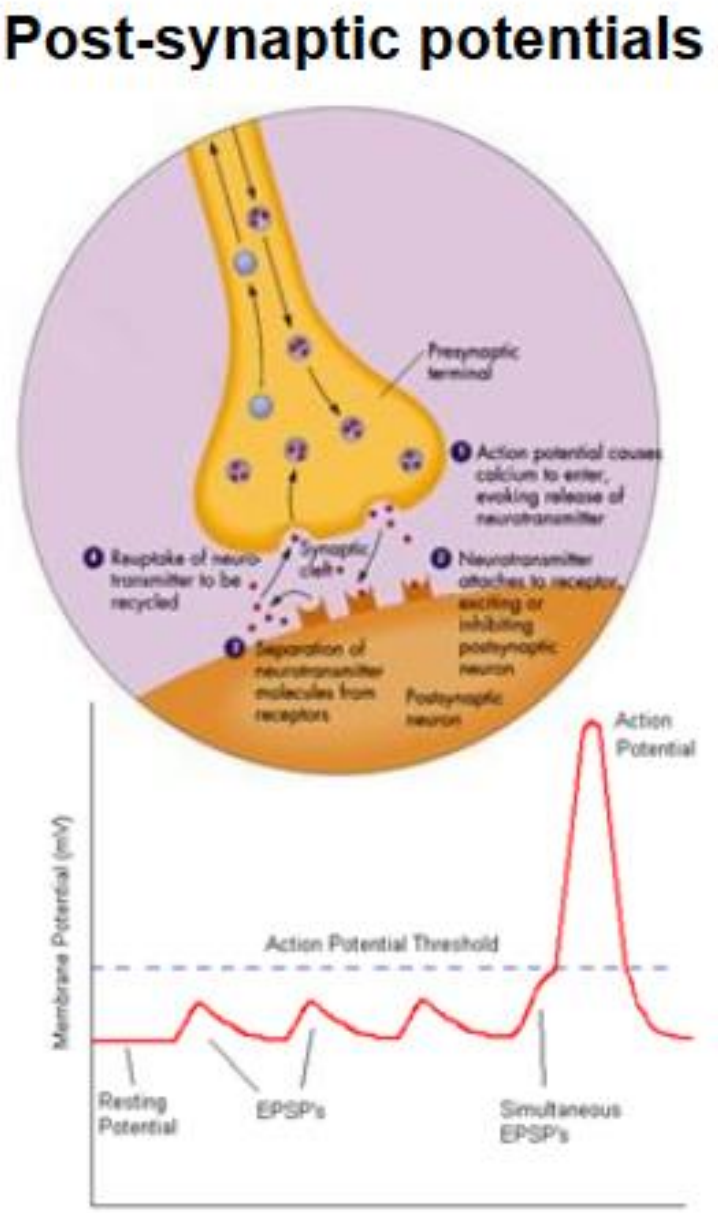
- Electroencephalography, EEG
- Source: various neuron based processes
  - Electrical and chemical

Action potential

Neurotransmitters

Post synaptic potential





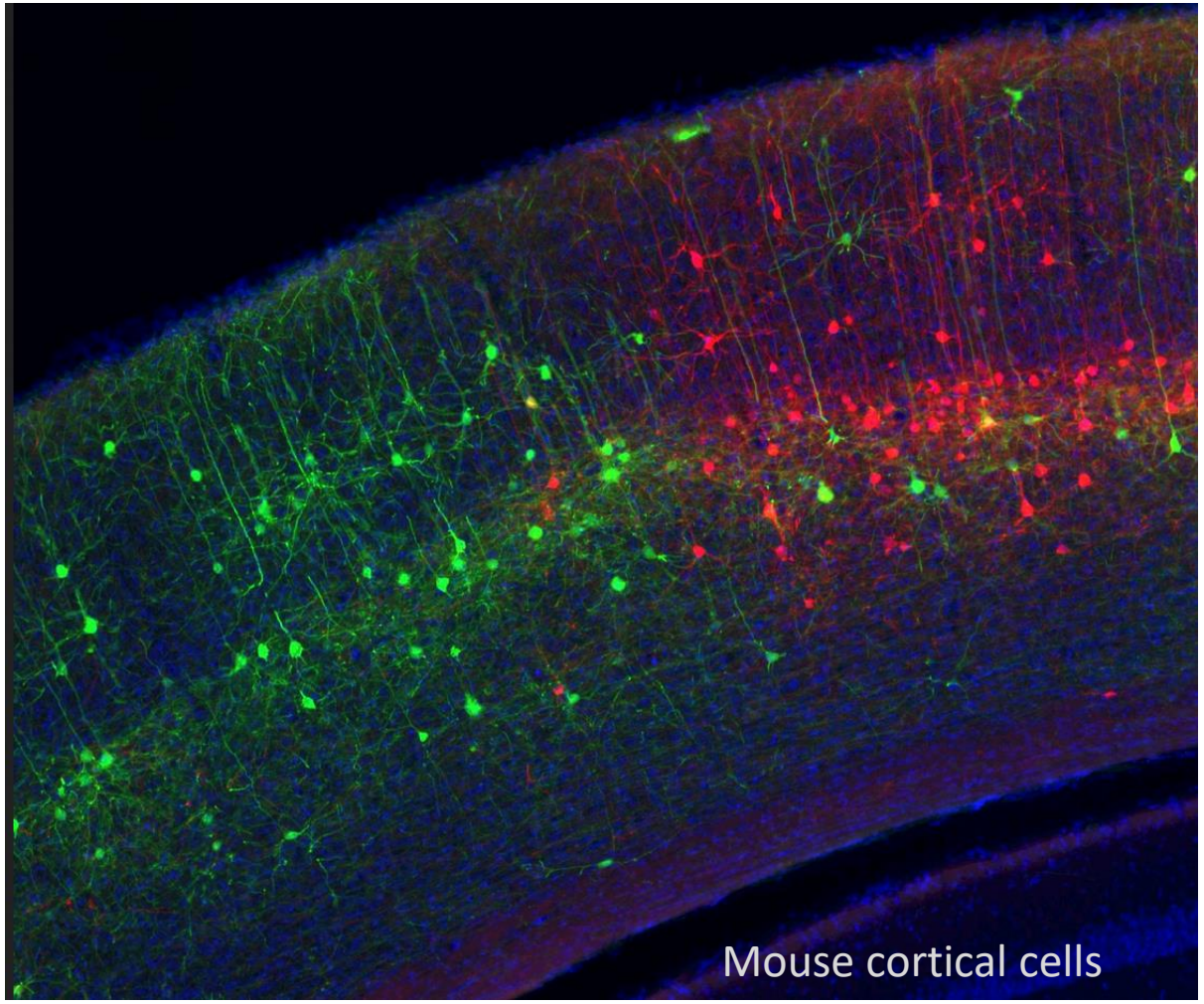
Origins of EEG signal

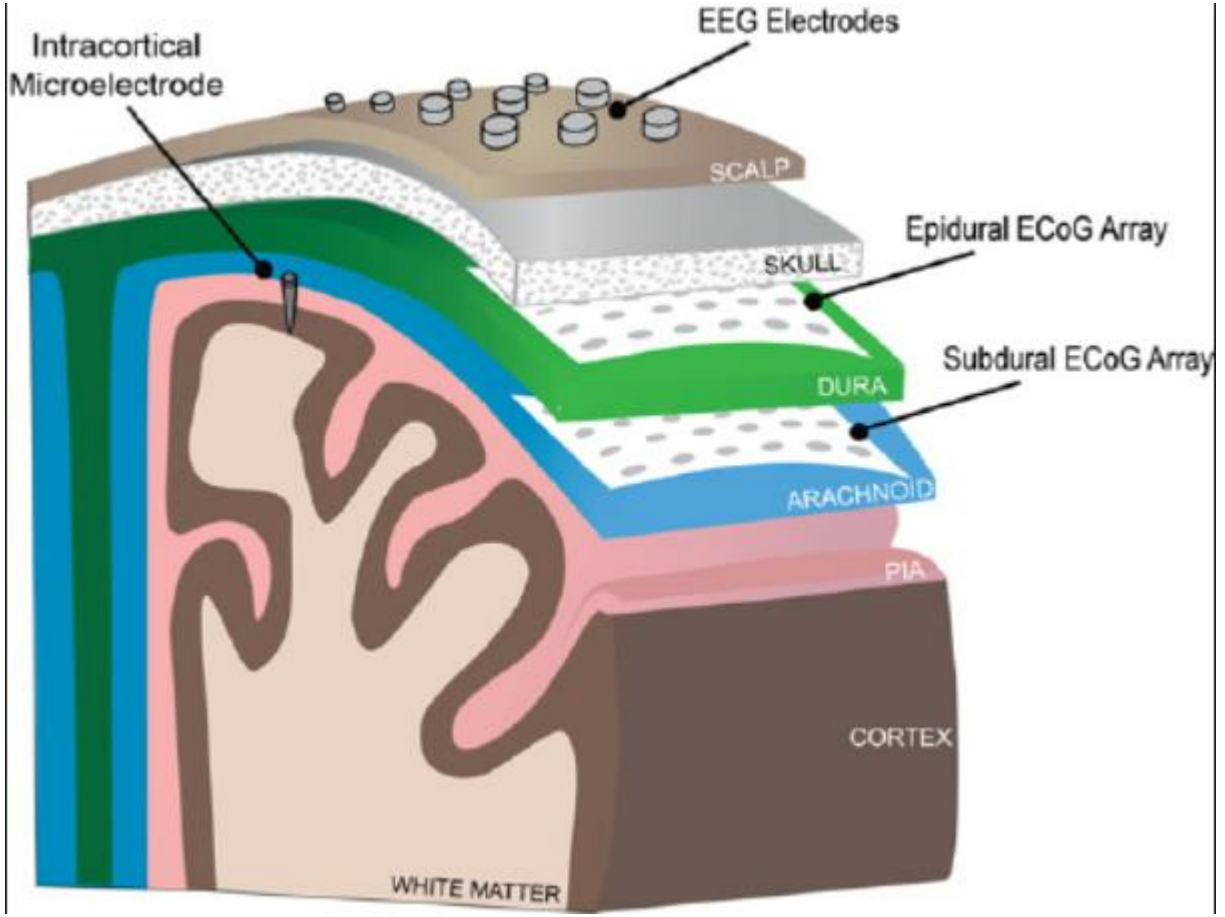
Billions of neurons all electrically active… what does the EEG measure?

- Post-synaptic potential
- Synchronicity
- 1% of cells in 1x1 square mm area in synchrony → create 96% of the signal
- Deep, thalamic structures create rythmic activity
- Interconnected cells might fire in sync for other reasons

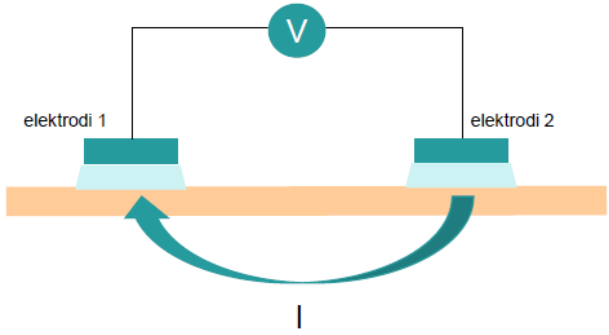
"It takes a combined synchronous electrical activity of approximately 108 neurons in a minimal cortical area of 6cm^2 to create visible EEG"… *Olejniczak J. Clinical Neurophysiology 2006.*

Origin of EEG signal

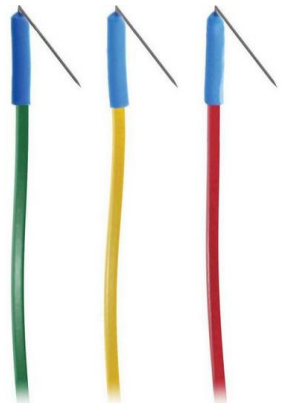


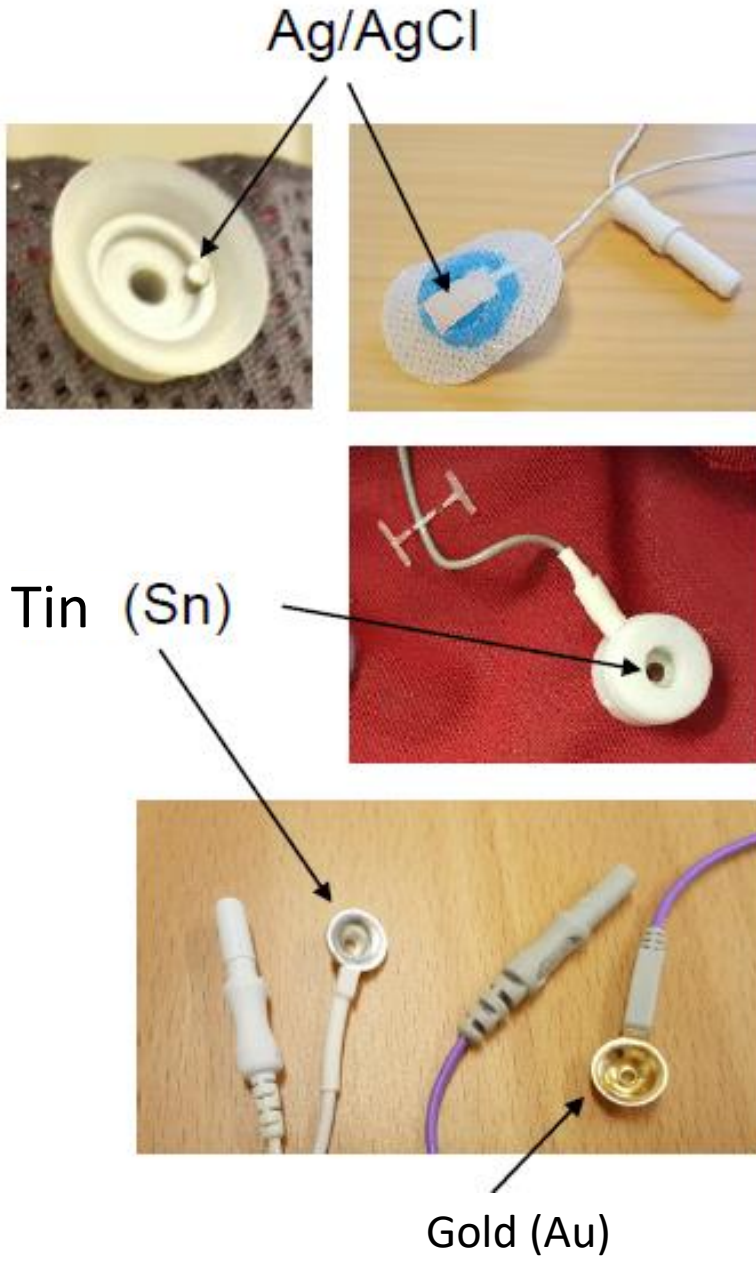


Measuring EEG



- Voltage
- Always between two points: reference and active electrode
- EEG-electrodes
  - Metal (Silver, silver-chloride, gold, tin…)
  - Different designs (Caps, needles, screws, plates,…)

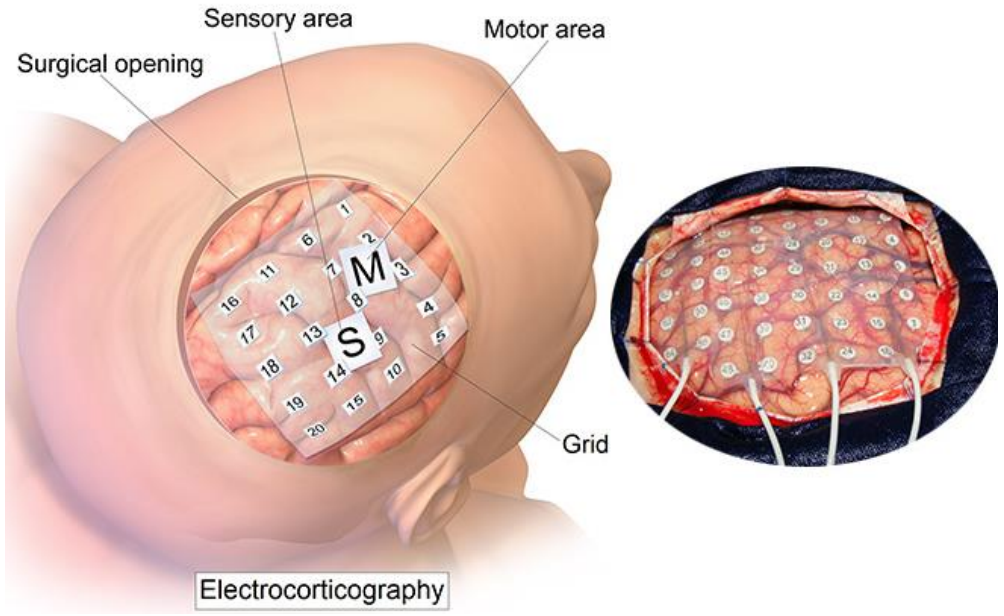




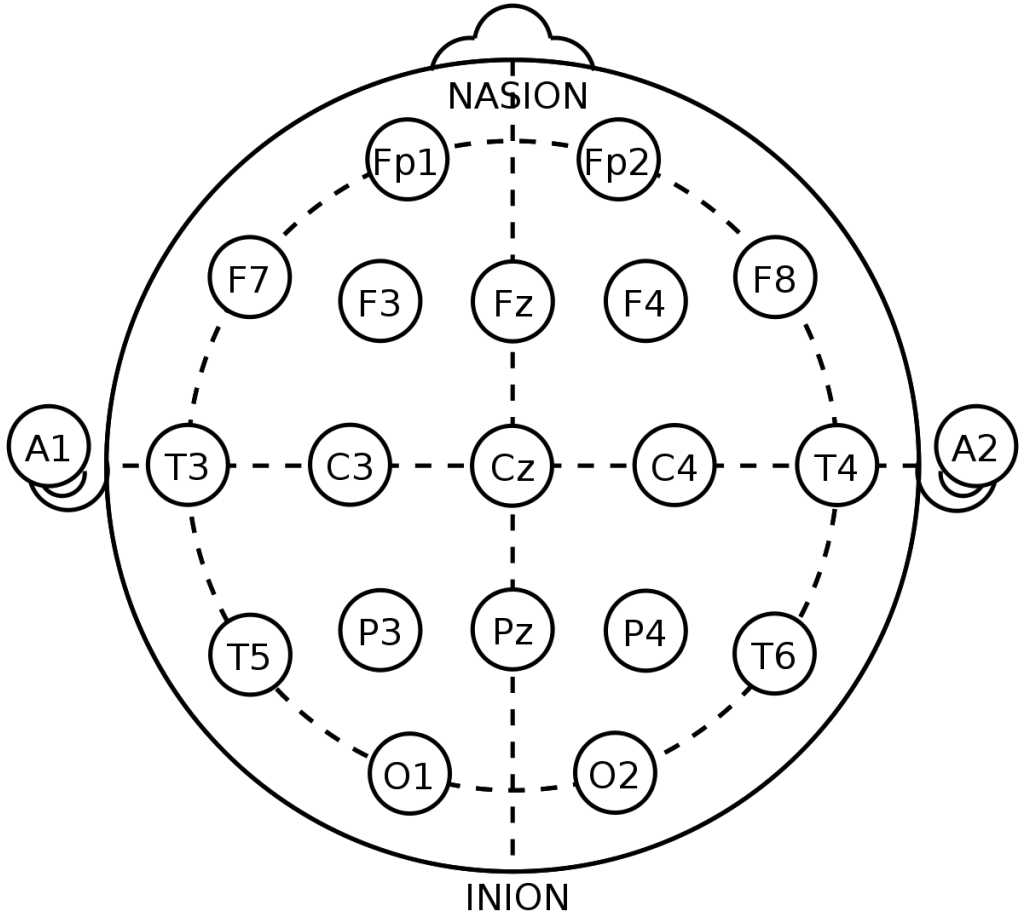
Measuring EEG

- Mainly from scalp surface
- Also Subcortical recordings
  - Neurosurgery monitoring,
  - Advanced epilepsy diagnostics

Skull attenuates 90% of the signal



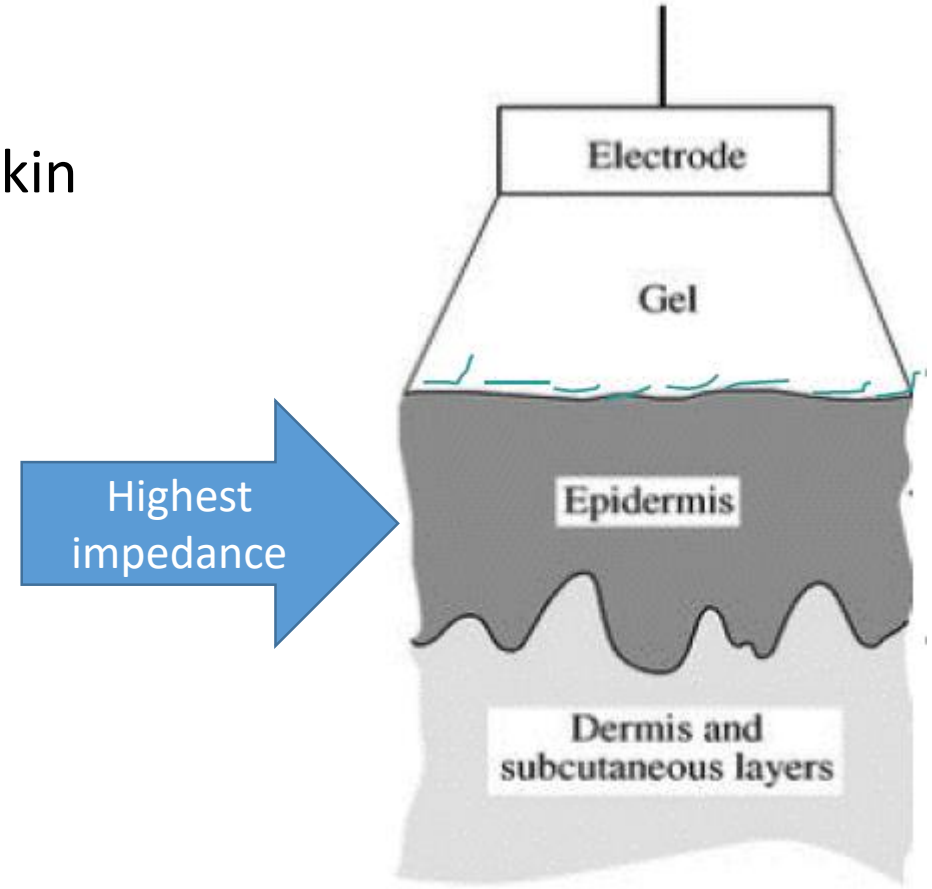
From 21 up to 500 electrodes



10-20 system for finding locations: 10 or 20% measured from the key locations from nasion and inion

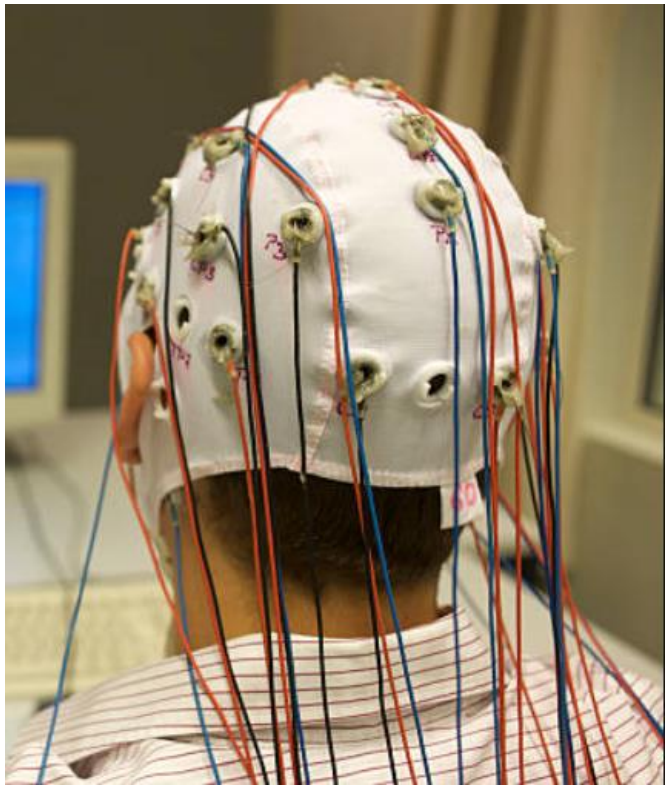
Measuring EEG

- Good quality measurement requires
  1. Good contact between electrode and skin
     Impedance
     Scratching the epidermis
     Preparing with conductive gel
  2. Good quality amplifier
  3. Proper choice of reference
  4. Noise cancellation strategies
     Amplifier
     Electrodes
     Signal processing



Amplifiers

- Differential amplifiers amplify difference only
  - Common noise is cancelled out



- Leads have different EM environment→also noise gets amplified

Twisting leads together helps

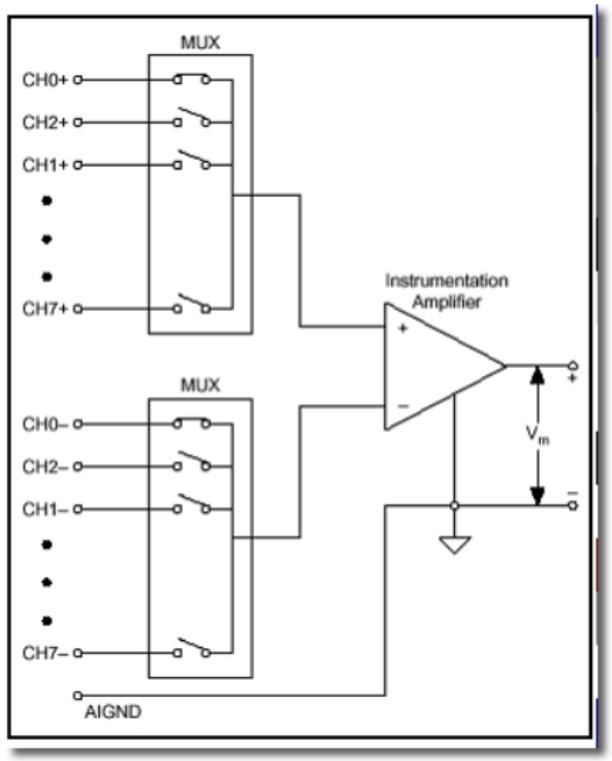
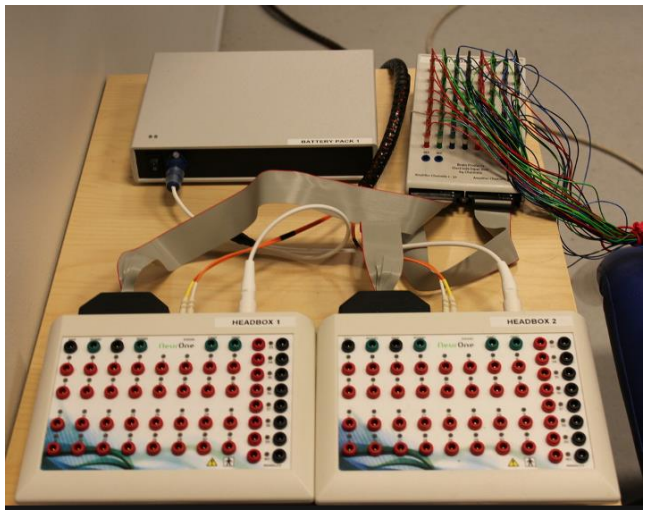


Figure 4. Differential Measurement System

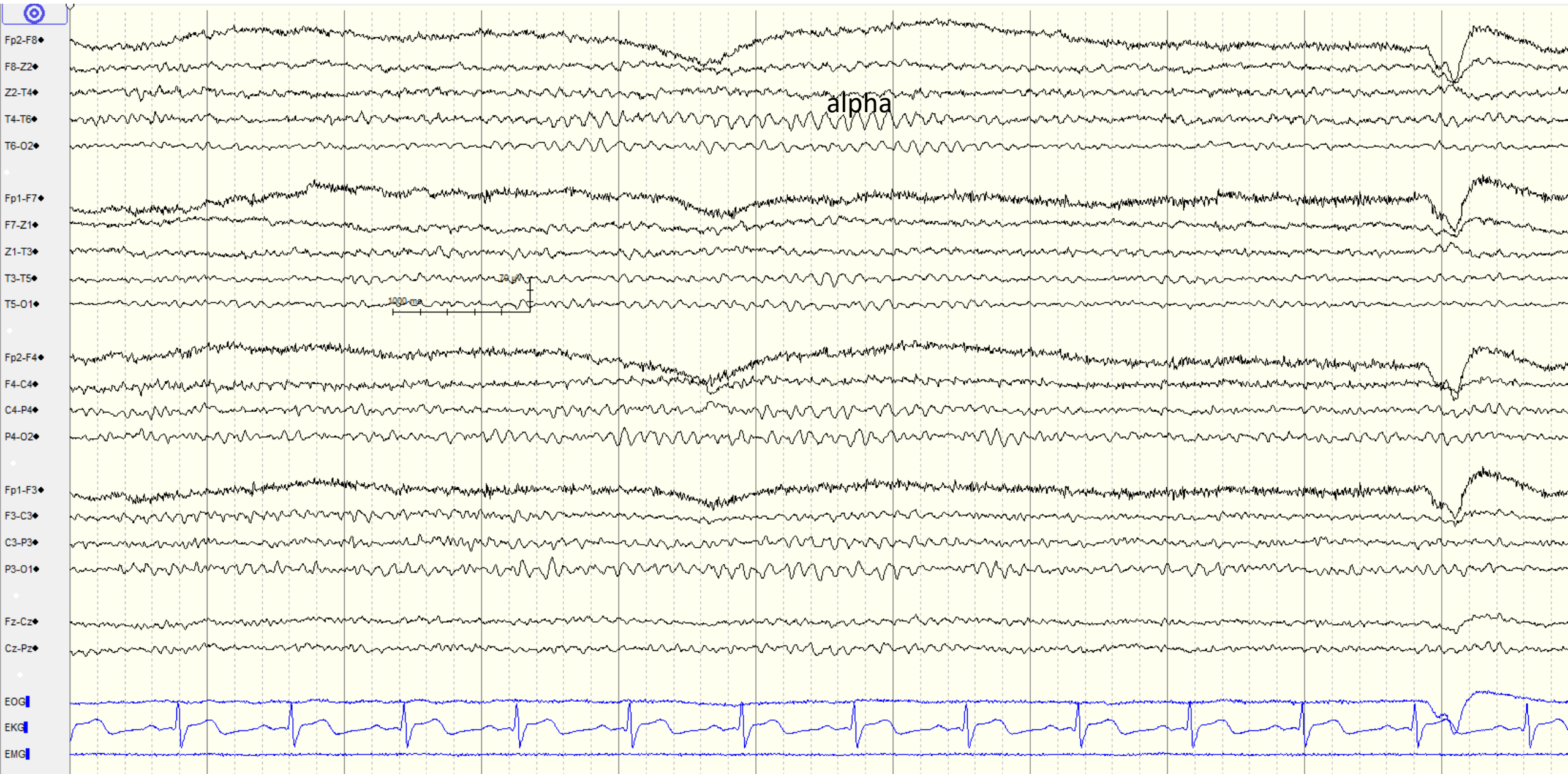


What does the signal look like?

- Amplitude few tens of microvolts
- Frequency spectrum typically under 30 Hz

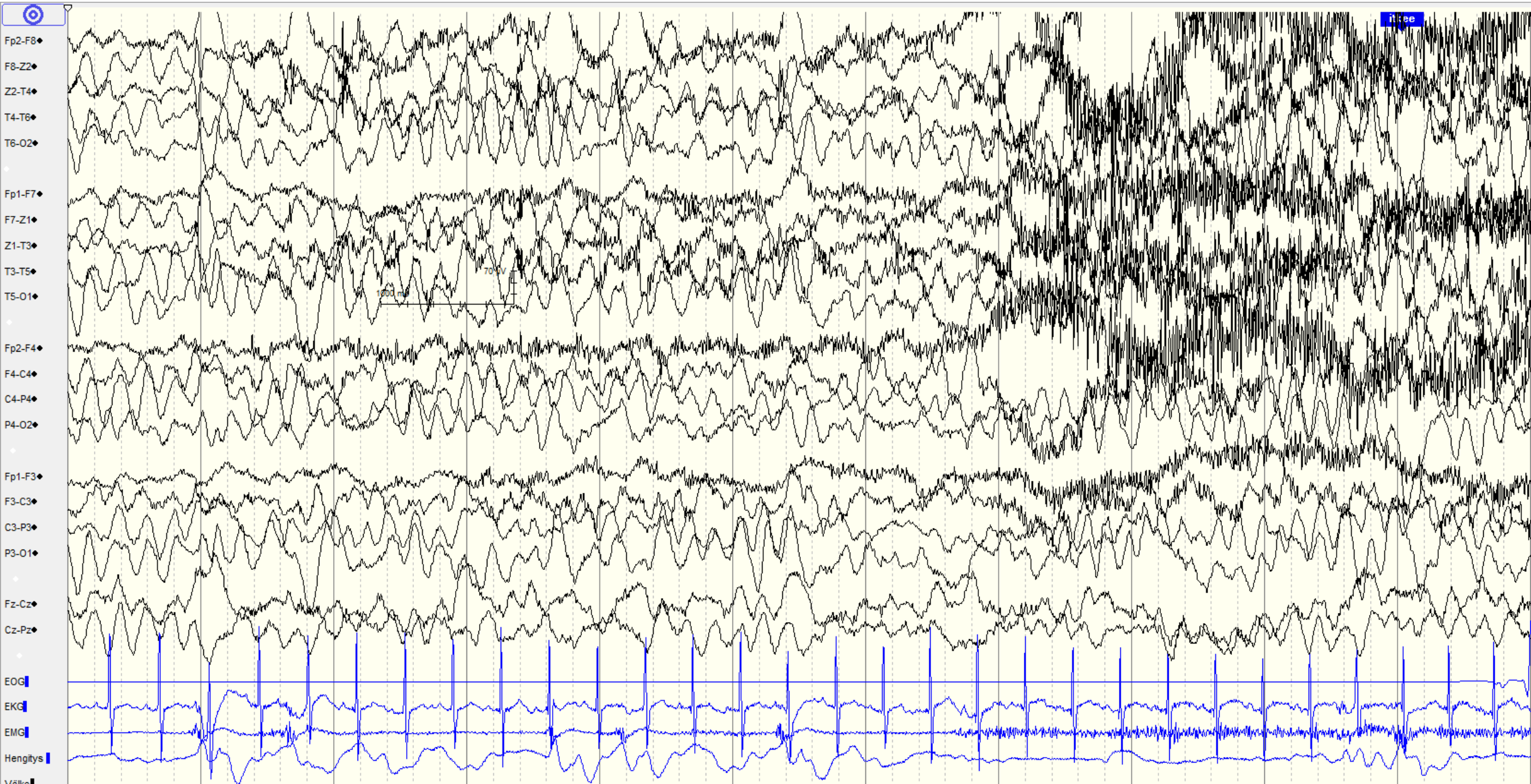
Normal EEG eyes closed

Blinking



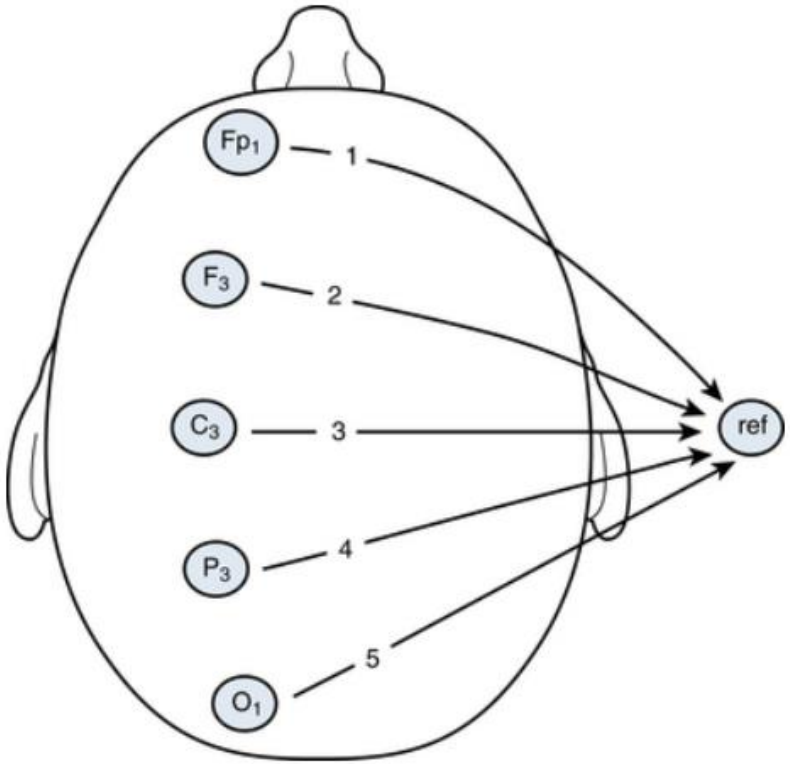
Abnormal EEG (or a baby…)

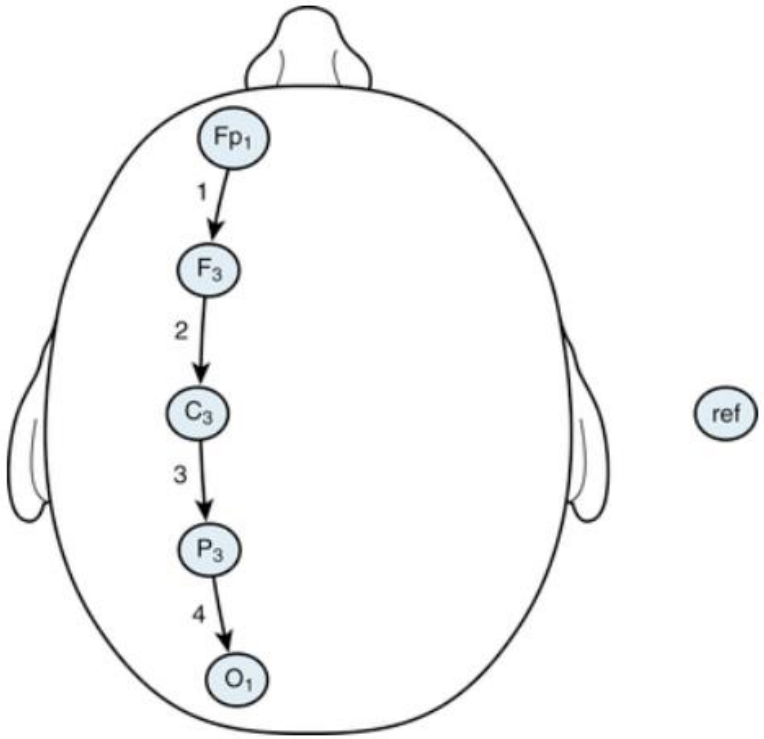
Muscle artifact from crying



Electrode montages

- Montage – between which two electrodes you measure voltage





- Front-to-back: banana
- Ear-to-ear: transversal

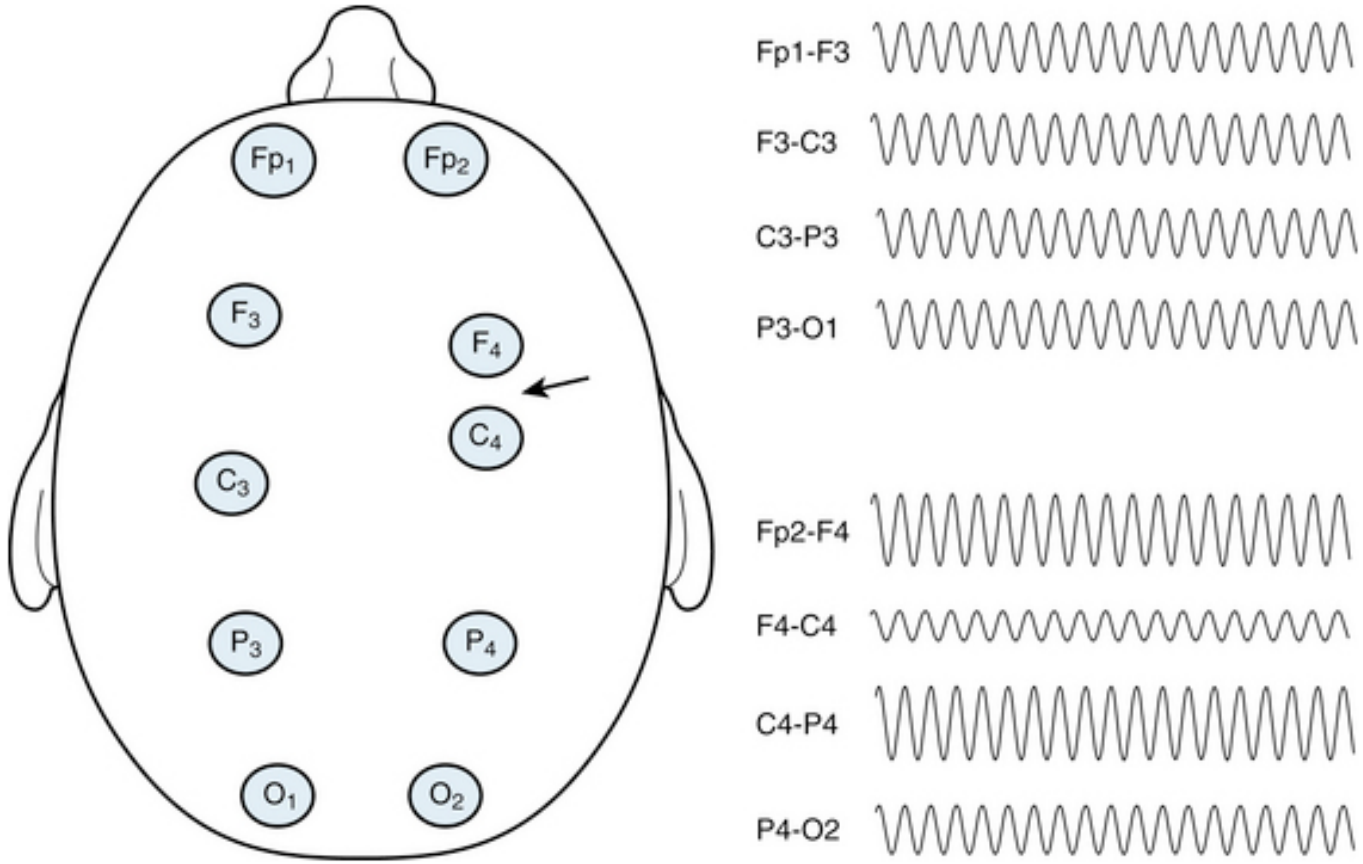
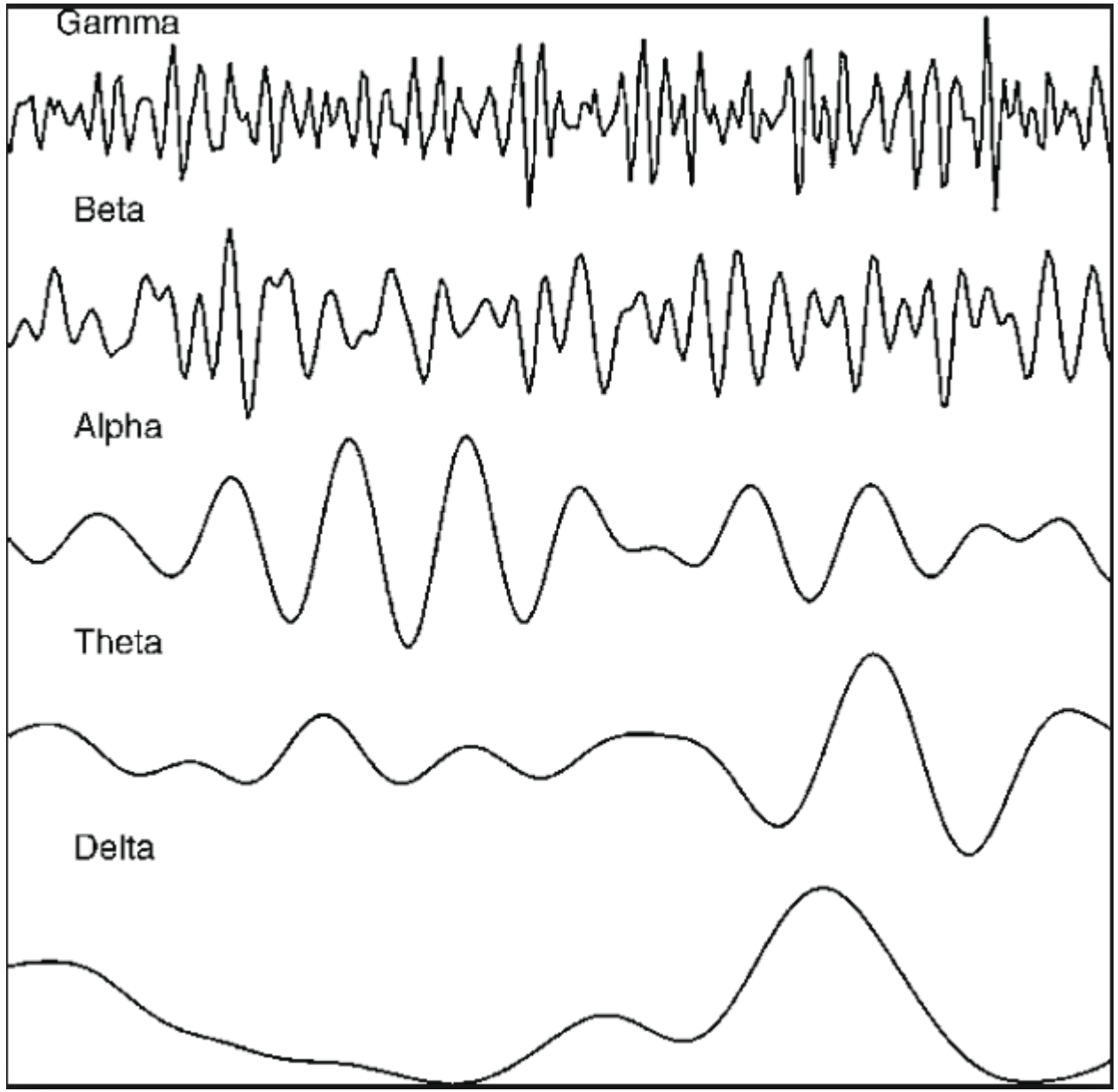


Figure 5-4 This figure illustrates the consequences of mismeasurement of electrode positions. Note that the electrodes of the left parasagittal chain, starting with Fp1, are measured in the usual way with constant interelectrode distances. The electrode positions of the right parasagittal chain, however, have been mismeasured so that the F4 and C4 electrodes have been placed too close together, resulting in an inadvertent increase in the interelectrode distance in the Fp2-F4 and C4-P4 electrode pairs, while the F4-C4 interelectrode distance is too small (arrow). The left parasagittal chain, the output of which is represented by the top four channels on the right side of the page, correctly displays equal voltages in each channel. As a consequence of the mismeasurement in the right parasagittal chain, the channels for which interelectrode distances are too large, Fp2-F4 and C4-P4, show exaggerated, higher voltages, and the channel with the decreased interelectrode distance, F4-C4, shows a misleadingly decreased voltage. Note that if each of these chains had been displayed using a referential montage, the error in measurement in the right parasagittal chain would not necessarily be evident.

Doctors look a different montages to get an overview of the signal



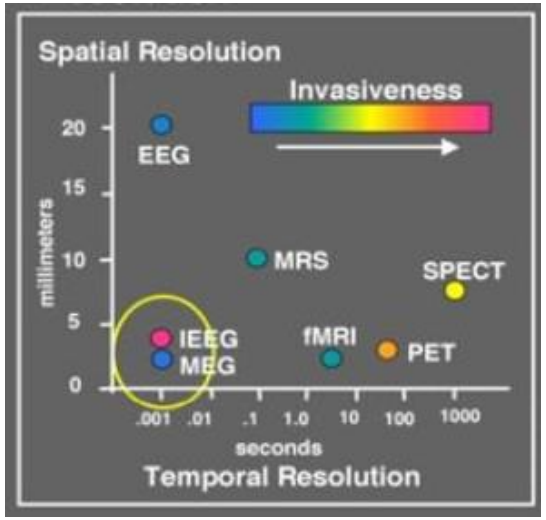
- Gamma 30 – 70 Hz
- Beta 12 – 30 Hz
- Alpha 8 – 12 Hz
- Theta 4 – 8 Hz
- Delta 0 – 4 Hz

Fp2	Fp1	F8	F7	F4	F3	A2	A1	T4	T3	C4	C3	T6	T5	P4	P3	O2	O1	Fz	Cz	Pz	ECG
7.17	7.32	0.61	-0.61	2.75	1.98	-12.82	-16.17	-12.51	-3.20	-4.73	-3.36	-14.95	-7.63	-14.04	-9.00	-11.29	-11.14	2.59	-4.88	-14.34	-10.99
8.39	4.88	2.14	1.53	2.14	1.53	-4.43	-9.16	-9.31	1.53	-3.81	-2.90	-11.14	-1.68	-12.21	-6.87	-10.38	-8.24	1.83	-4.43	-12.66	-11.29
9.00	3.97	3.05	2.44	0.76	1.07	5.04	-4.58	-5.19	4.88	-2.29	-1.68	-6.71	2.44	-9.31	-3.81	-8.24	-4.88	1.68	-3.20	-9.46	-11.60
10.83	4.88	3.20	0.92	0.61	0.61	3.97	-6.41	-5.49	4.43	-2.14	-1.07	-7.17	2.75	-8.70	-3.05	-6.87	-3.66	2.59	-2.29	-8.09	-16.78
9.92	3.81	2.59	-0.31	2.59	-0.31	-2.14	-7.17	-7.32	3.05	-2.44	-1.83	-8.09	2.75	-8.70	-3.20	-5.95	-3.05	2.59	-2.14	-7.78	-22.74
3.97	1.22	1.98	-0.92	4.43	-0.92	-1.37	-5.49	-5.34	1.53	-1.83	-3.36	-5.04	2.75	-7.02	-3.81	-5.04	-2.59	1.22	-2.29	-7.17	-20.90
0.00	0.61	3.36	-2.44	3.36	-0.76	4.43	-8.09	-1.37	-1.37	-0.46	-4.73	-1.68	0.61	-5.95	-5.49	-5.49	-3.66	0.00	-3.05	-7.48	-14.65
3.20	2.44	6.41	-2.59	0.61	-0.15	4.73	-12.82	0.31	-2.14	0.15	-4.58	-1.83	-3.05	-6.71	-7.63	-7.63	-6.56	0.46	-3.51	-9.16	-16.02
7.02	4.73	7.93	1.22	-0.61	1.07	-0.31	-12.21	-0.31	1.22	0.00	-3.36	-3.05	-4.88	-8.09	-8.39	-9.77	-8.70	1.83	-3.05	-10.68	-25.02
4.58	6.71	6.87	4.12	0.46	1.53	-1.22	-7.17	0.61	2.75	0.00	-2.90	-2.29	-4.73	-8.09	-7.17	-9.77	-7.32	2.14	-2.14	-10.38	-28.84
1.37	6.10	5.80	0.46	0.92	0.00	3.97	-5.80	3.20	-1.22	0.46	-4.12	-0.46	-4.27	-6.56	-5.80	-7.63	-3.97	1.22	-1.68	-8.70	-24.26
4.12	2.29	6.71	-4.73	0.61	-2.75	8.39	-8.24	4.43	-5.04	0.76	-4.73	0.92	-4.43	-4.73	-4.88	-4.58	-1.07	-0.31	-1.22	-6.26	-21.97
8.39	-1.07	7.48	-5.19	0.46	-3.97	9.00	-9.16	3.51	-5.04	0.46	-3.36	1.53	-4.73	-2.59	-3.36	-1.22	1.07	-0.61	-0.31	-3.20	-26.40
7.78	-1.22	6.10	-4.43	0.76	-3.36	7.78	-8.24	2.44	-5.19	0.46	-1.98	1.37	-5.04	-0.15	-1.53	3.05	3.20	-0.31	0.92	0.00	-30.36
6.10	-1.07	4.43	-7.63	0.61	-3.81	6.26	-7.93	2.29	-7.17	0.92	-2.59	0.92	-5.34	1.53	-1.07	7.02	4.43	-0.31	1.07	1.53	-30.82
7.93	-3.05	3.81	-10.99	0.31	-5.49	4.58	-10.07	2.75	-8.24	1.53	-5.19	1.98	-6.71	1.83	-3.51	8.54	2.44	-1.22	0.31	0.31	-32.20
8.24	-4.12	3.66	-10.07	0.46	-6.56	3.05	-13.12	3.05	-9.16	1.68	-8.54	4.27	-9.61	1.53	-7.32	8.09	-0.61	-2.29	-0.92	-2.44	-34.64
1.83	-3.05	4.88	-10.38	0.92	-7.48	0.92	-14.50	2.90	-12.36	1.68	-11.44	4.27	-11.90	0.76	-9.92	7.63	-1.83	-2.90	-1.83	-4.27	-33.87
-5.19	-3.51	7.32	-14.95	1.53	-9.31	0.00	-12.82	2.29	-13.89	1.68	-12.82	1.22	-11.75	-0.46	-10.22	7.93	-1.37	-3.36	-2.59	-4.88	-32.50
-4.43	-5.95	7.93	-16.02	1.83	-10.07	1.83	-10.38	1.68	-10.99	1.22	-11.44	-0.61	-9.00	-1.22	-8.85	8.85	-0.61	-3.20	-2.59	-4.12	-37.69
0.92	-5.49	4.43	-9.16	1.37	-7.17	4.43	-9.31	0.92	-7.63	0.15	-7.63	1.98	-5.04	0.15	-5.80	10.83	2.59	-2.14	-1.53	-1.83	-45.32
3.20	-1.22	1.68	-1.68	0.46	-3.05	3.81	-6.87	0.61	-5.34	-0.15	-3.66	5.04	-1.22	2.90	-2.29	13.28	6.56	-0.92	0.00	1.07	-47.15
2.90	2.75	3.51	-1.37	0.31	-1.53	1.37	-3.36	0.92	-1.53	0.46	-1.07	3.97	0.00	3.81	-0.92	12.82	5.65	-0.31	0.61	1.68	-45.32
4.58	3.81	6.26	-5.19	0.76	-2.44	0.46	-4.12	0.46	0.76	0.61	-1.22	0.00	-2.75	2.14	-2.90	8.09	-0.31	0.31	0.15	-0.76	-49.13
7.32	2.14	5.95	-6.87	1.07	-3.20	0.61	-10.68	-1.37	-3.81	0.00	-4.12	-2.75	-7.02	-0.15	-5.80	3.36	-4.27	0.46	-0.31	-2.90	-56.61
6.87	-1.98	5.04	-6.41	0.92	-4.27	-0.92	-15.41	-2.59	-9.46	-0.46	-7.32	-3.51	-8.70	-1.07	-7.32	0.31	-3.81	-0.31	-0.61	-3.05	-59.66
4.12	-4.58	6.26	-5.65	1.22	-5.49	-2.44	-12.97	-1.53	-7.93	0.00	-8.39	-3.66	-6.56	-2.14	-7.02	-1.83	-3.36	-1.53	-0.92	-3.20	-59.36
3.05	-1.98	7.48	-5.49	1.83	-5.80	-0.76	-9.00	0.76	-3.97	0.46	-7.93	-2.59	-2.59	-3.20	-5.80	-2.90	-2.75	-1.37	-1.37	-3.81	-64.09
4.27	1.98	7.17	-4.12	2.44	-4.73	4.12	-6.56	1.68	-3.66	0.31	-6.71	-0.15	1.07	-3.51	-3.51	-1.53	0.92	-0.31	-1.53	-3.66	-73.39
4.27	1.83	7.63	-0.46	2.29	-3.20	7.63	-1.83	1.37	-2.14	-0.15	-4.58	1.53	4.27	-3.20	-1.07	-0.31	5.04	0.31	-1.22	-3.51	-80.26
1.83	-0.15	8.24	3.05	1.37	-1.68	5.95	4.58	0.61	4.12	-0.76	-1.68	-0.15	6.26	-3.97	-0.31	-2.59	3.97	0.46	-0.46	-4.43	-83.31
-0.46	0.76	5.80	3.05	0.15	0.00	1.68	5.49	-1.07	6.87	-1.83	0.31	-2.29	5.19	-5.34	-1.37	-6.87	-0.61	0.61	0.15	-5.49	-87.43
-0.61	3.36	0.61	1.98	-0.92	1.37	1.37	0.61	-3.05	3.05	-2.44	1.37	-1.53	2.44	-4.88	-1.83	-8.24	-2.44	0.92	0.46	-4.73	-94.15
1.22	4.43	-2.29	4.27	-1.68	2.75	5.34	-2.75	-2.90	2.29	-1.83	2.59	0.76	1.98	-2.29	-0.31	-5.65	0.00	1.68	0.61	-2.14	-103.00
4.12	3.81	-0.46	6.26	-1.37	3.05	6.56	-2.75	-1.37	6.41	-0.92	2.90	1.37	3.66	-0.61	1.37	-3.20	1.98	2.44	0.61	-0.92	-113.37
7.32	1.68	3.51	1.68	1.37	0.46	4.27	-4.27	-0.61	5.04	-0.61	0.46	0.61	3.20	-0.92	0.00	-3.36	0.61	1.98	0.00	-1.53	-123.29
8.54	-0.46	6.10	-4.73	5.19	-2.75	5.04	-7.32	0.00	-2.29	-0.31	-3.20	0.92	0.00	-1.37	-2.59	-3.66	-1.22	0.31	-0.92	-2.14	-130.00
5.34	0.15	5.65	-3.97	5.34	-2.90	8.85	-6.41	1.83	-4.12	0.92	-3.97	2.59	-0.76	0.61	-2.44	-0.76	1.07	-0.76	-1.22	-0.92	-136.72
-1.68	1.37	3.05	-0.31	0.46	-1.37	8.09	-1.68	2.90	1.98	2.14	-1.83	4.12	3.20	3.36	1.37	4.27	7.17	-0.46	-0.31	1.83	-146.33
-7.32	-1.22	0.31	-2.14	-4.43	-2.14	0.61	1.37	1.22	5.19	1.98	0.31	5.49	6.87	4.73	4.43	7.48	11.75	-0.15	1.22	3.66	-155.33
-5.65	-4.73	-0.31	-6.26	-4.27	-4.43	-4.43	0.00	-0.92	0.92	0.61	0.00	5.04	5.65	3.81	3.97	7.02	11.29	-0.46	1.53	3.20	-160.22
3.97	-2.75	1.68	-6.10	-0.61	-3.97	-2.44	-1.53	-1.22	-3.97	-0.92	-1.98	1.53	1.83	1.68	0.76	4.88	7.32	0.15	0.31	1.22	-166.63
12.36	1.98	4.43	-5.95	2.14	-1.83	2.75	-0.92	-0.46	-5.65	-1.83	-4.12	-1.68	-1.68	0.00	-2.14	3.36	3.66	1.37	-1.37	-0.31	-177.76
9.46	1.07	4.88	-9.92	1.83	-2.14	6.10	-0.76	0.31	-7.02	-1.98	-5.34	-1.22	-4.12	-0.61	-3.51	1.83	1.07	1.22	-1.83	-0.31	-187.23
-0.61	-3.81	1.83	-12.36	0.15	-3.97	3.97	-3.97	-0.31	-8.54	-1.98	-5.95	-0.92	-6.10	-1.22	-4.43	-1.22	-1.22	0.15	-1.22	-0.15	-189.97
-4.27	-4.58	-1.83	-10.07	-0.46	-4.43	-6.26	-8.24	-4.73	-9.31	-3.05	-6.56	-6.56	-8.24	-3.81	-6.10	-6.26	-3.66	-0.31	-0.61	-1.98	-190.58
1.68	-1.68	-2.59	-8.54	0.61	-4.27	-18.92	-11.29	-11.44	-9.77	-4.73	-7.78	-14.80	-10.38	-7.78	-9.31	-11.44	-6.56	0.15	-0.92	-5.80	-193.63
7.63	-1.37	-0.76	-10.38	2.29	-5.34	-21.51	-13.58	-13.89	-10.68	-5.65	-8.70	-16.78	-11.90	-10.22	-11.90	-14.80	-9.46	0.31	-1.83	-8.70	-195.77
7.78	-3.51	1.07	-11.60	3.05	-7.17	-12.21	-16.17	-9.92	-10.53	-4.43	-9.31	-12.97	-11.44	-9.61	-11.90	-15.41	-9.92	0.00	-2.59	-9.00	-193.18
6.10	-4.43	2.29	-11.60	2.44	-8.39	-3.97	-16.48	-6.26	-9.61	-3.20	-9.31	-9.92	-8.70	-7.78	-9.46	-13.89	-6.87	-0.15	-2.90	-7.32	-188.14
4.73	-3.66	2.59	-12.82	1.53	-8.54	-5.04	-12.36	-6.56	-8.70	-3.20	-8.09	-9.46	-5.34	-6.41	-6.87	-11.75	-2.75	0.00	-2.90	-5.34	-180.36
1.53	-2.44	1.53	-12.51	0.92	-6.87	-9.16	-8.09	-7.32	-7.02	-3.66	-6.56	-7.78	-2.29	-4.88	-4.88	-9.77	-0.15	0.61	-2.29	-3.36	-167.85
-2.29	-0.15	-1.07	-7.48	0.76	-3.36	-10.07	-7.17	-7.78	-3.51	-3.66	-5.49	-5.95	-0.61	-2.75	-3.51	-8.54	0.31	1.68	-1.53	-1.98	-151.82
-2.90	3.36	-3.81	-0.76	0.15	-0.15	-12.05	-7.17	-11.44	-0.92	-3.97	-4.58	-8.09	-1.07	-2.59	-2.75	-9.92	-0.31	3.05	-0.92	-1.98	-134.12
-0.76	5.19	-5.19	2.29	-0.31	0.92	-17.70	-6.10	-16.78	-1.07	-5.65	-2.90	-12.66	-3.05	-5.19	-3.05	-13.58	-1.68	3.97	-0.46	-3.51	-113.22
1.68	1.98	-4.88	0.61	-0.15	-0.61	-19.23	-7.48	-16.63	-2.75	-6.87	-1.83	-14.34	-4.27	-7.78	-3.81	-16.94	-3.66	3.20	0.15	-4.73	-86.21
2.44	4.27	3.20	4.27	0.31	3.81	12.51	12.05	10.53	3.66	5.95	2.59	11.44	3.97	7.63	4.27	17.09	4.73	0.92	0.31	4.58	56.00

EEG pros and cons

+

- Time resolution in milliseconds
- Cheap and portable
- Tolerates movement
- Functional information



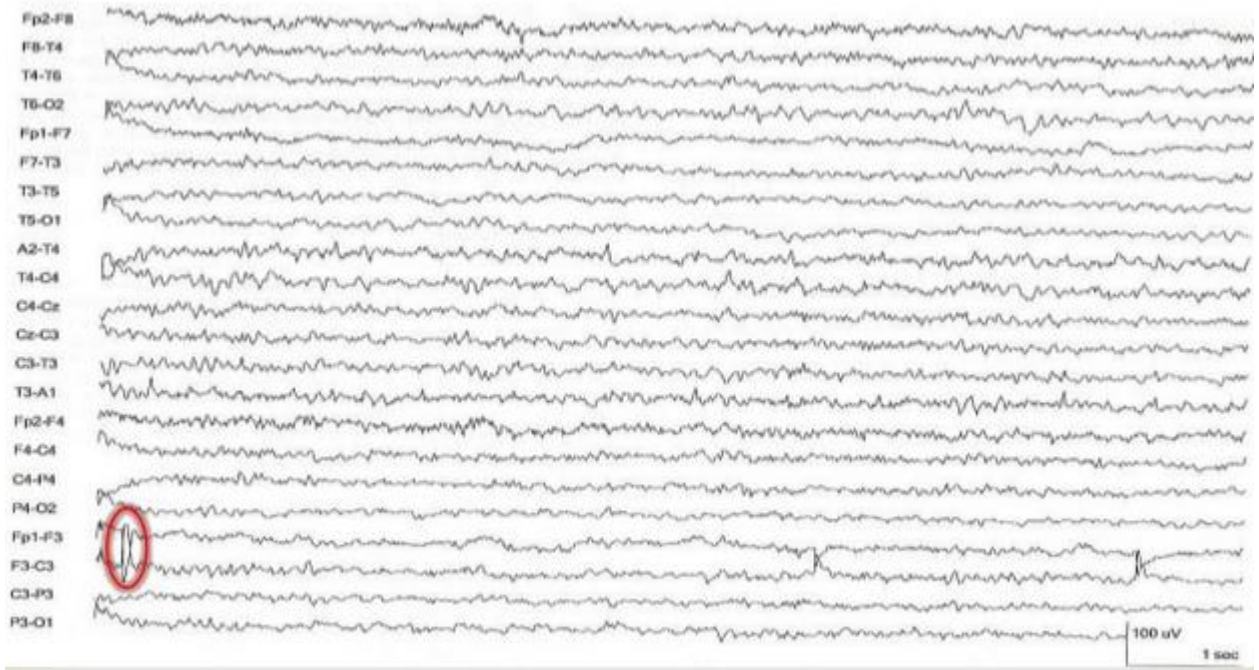
-

- Spatial resolution poor
- No anatomical information
- Artifacts and noise

Artifacts

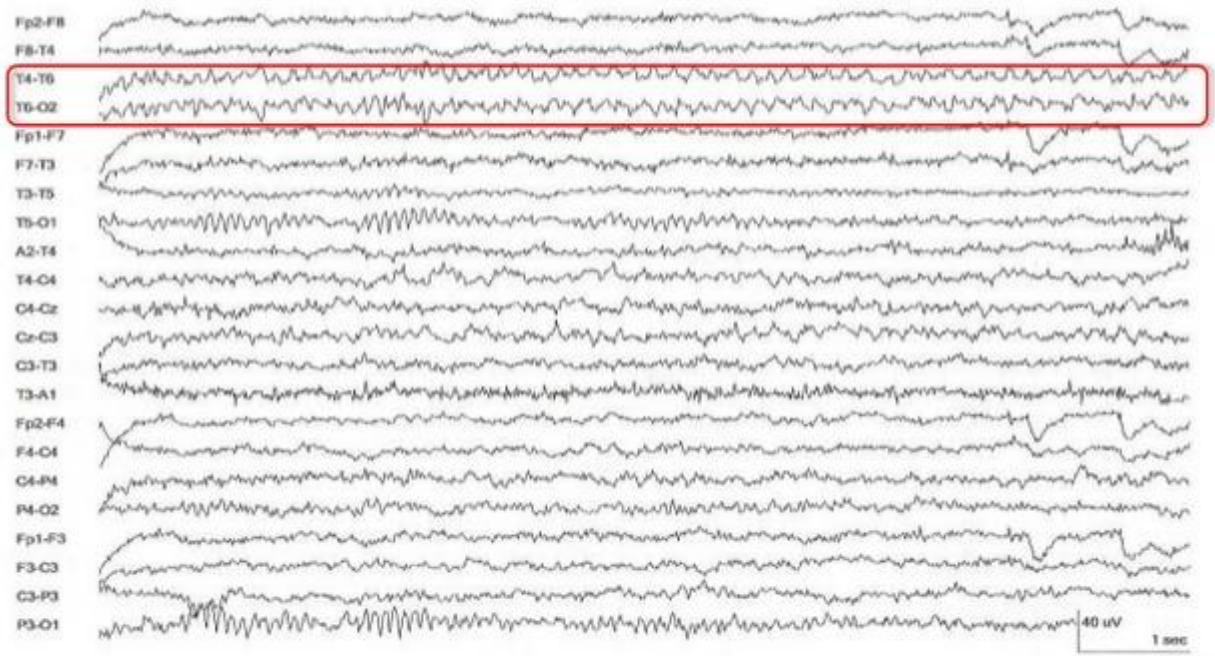
- Noise and physiological events that or not under investigation
  - Ocular
  - Muscle
  - Cardiac
    - Pacemakers
    - Normal heart function (mechanical and electrical)
  - Electrode artifacts
    - Movement of leads
    - Mixing materials
    - Salt bridges
  - EM noise

Electrode pop



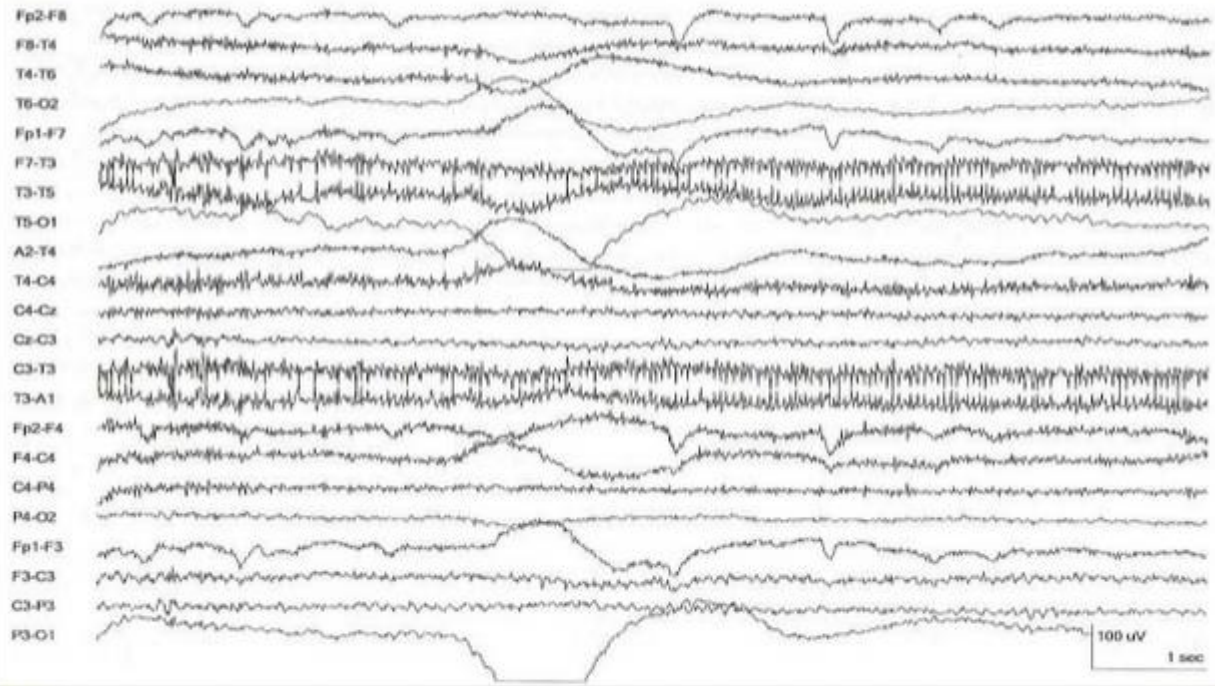
The nearly vertical rise followed by the slower fall at the F3 electrode is typical of electrode pop artifact. Also typical is an amplitude that is much greater than the surrounding activity, a field that is limited to one electrode, and repeated recurrence within a short time

Electrode Movement artifact



The focal slowing in the T4-T6 and T6-O2 channels has no field beyond T6 electrode and has the oscillations typical of rhythmic electrode movement

Lead movement



Multiple channels demonstrate the artifact through activity that is both unusually high amplitude and low frequency and also disorganized without a plausible field

From Dr. S. Marella

To finish…

Signal processing is about getting rid of the unwanted artifacts and obtaining useful information from the measured signal

EEG measurement requires skill in order to obtain reliable signal with as good quality as possible

Diagnostic and experimental uses for the signal, for example Brain computer interface for prosthetic arms