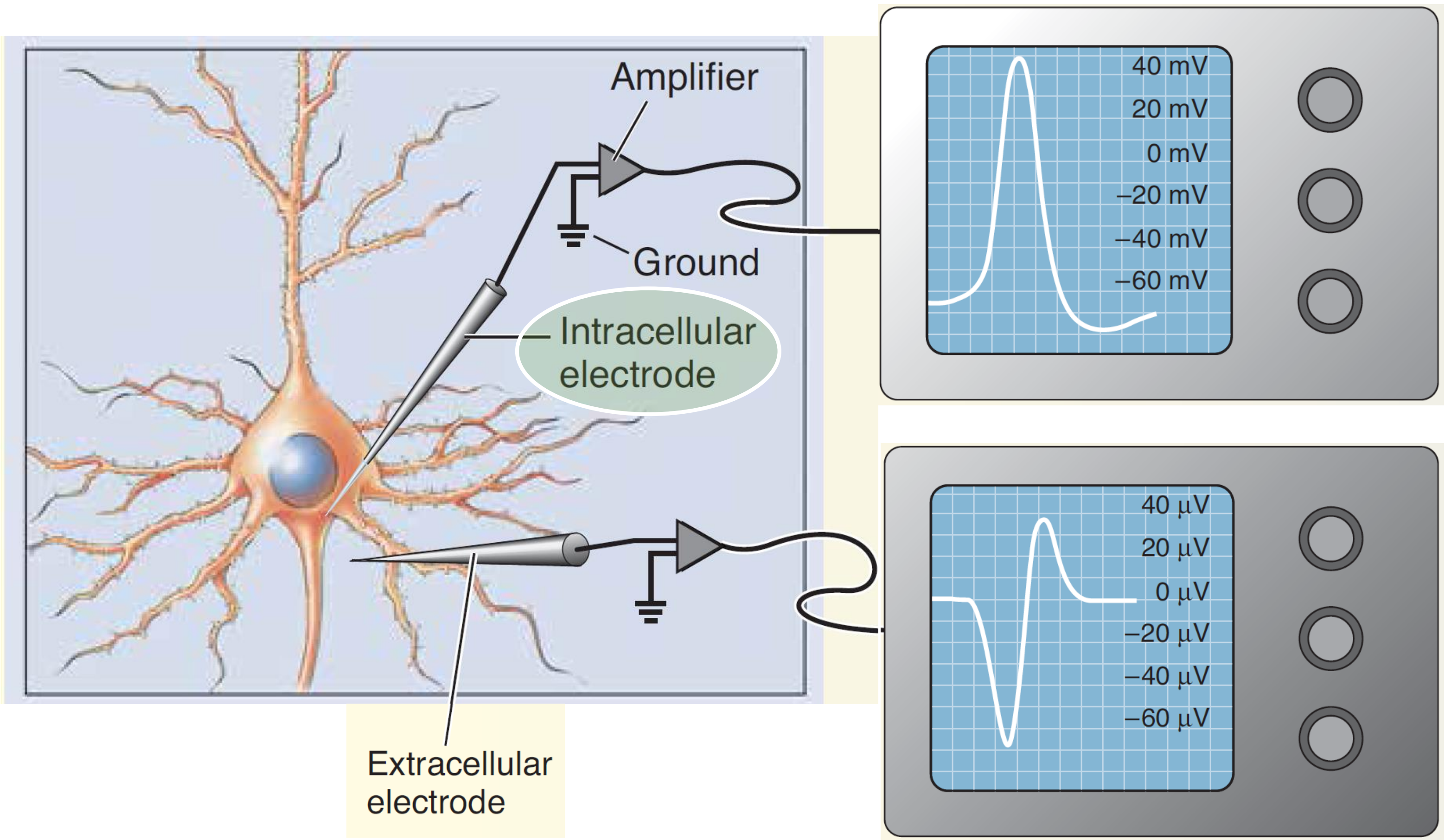
Introduction to Cognitive Neuroscience

Lecture 7 Electrophysiology

Mohammad-Reza A. Dehaqani

dehaqani@ut.ac.ir

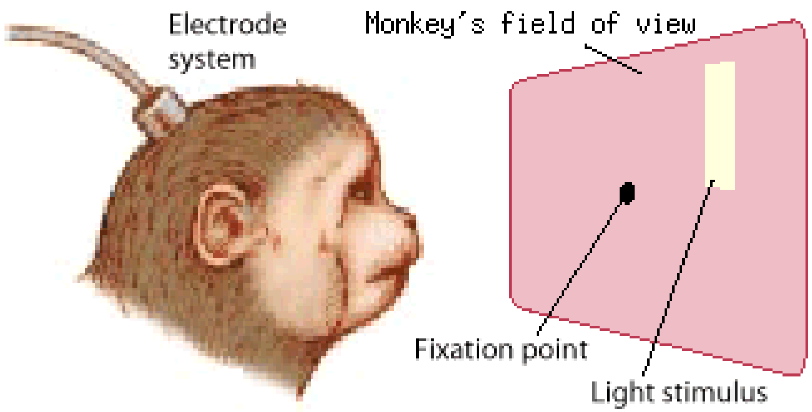
Methods of recording action potentials

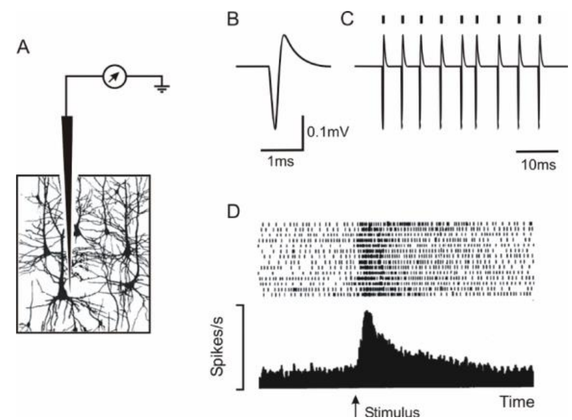


Single cell recording in the 1960s and 1970s

Robert Wurtz

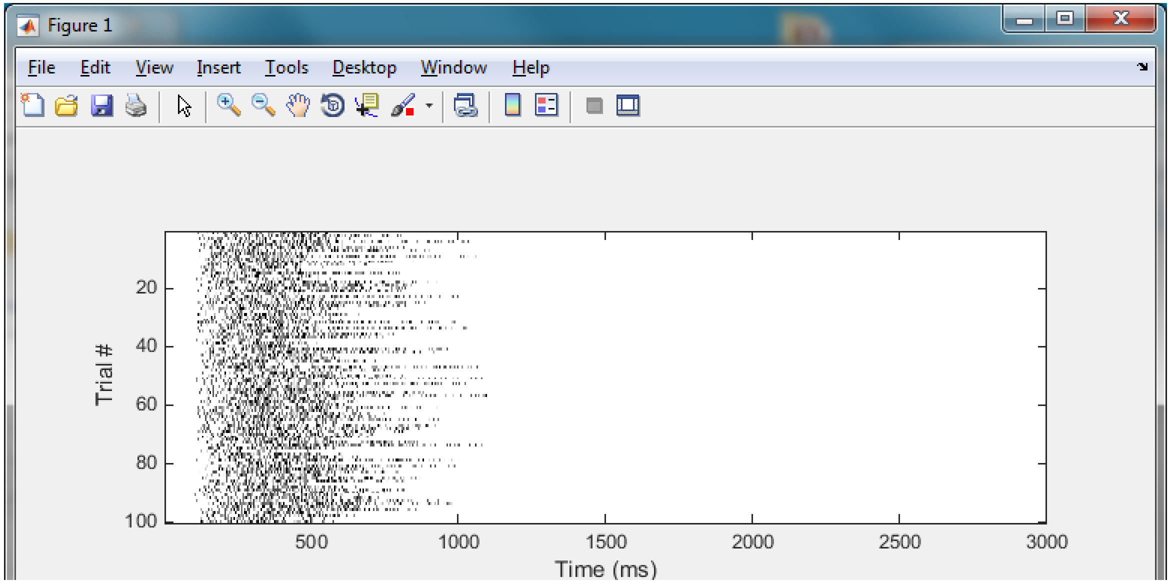
Edward Evarts



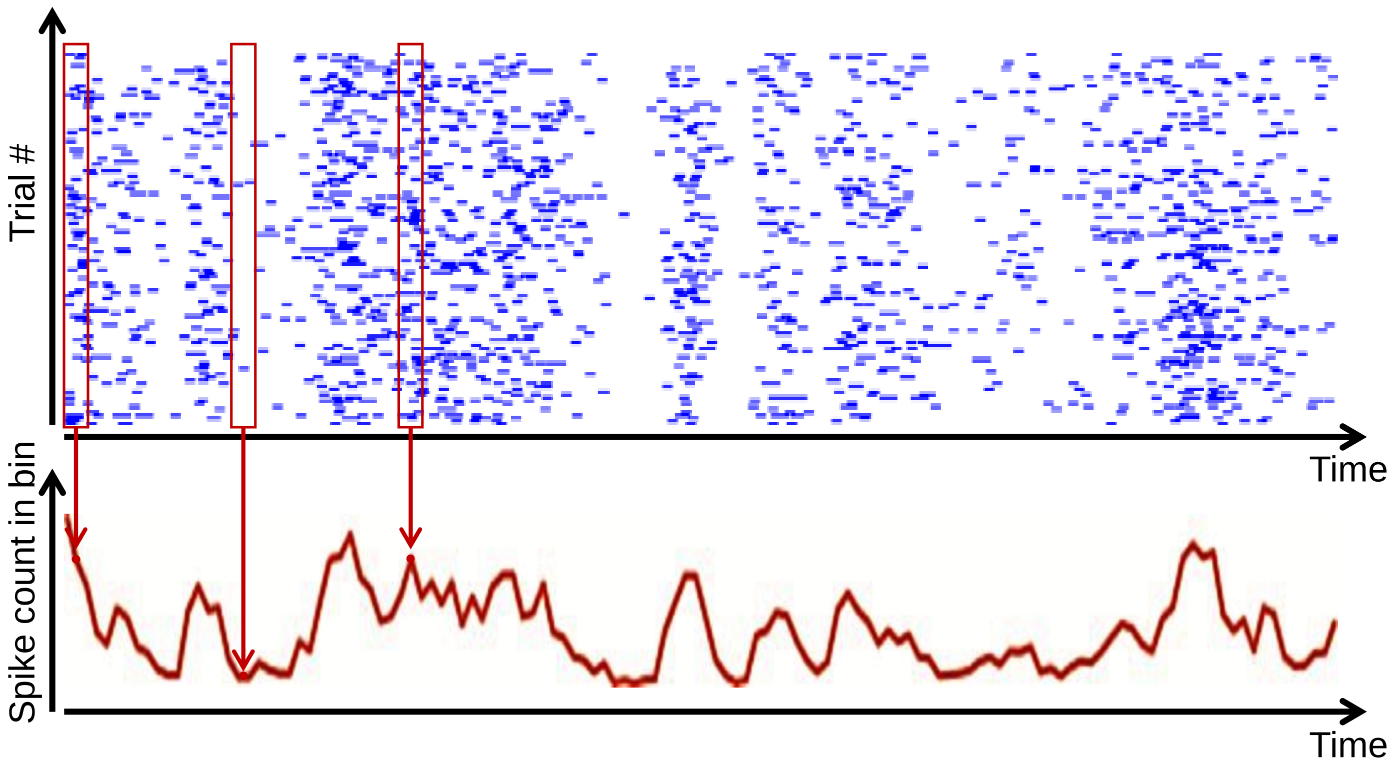


The raster plot

- Stimulus onset at 100ms



Peri-Stimulus time histogram (PSTH)

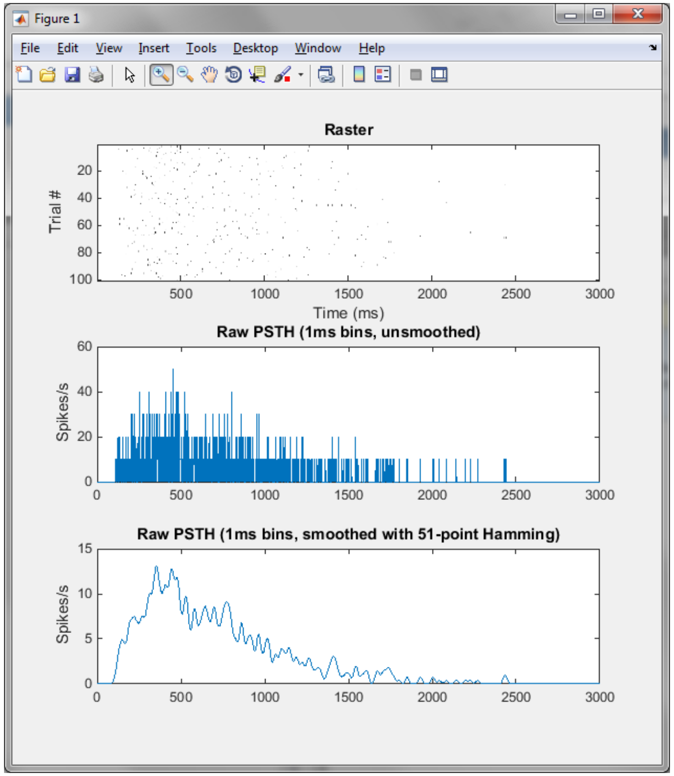


Estimated firing rate is $\frac{\#spikes}{bin\ size}$

How to compute PSTH from limited data

- Convolve PSTH with a kernel
- Kernel values must sum to 1!

- What kernel to use?
  - Wider means smoother, but lose time resolution
  - Causal?

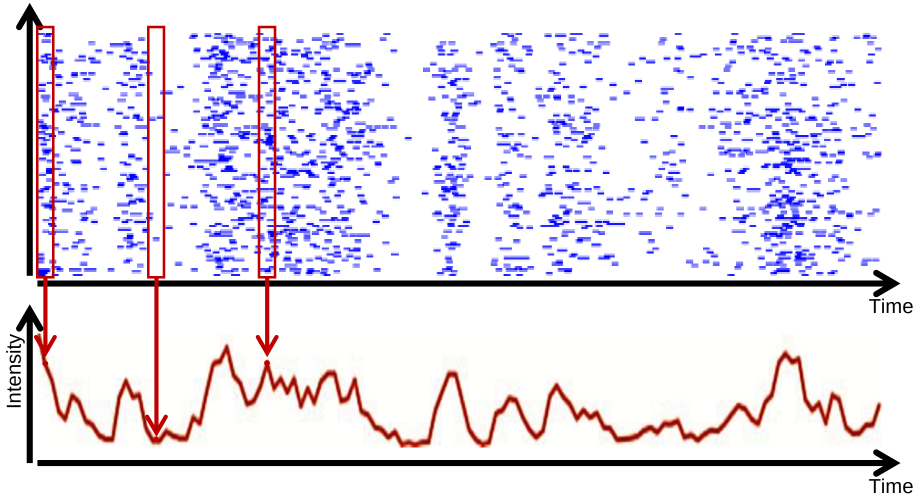


Inhomogeneous Poisson process

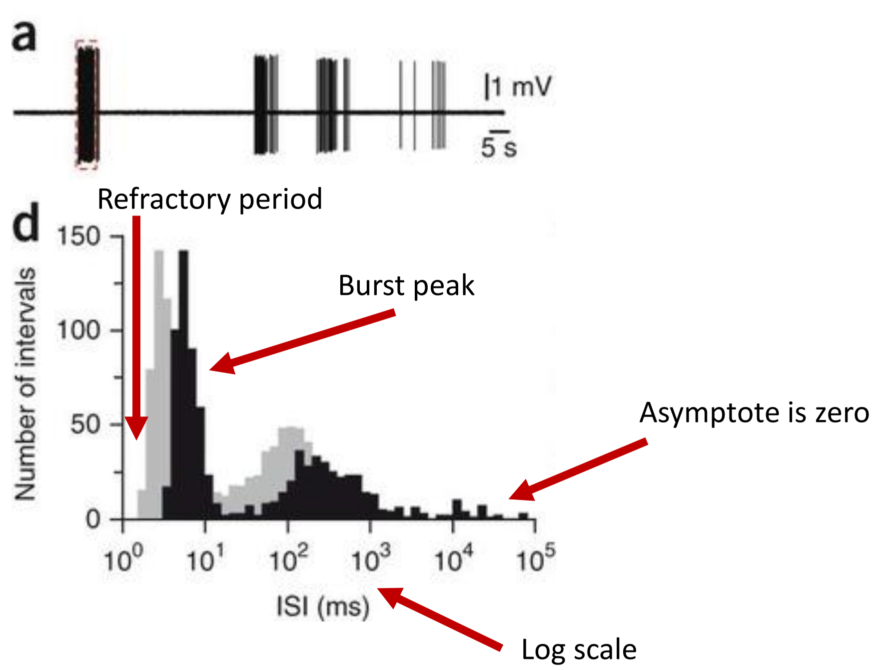
- Intensity depends on time:

$$\lambda(t) = \lim_{\delta t \to 0} Prob \frac{[Spike\ between\ t\ and\ t + \delta t]}{\delta t}$$

- PSTH is an estimator of $\lambda(t)$

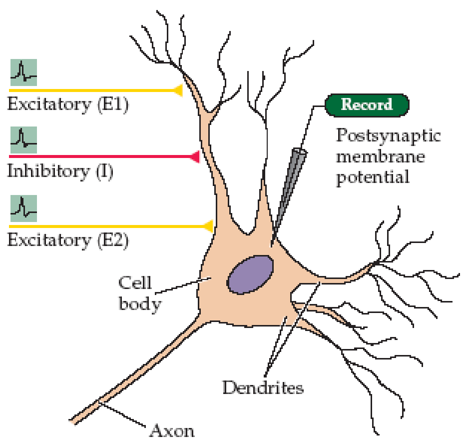


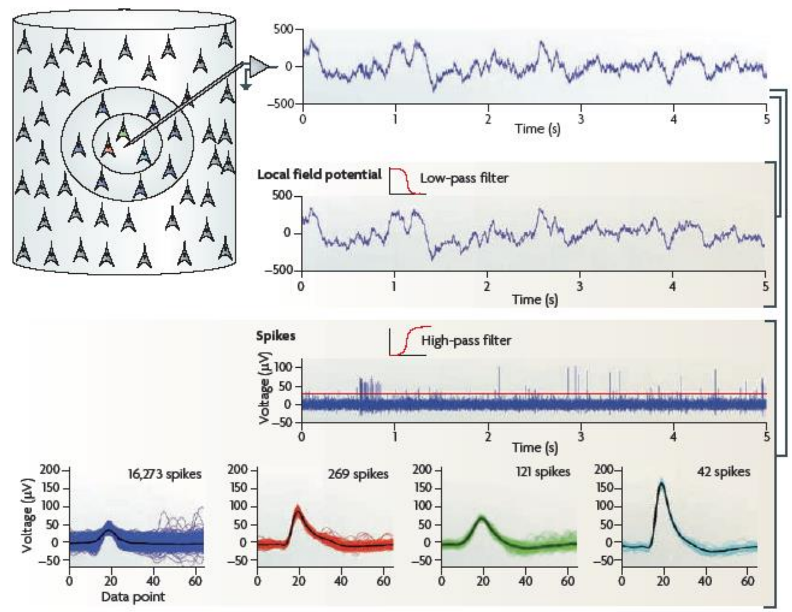
Interspike-interval histogram



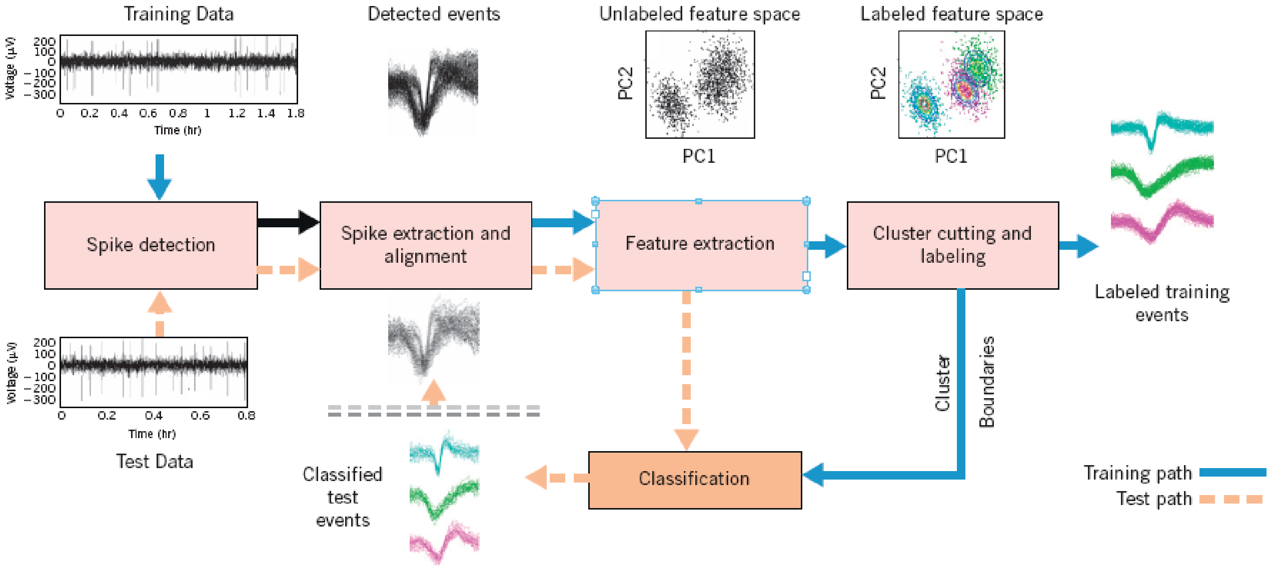
Developing cochlear hair cells,
Tritsch et al, Nature Neurosci 2010

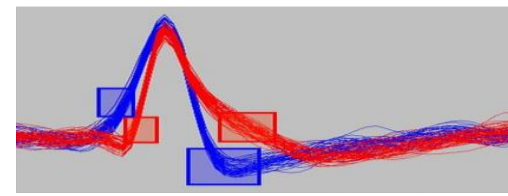
Intra and extracellular recording



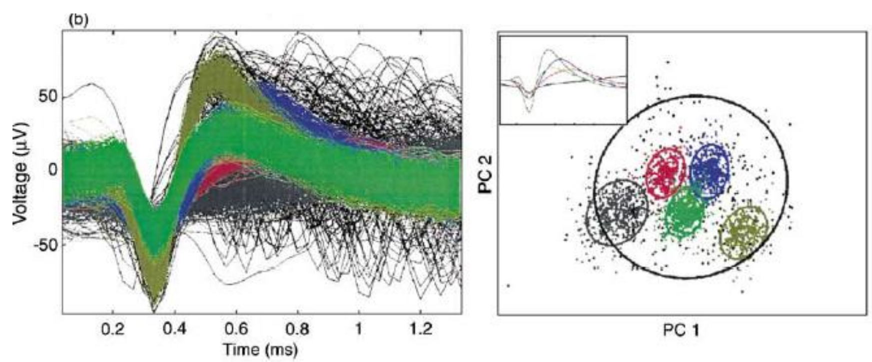


http://www.zoology.ubc.ca/~gardner/chemical_synapses%20-%20postsynaptic.htm



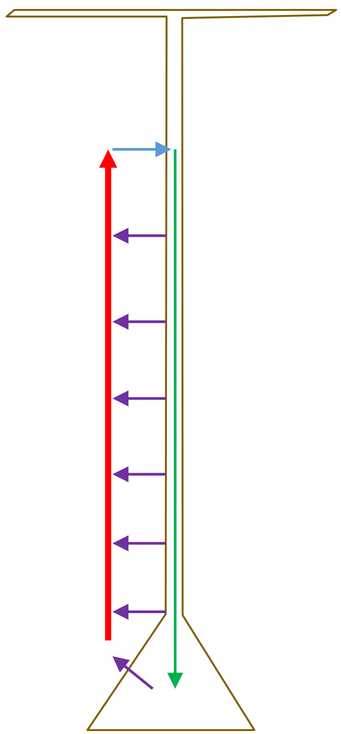


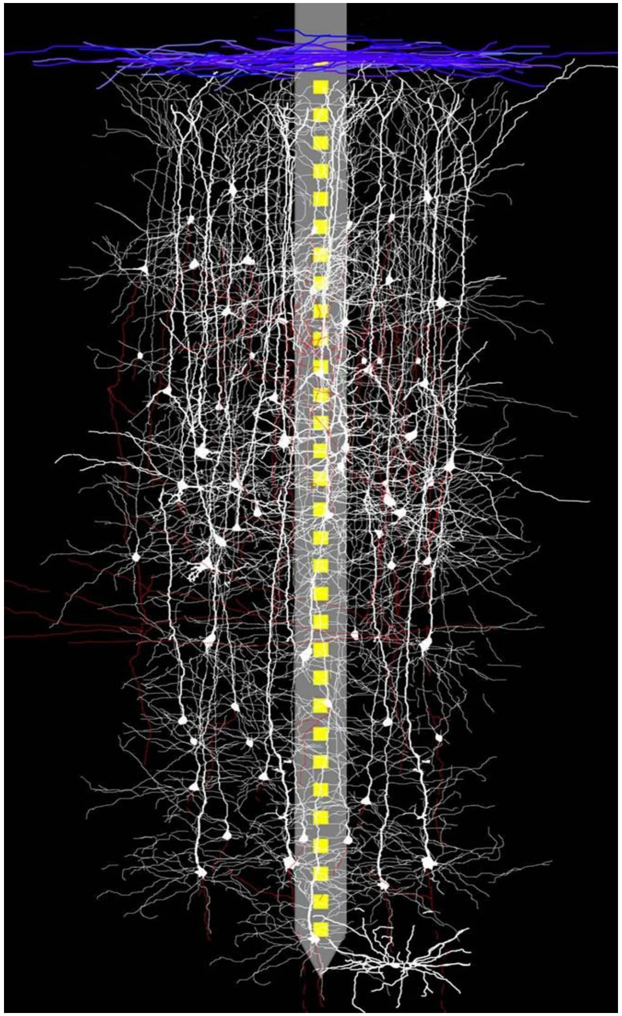
Spike sorting methods



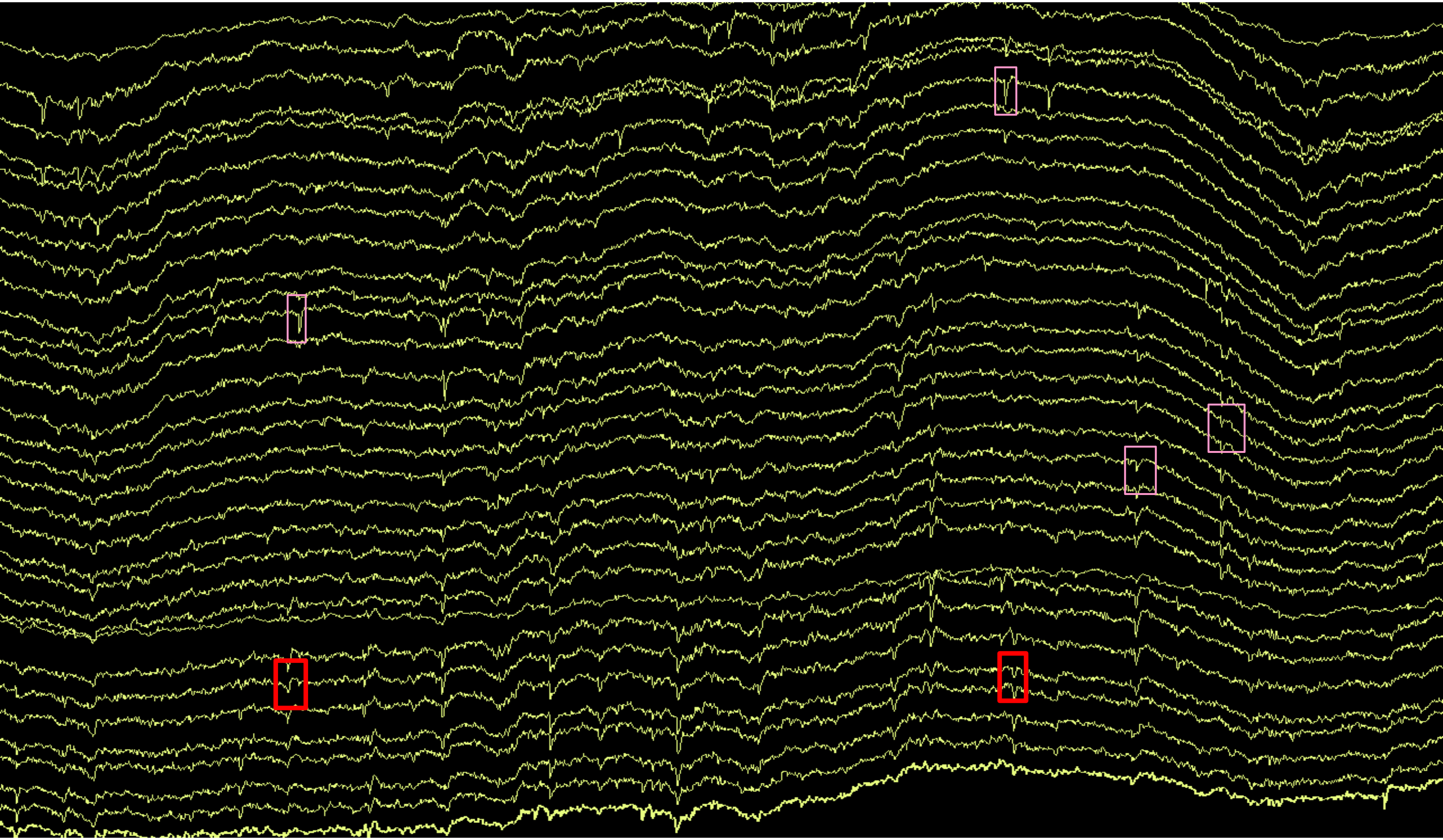
Shoham, S., Fellows, M. R., & Normann, R. a. (2003). Robust, automatic spike sorting using mixtures of multivariate t-distributions. *Journal of Neuroscience Methods*, *127*(2), 111–122. doi:10.1016/S0165-0270(03)00120-1

Linear probe recordings

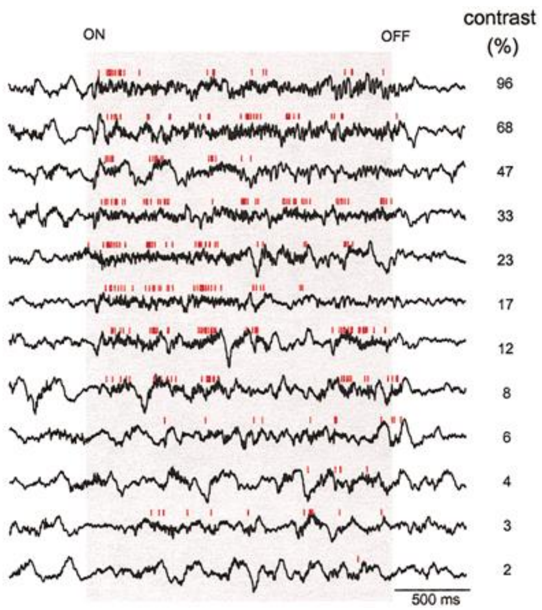


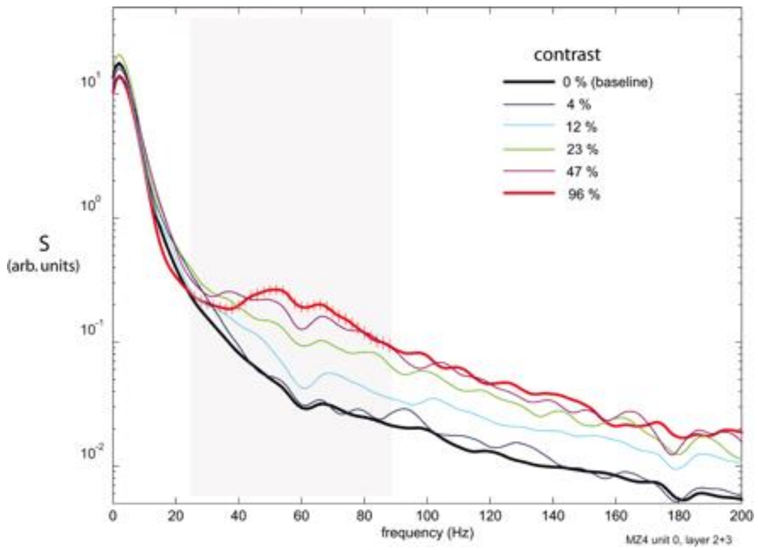


Local field potentials



Stimulus changes power spectrum in V1



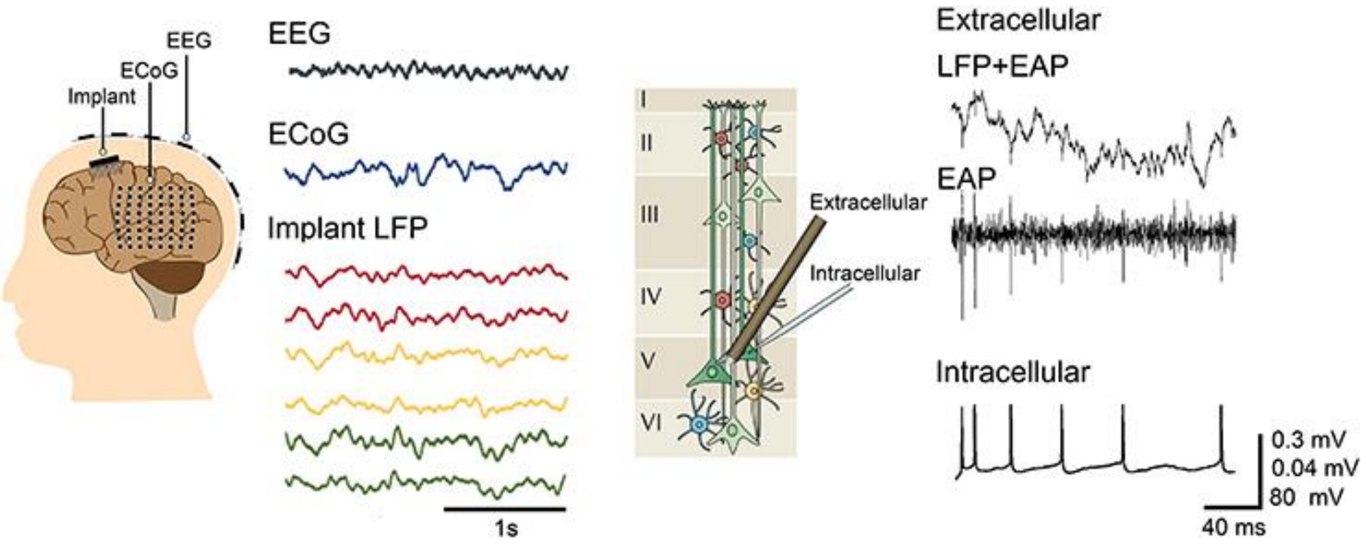


- High-frequency broadband power usually correlates with firing rate
- Is this a gamma oscillation?

Henrie and Shapley J Neurophys 2005

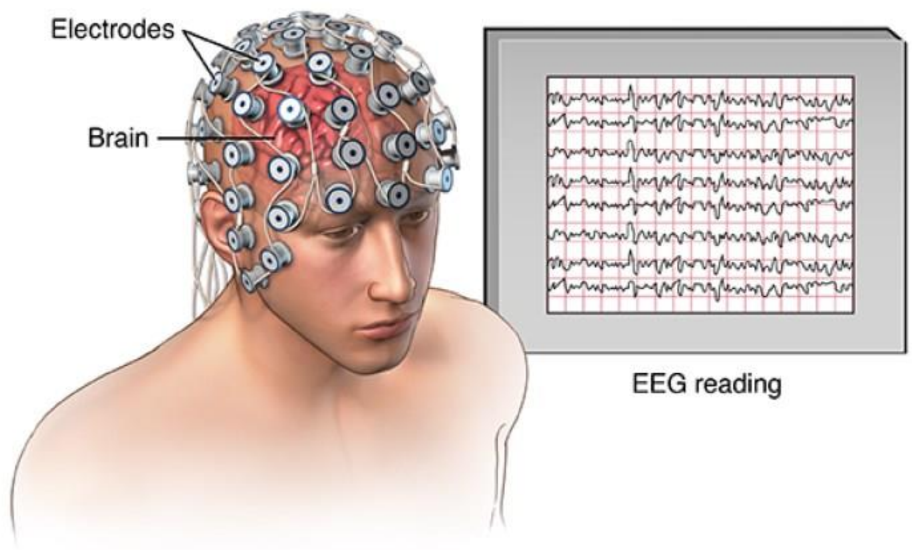
Five Common Eelectrophysiology Approaches:

- **EEG/ MEG**
- **Extracellular/Local Field Potentials**
- **Intracellular – Sharp Electrode**
- **Patch-Clamp Configurations**
- **Multi-Unit Array Recordings**

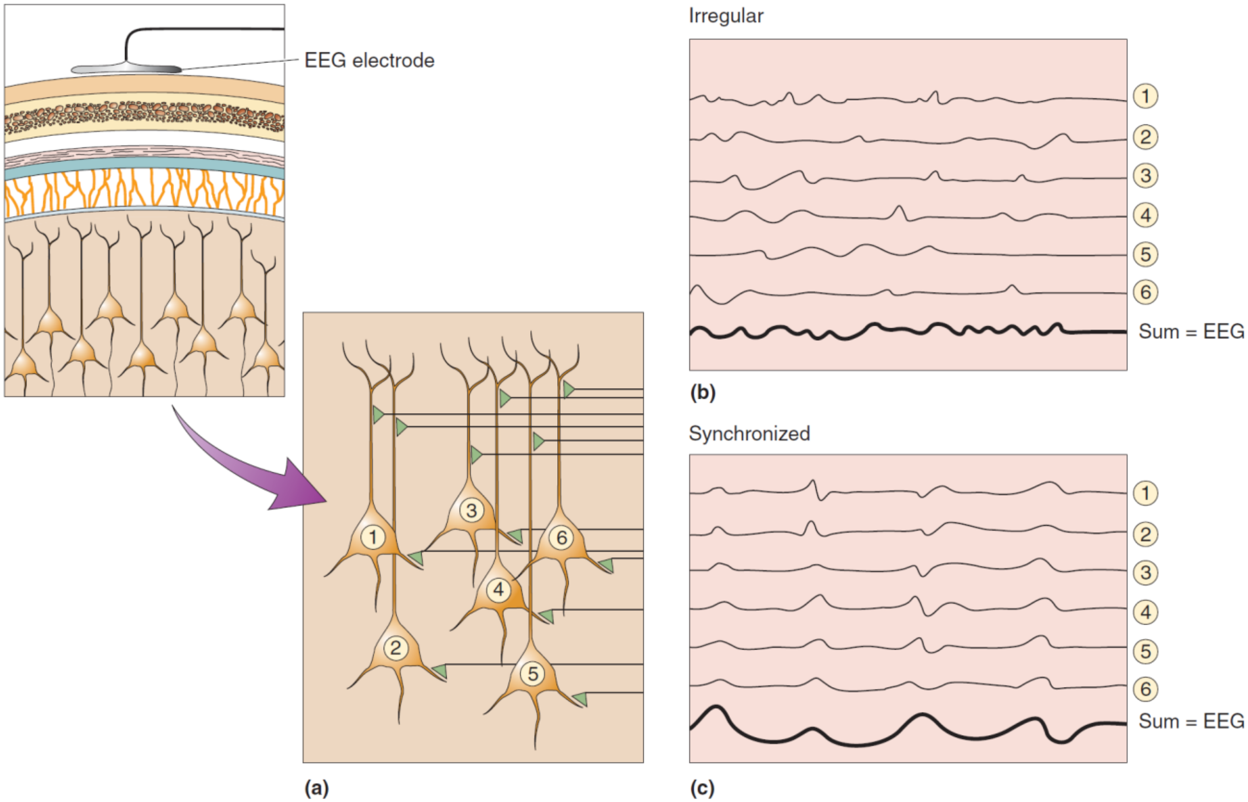


EEG: Electroencephalogram

- Non-invasive
- Used to capture cortical information processing
- High temporal resolution
- Tool for investigation of real time processing + for the development of brain-computer interfaces



Many **neurons need to sum their activity** in order to be detected by EEG electrodes. The **timing** of their activity is crucial. **Synchronized neural** activity produces larger signals.



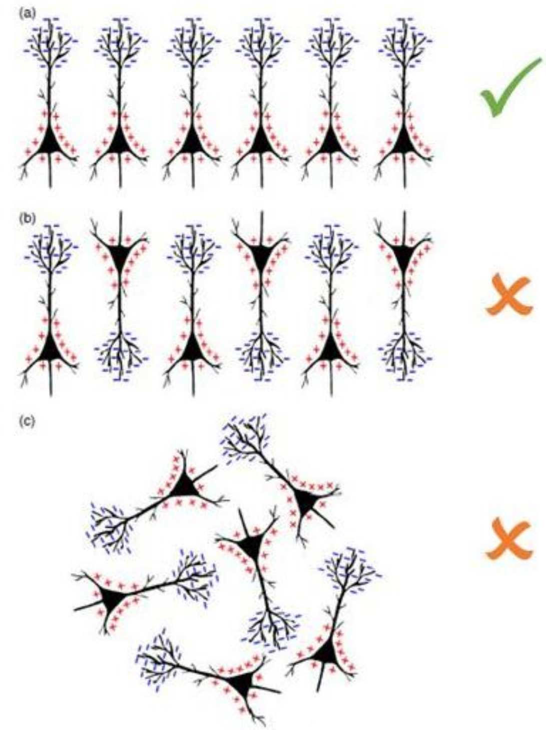
EEG: Basis of the signal

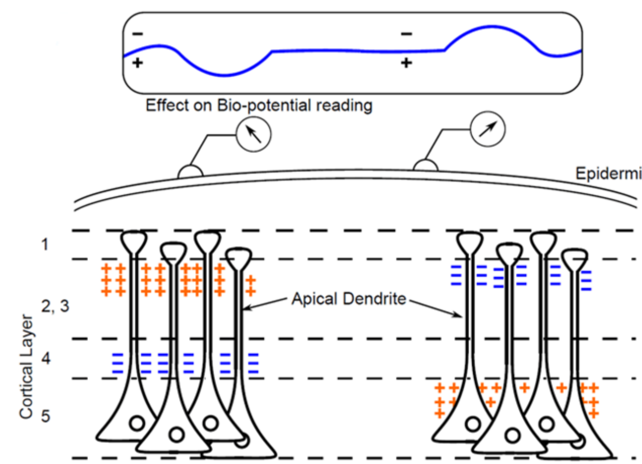
Necessary conditions for neural signal to be detected:

- Timing or Synchrony
- Large numbers
- Orientation

→ Pyramidal neurons in layer V

- Population of pyramidal neurons create a **dipole**
- Negative and positive pole
- Depends on excitatory or inhibitory
- Orientation determines the deflections in the EEG signal



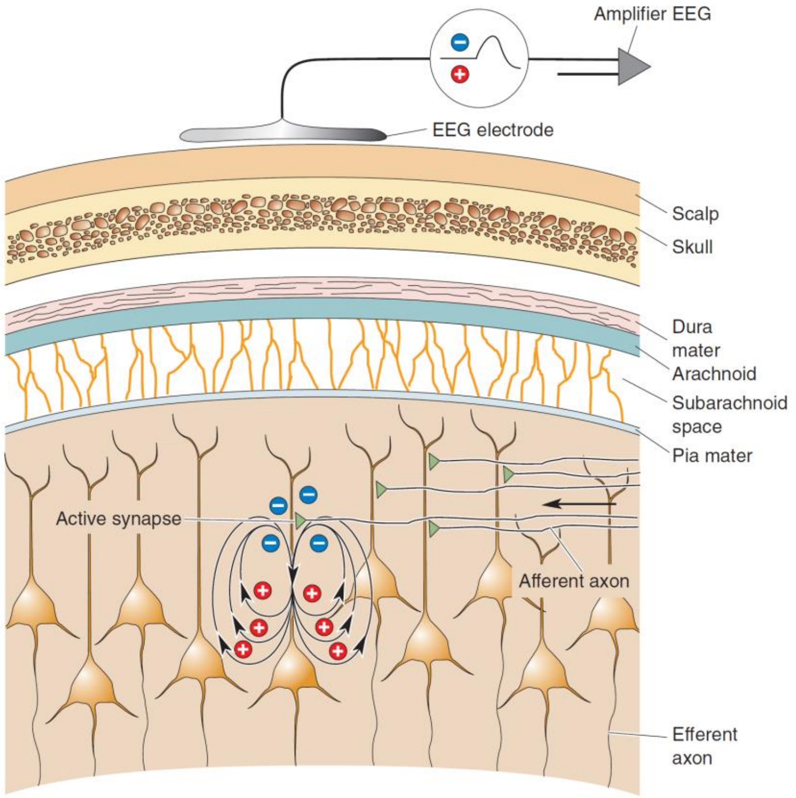


EEGs

- Recording spontaneous brain (voltage volume conductance) activity from the scalp, described in rhythmic activity: Delta (<4 Hz), theta (4-7 Hz), Alpha (8 – 13 Hz), Beta (14 – 30 Hz), gamma (30-100 Hz)

- **Clinical Neuroscience**: epilepsy, coma, tumors, stroke, focal brain damage, depth of anesthesia

- Coordinate cortical activity = high contribution
  Deep structure activity = low contribution



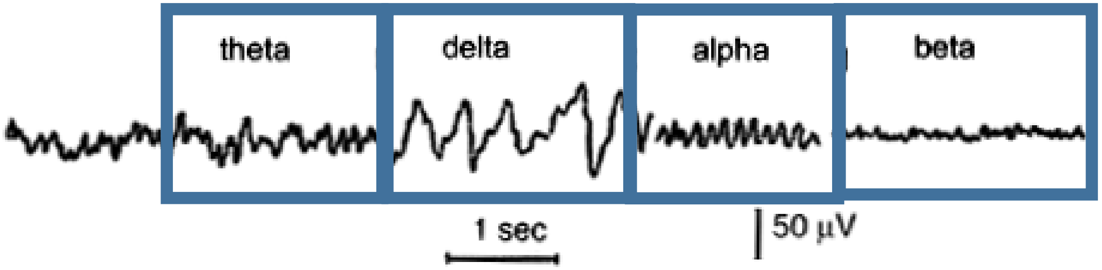
EEG: Frequency spectrum

- **Delta**:
  - Frequency of < 3.5 Hz
  - Highest in amplitude + slowest waves
  - Dominant rhythm in infants (< 1 year) and in stages 3 and 4 of sleep

- **Theta**:
  - Frequency: 3.5 - 7.5 Hz → "slow" activity
  - In children (< 13 years) and in sleep.
  - Abnormal in awake adults.

- **Alpha**:
  - Frequency: 7.5 - 13 Hz
  - Seen in posterior regions of the head, higher in amplitude on the dominant side.
  - Appears when closing the eyes and relaxing.
  - Major rhythm in relaxed adults (> 13 years)

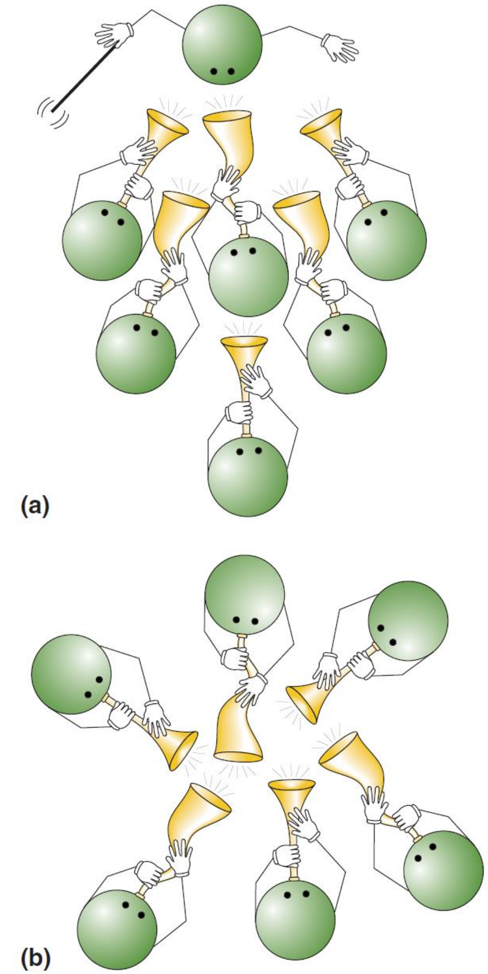
- **Beta**:
  - Frequency > 14 and greater Hz → "Fast" activity
  - Seen on both sides in symmetrical distribution and is most evident frontally
  - Dominant rhythm in patients who are alert or anxious.



Two ways of generating synchronicity

a) **Pacemaker**

b) **mutual coordination:** collective behavior of all participants



Standard placements of electrodes on the human scalp

A, auricle;

C, central;

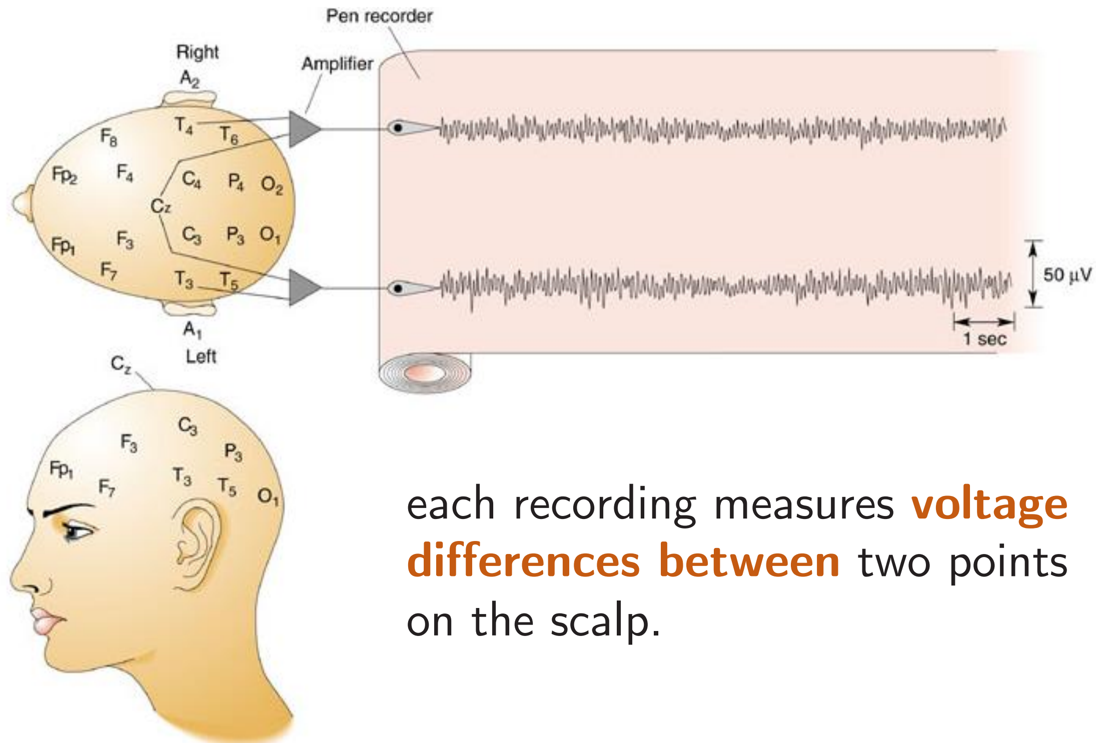
F, frontal;

Fp, frontal pole;

O, occipital;

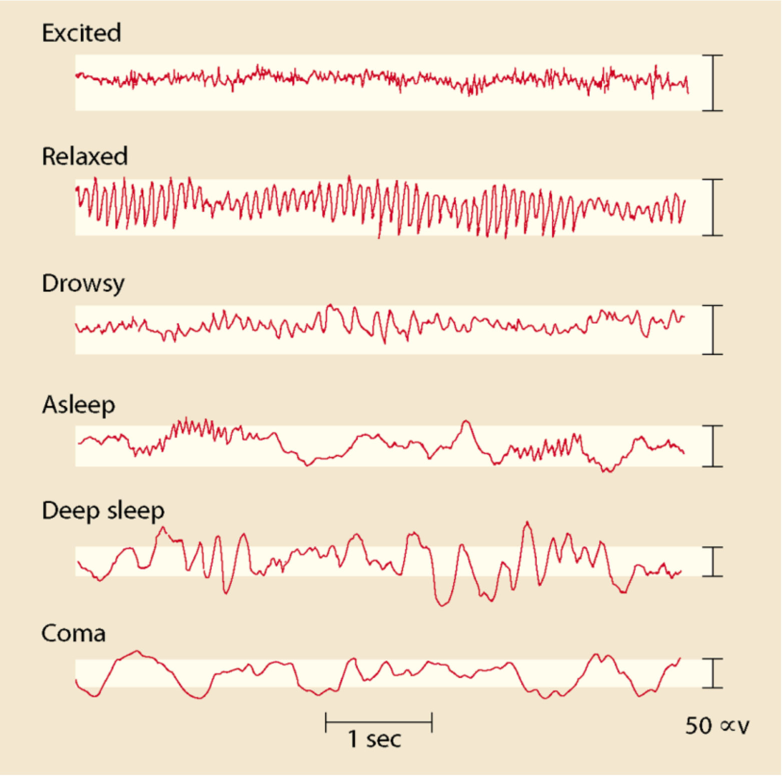
P, parietal;

T, temporal.



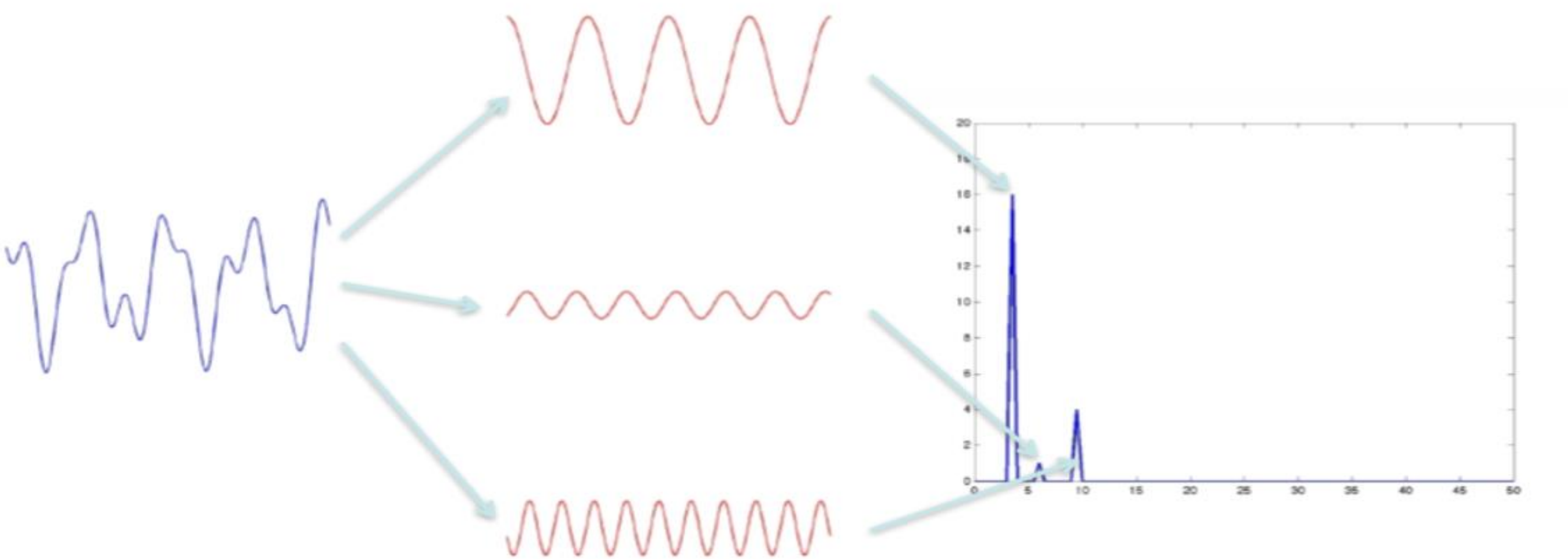
each recording measures **voltage differences between** two points on the scalp.

Good indicators of global brain state; EEG waves often display rhythmic patterns at characteristic frequencies

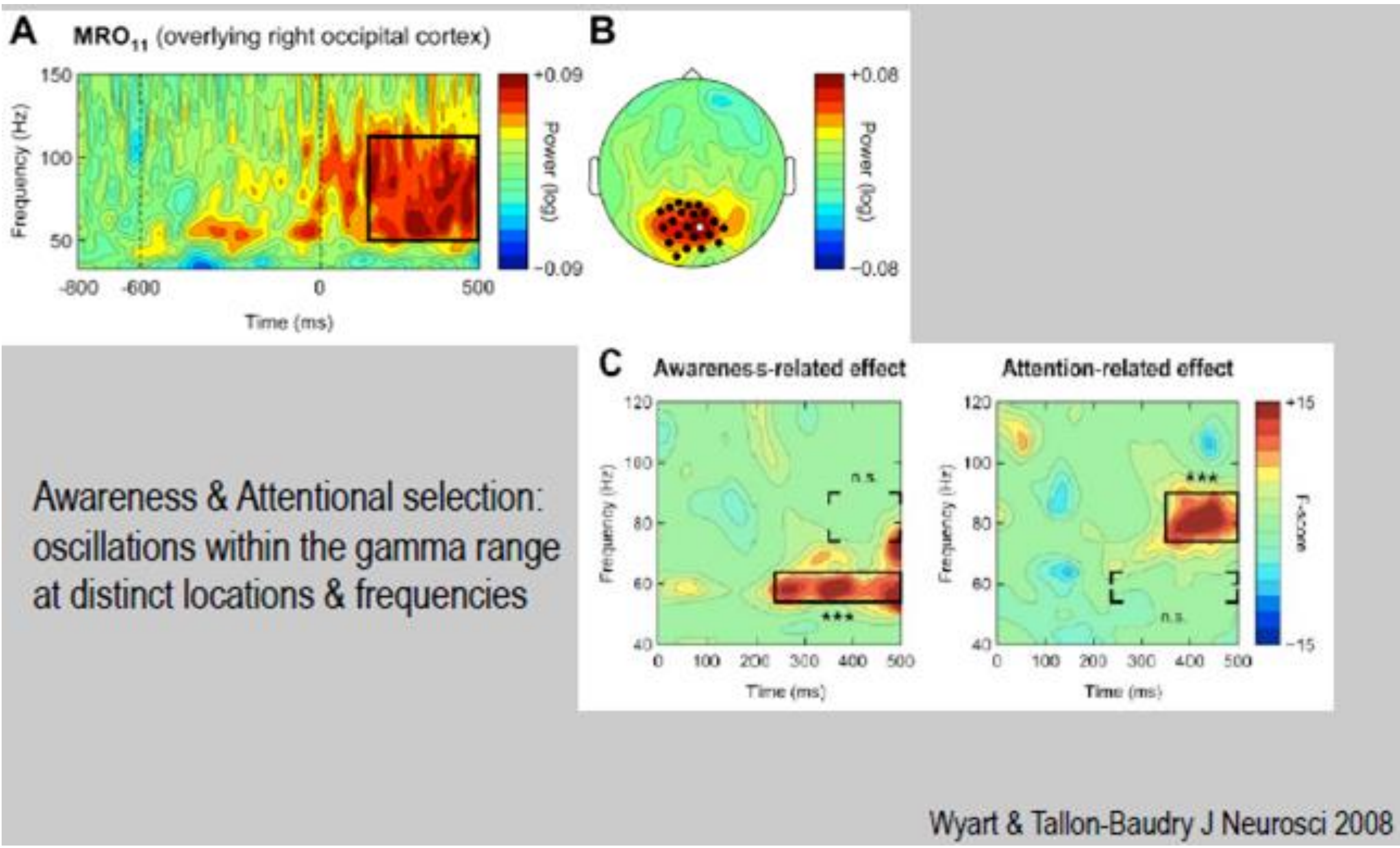


Brain rythms

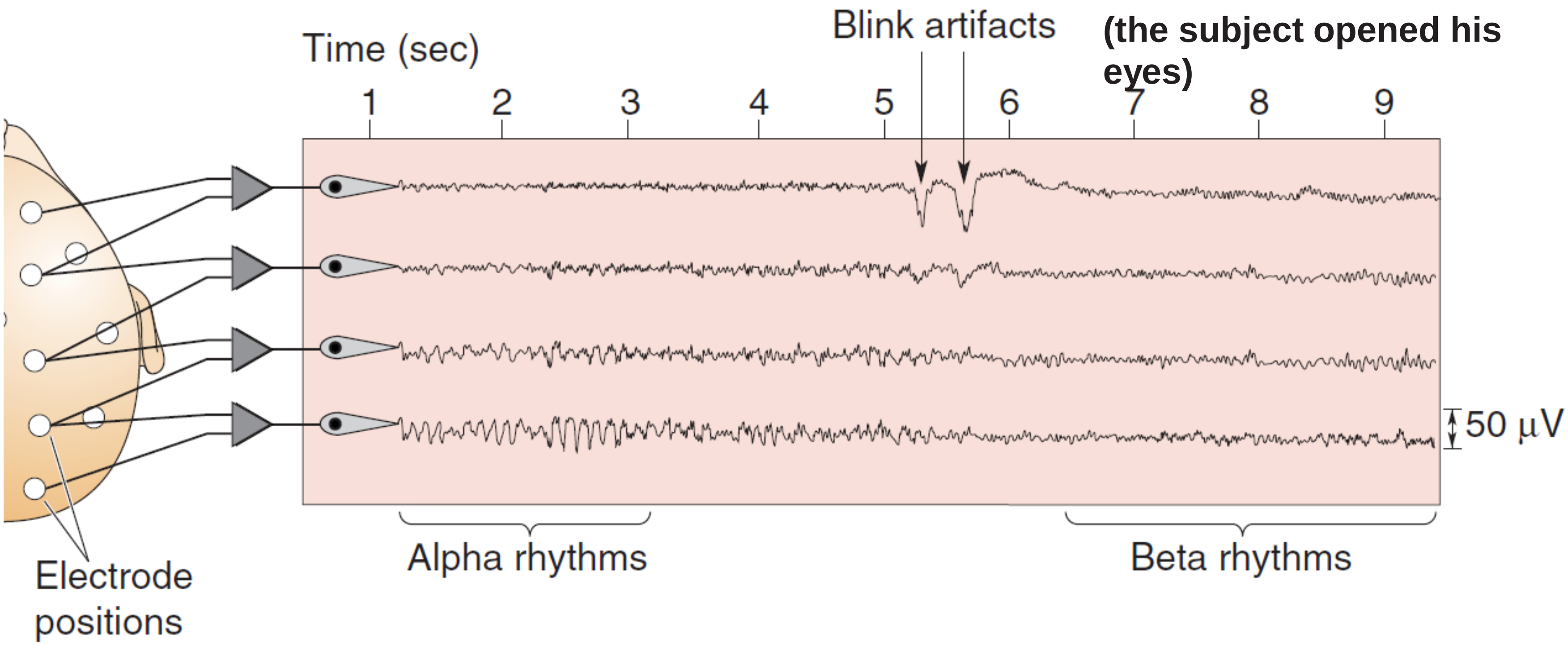
- Need to apply models on the data to quantify, for example the Fourier transform (simple oscillatory function such as sines and cosines)



Brain rythms

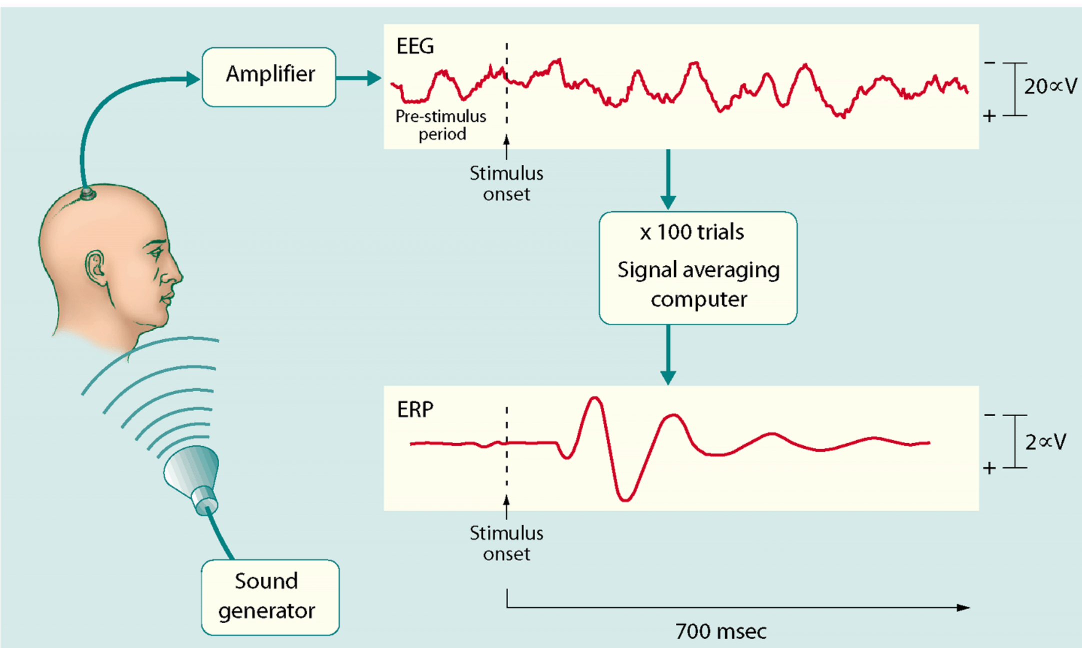


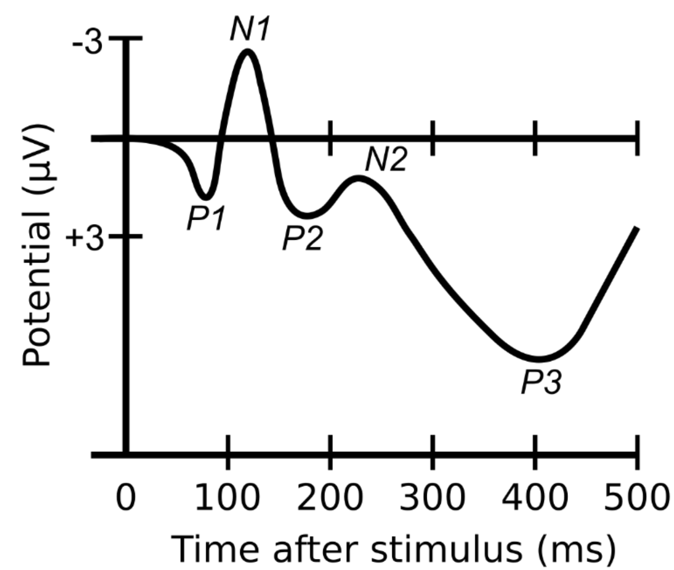
A normal EEG; preprocessing



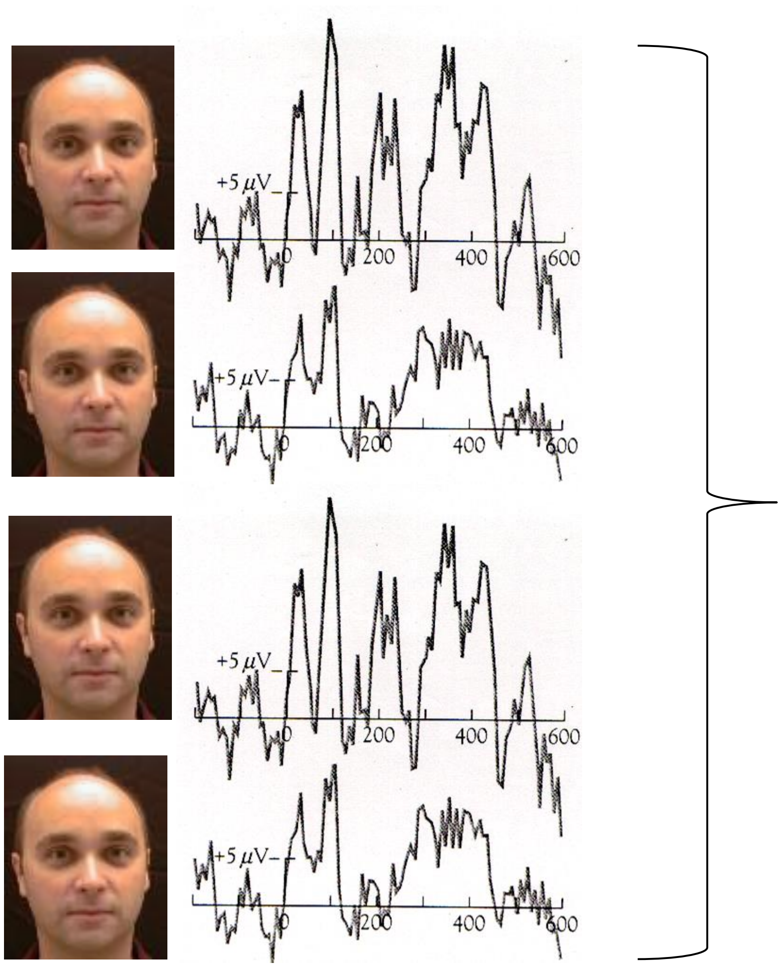
Event related potential

ERP's are extracted after **averaging EEG** signals obtained over multiple trials (trials are aligned by stimulus onset).

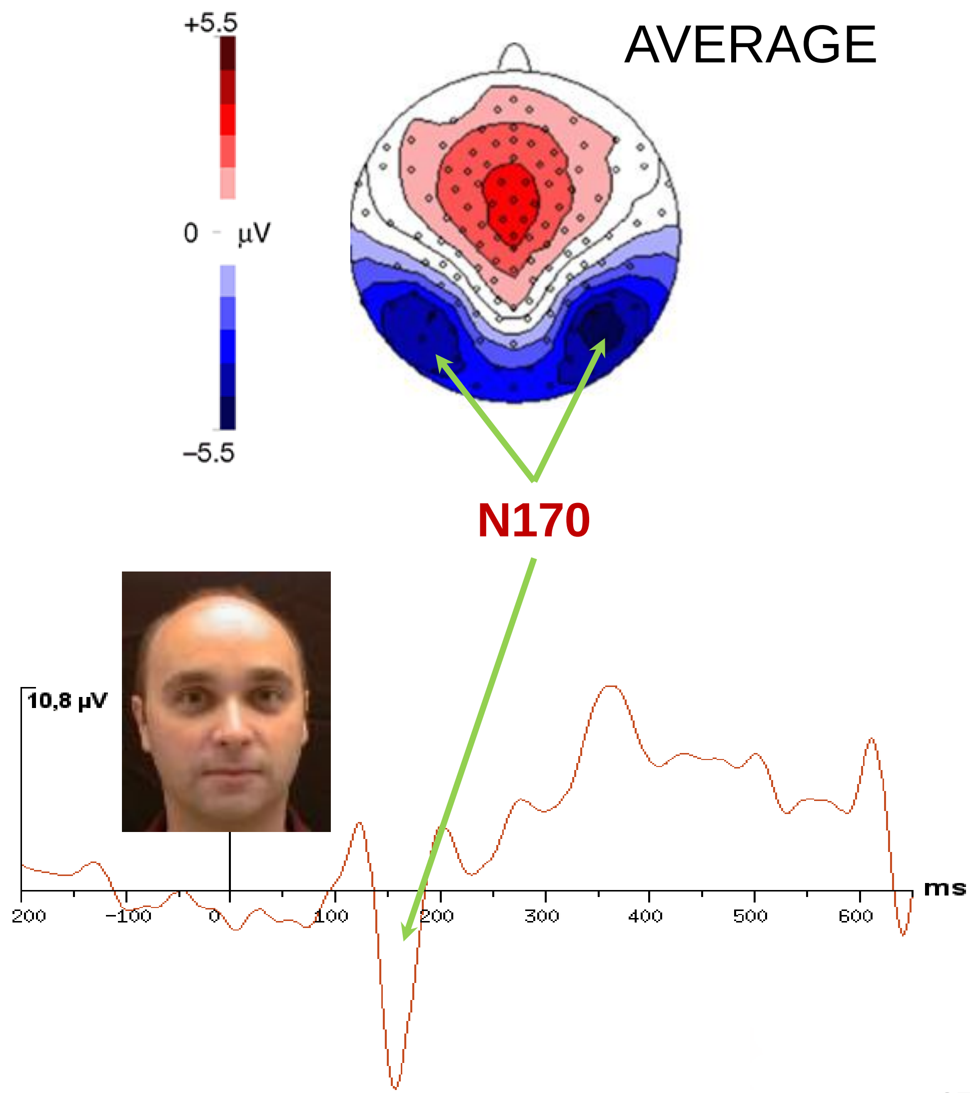




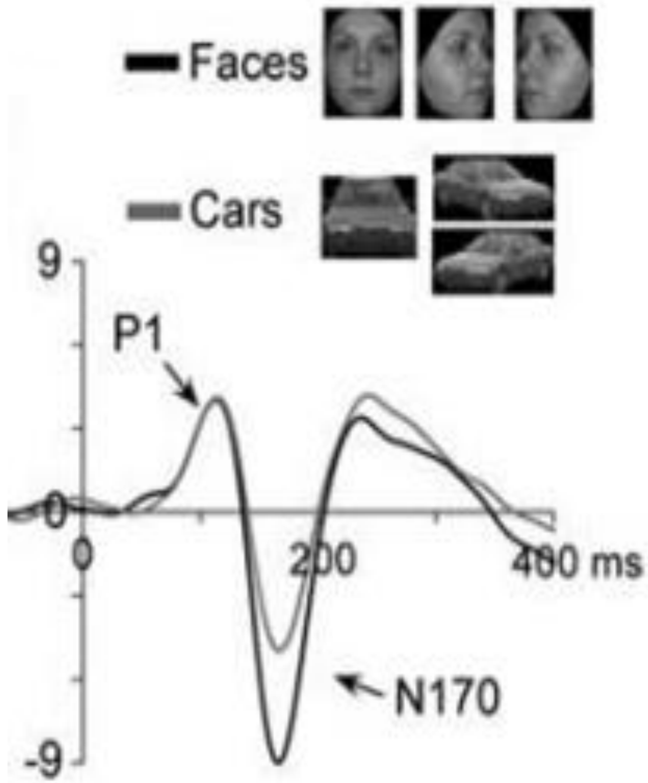
Evoked potentials:
Average on a LOT of trials to get a signal



Trial by trial signal



Interest: compare different types of trials



Georges et al. 2005

MEG: Introduction

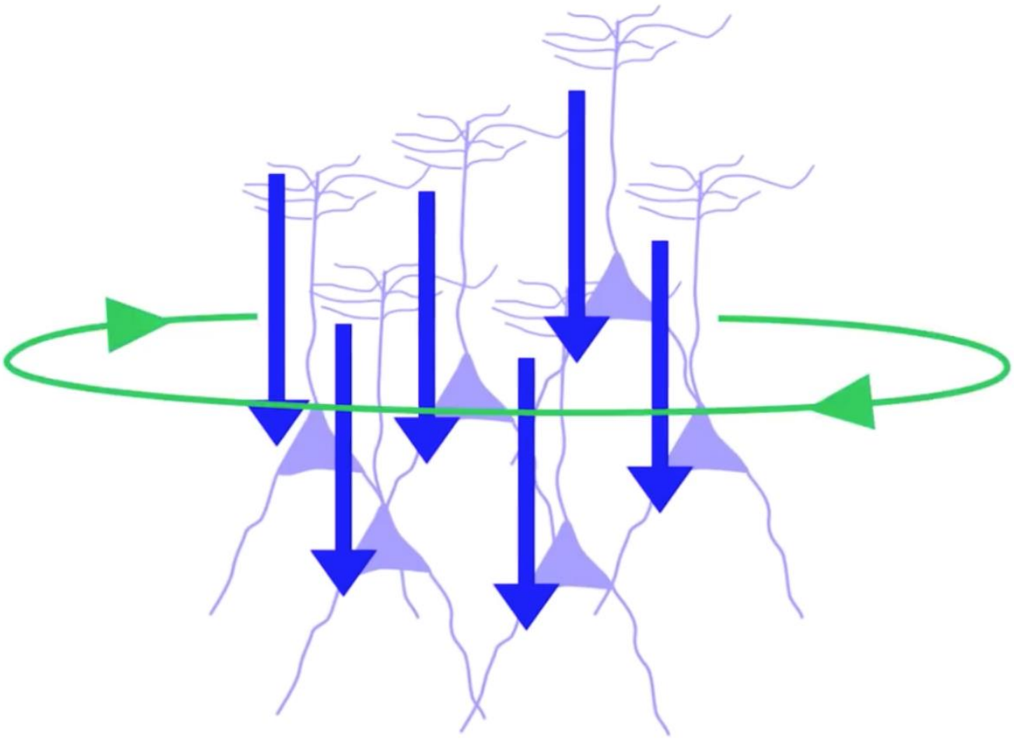
- Magnetoencephalography
- Non invasive
- High temporal + spatial resolution
- Measures magnetic fields
- Technology: SQUID
- Location of neuronal sources found via magnetic field analysis

Used for:

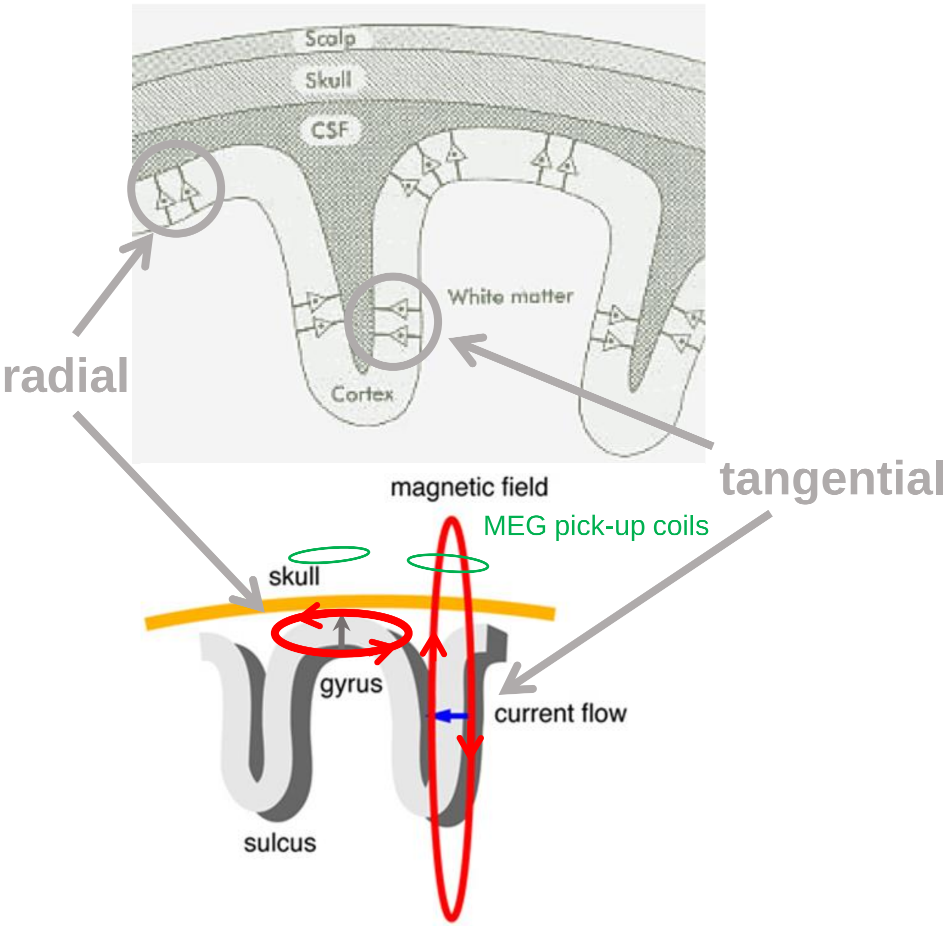
- Surgical planning (Source locations superimposed on MRI image)
- Neural correlates brain processes

MEG: Basis of the signal

- Postsynaptic potentials (PSPs) create current
- Current = magnetic field



MEG: Basis of the signal



- MEG coil not sensitive to perfectly radial sources
- Only a small proportion of cell are perfectly radial (top of gyri)
- No distortion of magnetic fields by conductive properties of scalp/head

MEG: Scale of the signal

- MEG signal is tiny
- Can be hidden by noise
- Requires:
  - A magnetically shielded room
  - Supersensitive magnetometers