Eric Maris

Neuronal signals for BCI

Outline

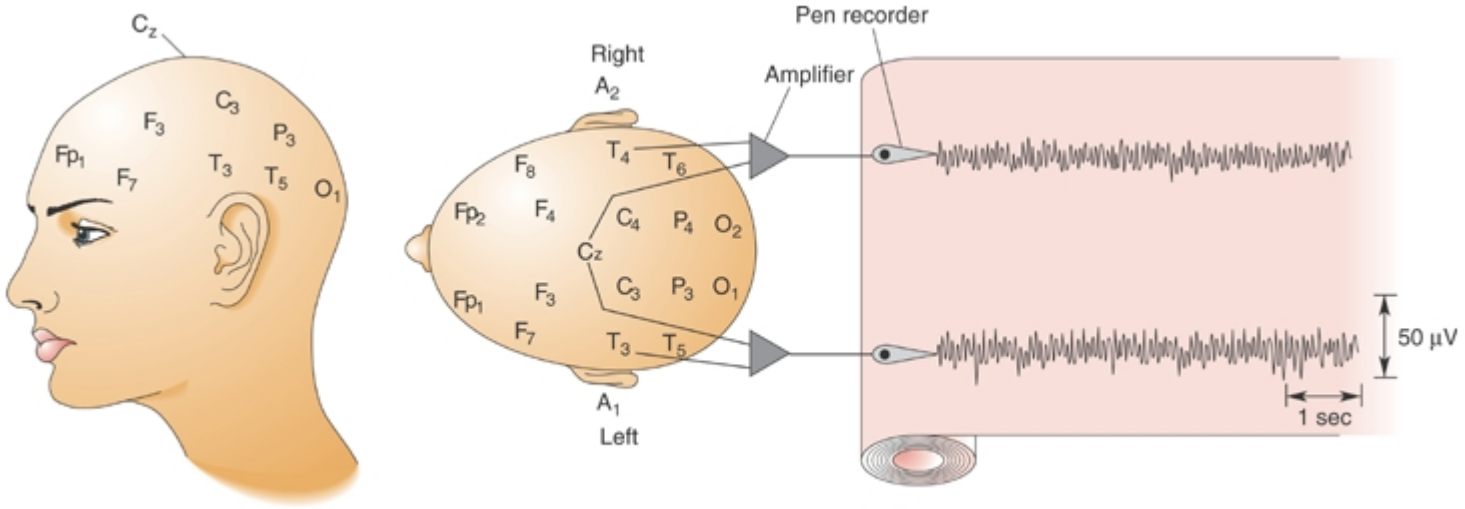
1. The different types of electrophysiological data
2. Electrophysiology versus fMRI
3. The physiology of EEG and MEG
4. Evoked responses and induced oscillations

Electrophysiological Data

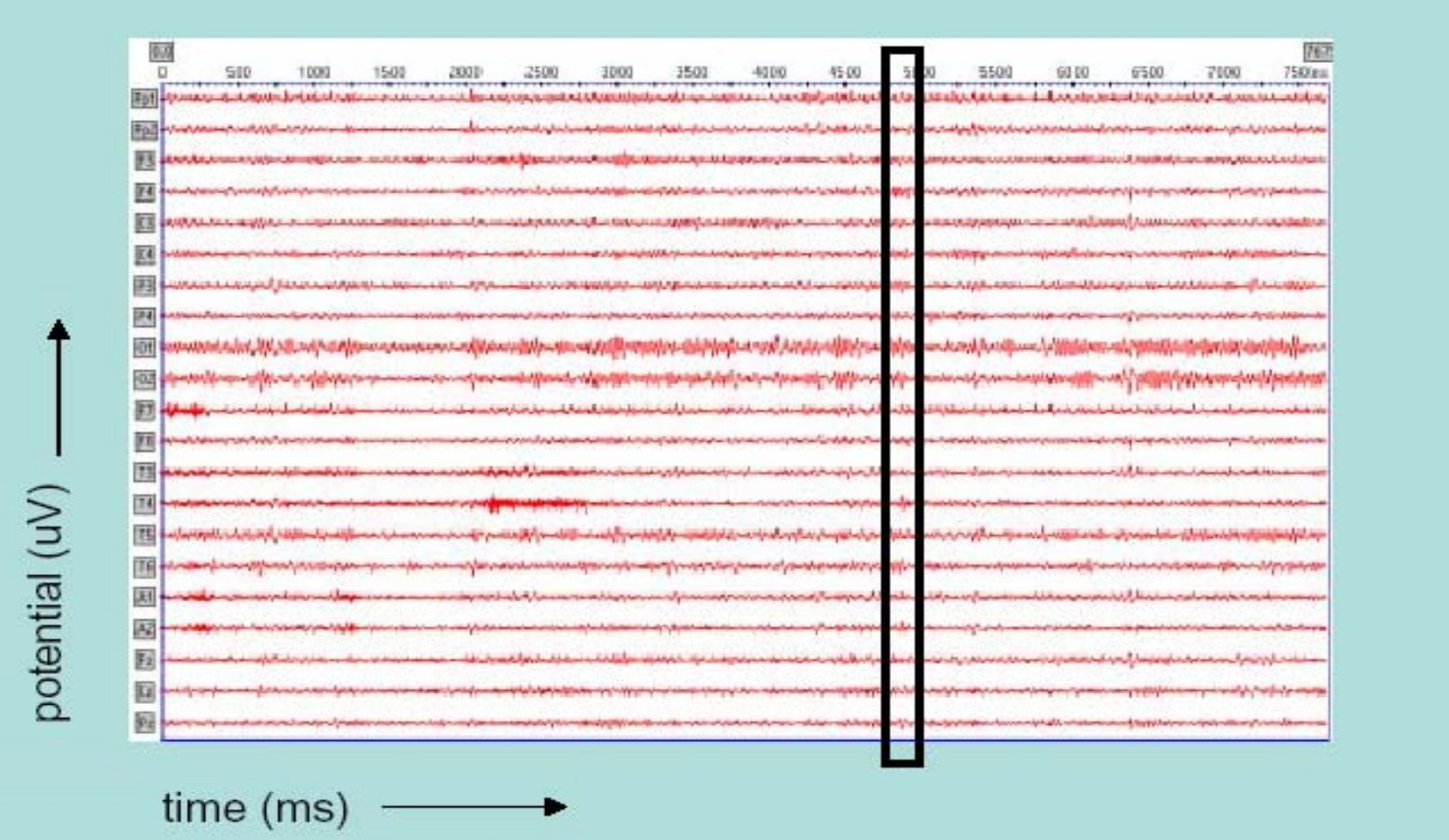
1. EEG = ElectroEncephaloGram

What is the EEG?

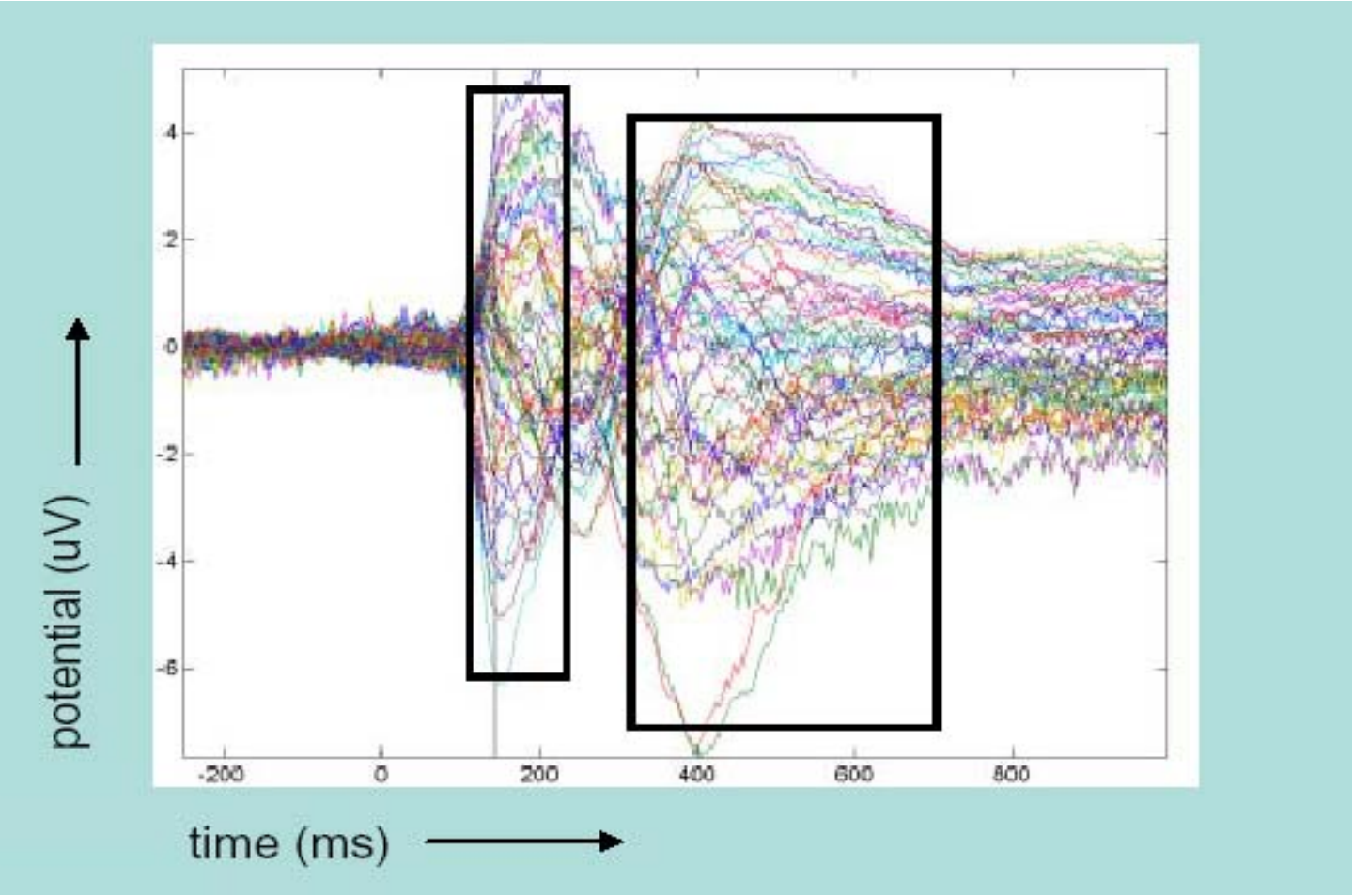
What is the EEG?



What is the EEG?



What is the EEG?

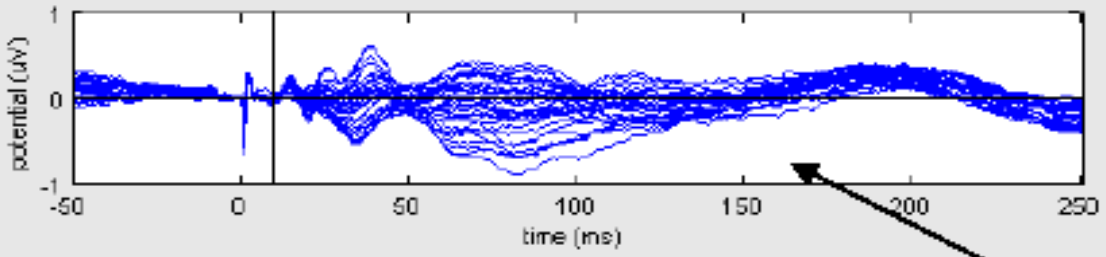


What is the EEG?

$$\text{data} = \begin{pmatrix} V_{11} & V_{12} & V_{13} & V_{14} & \cdots V_{1T} \\ V_{21} & V_{12} & V_{13} & V_{14} & \cdots V_{1T} \\ V_{31} & V_{12} & V_{13} & V_{14} & \cdots V_{1T} \\ \cdots & & & & \\ V_{N1} & V_{N2} & V_{N3} & V_{N4} & \cdots V_{NT} \end{pmatrix}$$

N rows x *T* columns

What is the EEG?



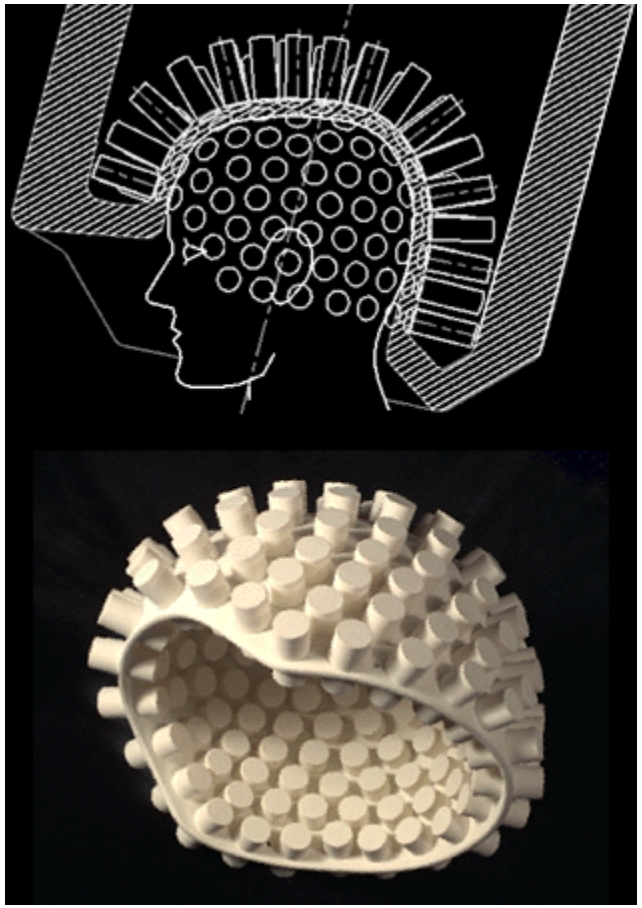
temporal

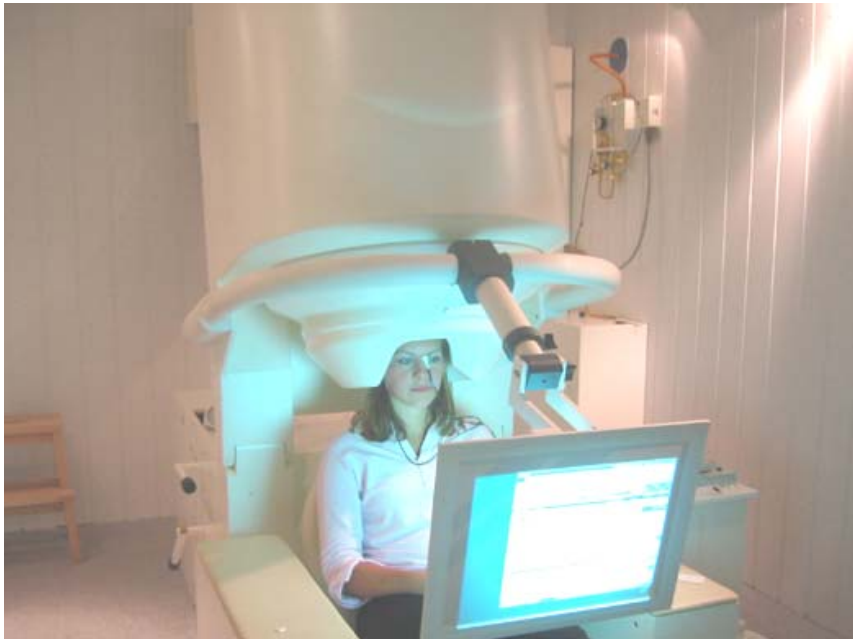
spatial

Electrophysiological Data

2. MEG = MagnetoEncephaloGram

What is the MEG?





Electrophysiological Data

3. ECoG = ElectroCorticoGram

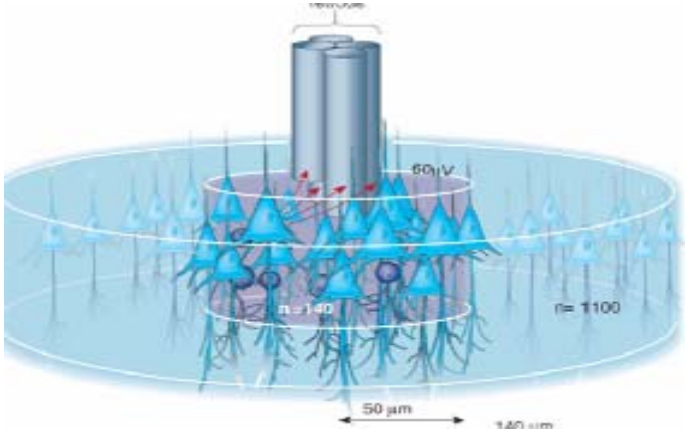
   (iEEG = intracranial EEG)

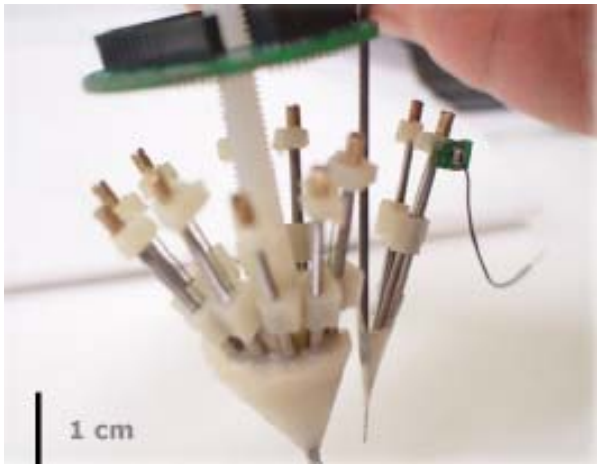
What is the ECoG?

Electrophysiological Data

4. Wire electrodes

What are Wire Electrodes?

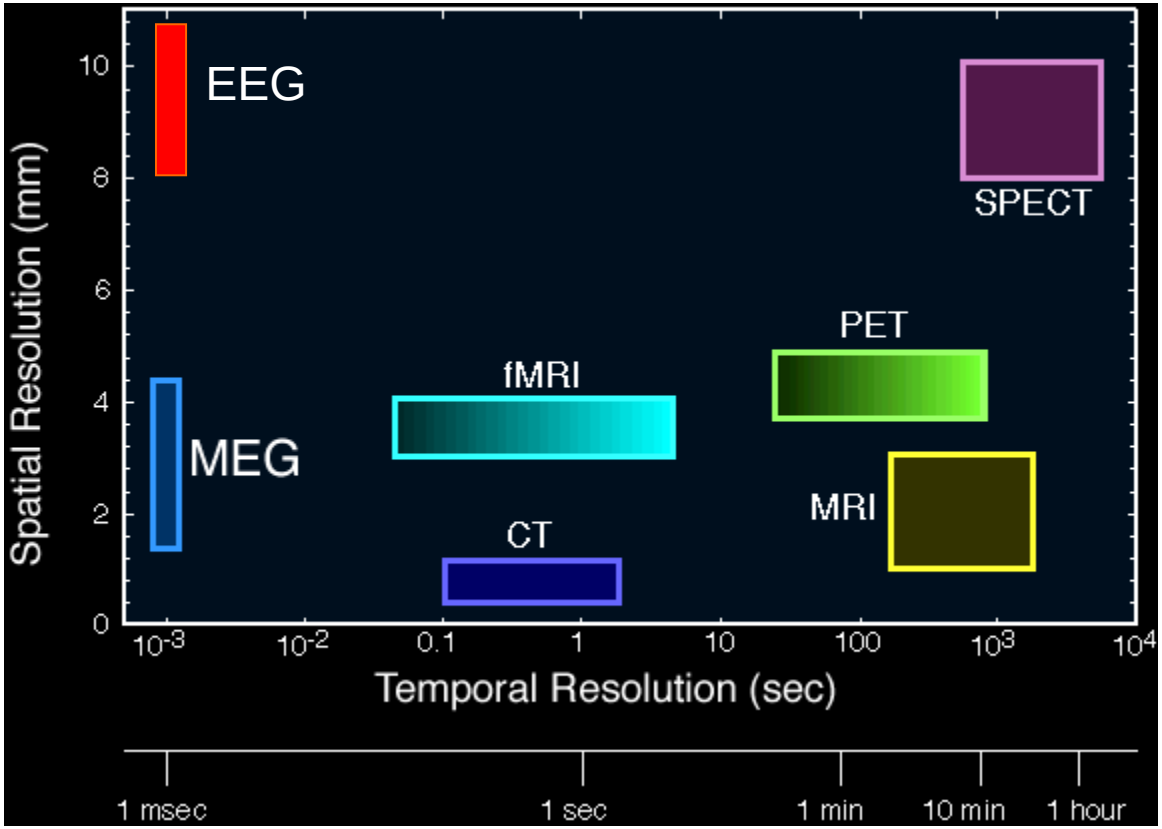




Electrophysiology versus fMRI

- Neuronal activity involves changes in the potential distribution in the brain
- These changes in potential distribution contribute to the signal that is measured in, on, or outside of the brain
- fMRI is a measure of *haemodynamic processes* in the brain
- The relation between electrophysiological measures and fMRI is unclear

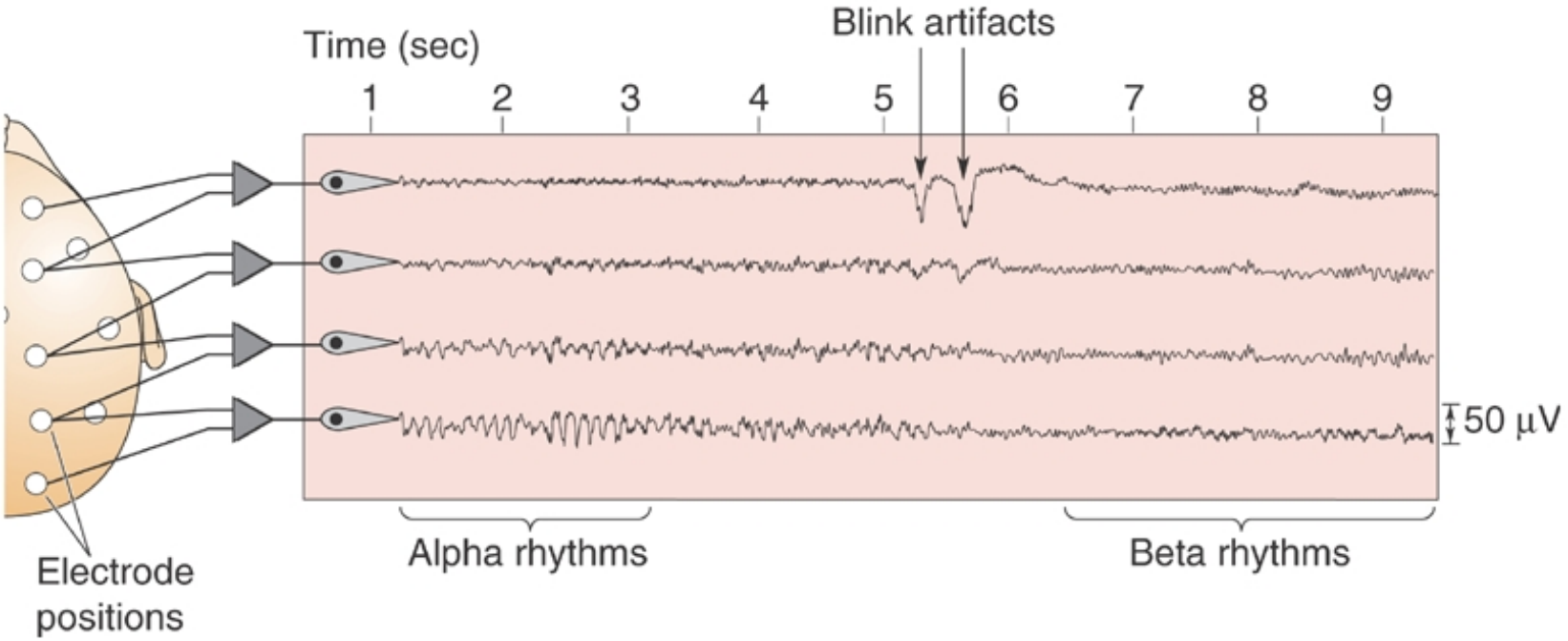
Electrophysiology vs fMRI



Artefacts in Electrophysiological Measurements

- Artefact = a component in the recorded signal that is not produced by neurophysiological activity
  - Non-neuronal physiological activity: muscle contraction, vascular activity
  - Non-physiological activity: line noise, moving magnetic fields
- The neurophysiological component in the recorded signal is often small!

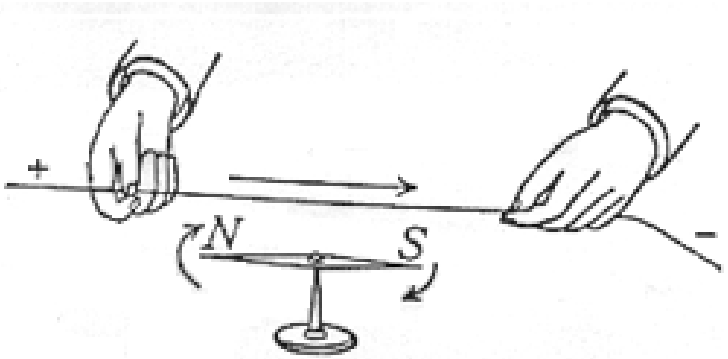
Artefacts in Electrophysiological Measurements



The Physiology of EEG/MEG

MEG first

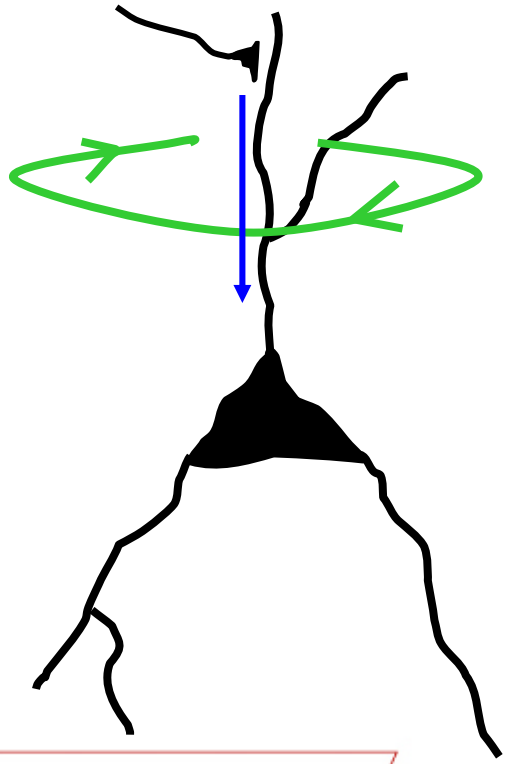
H.C. Ørsted, 1820

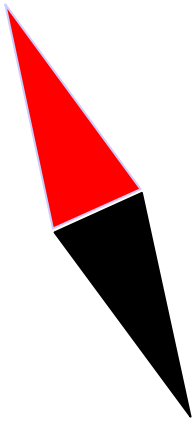


Electrical current deflects a compass

The Physiology of EEG/MEG

Measuring dendritic currents





The Physiology of EEG/MEG

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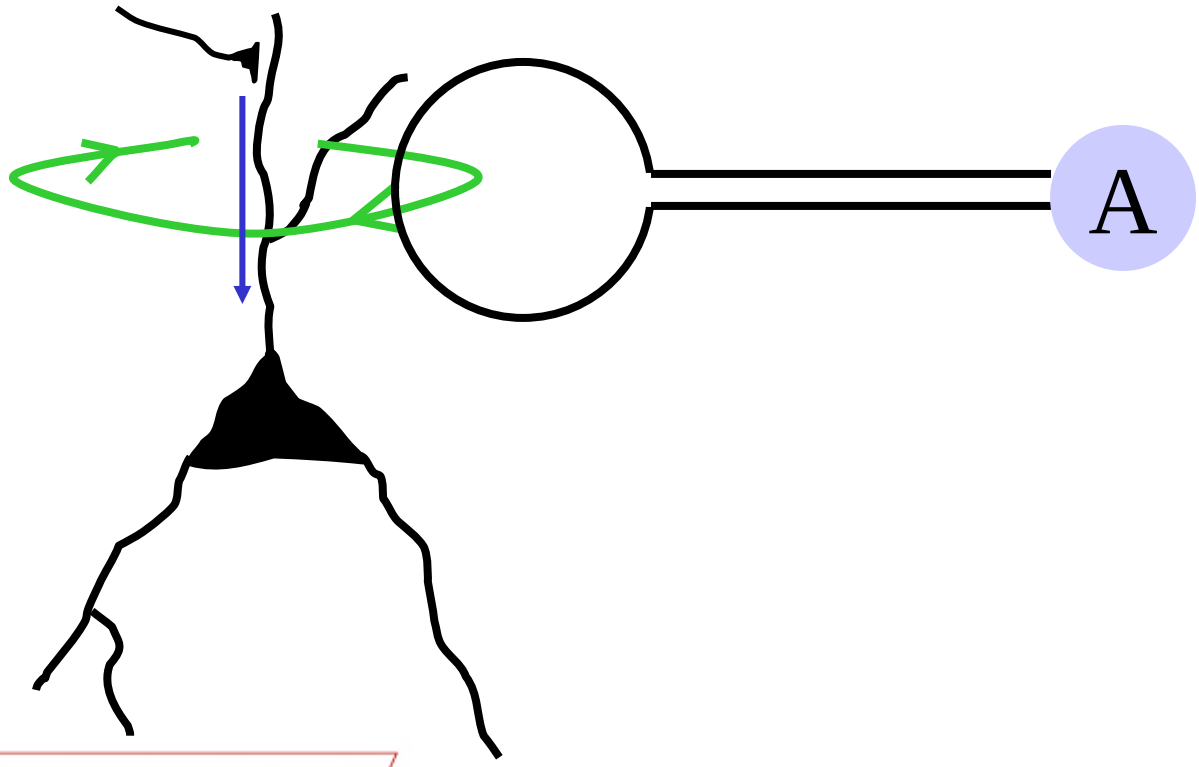
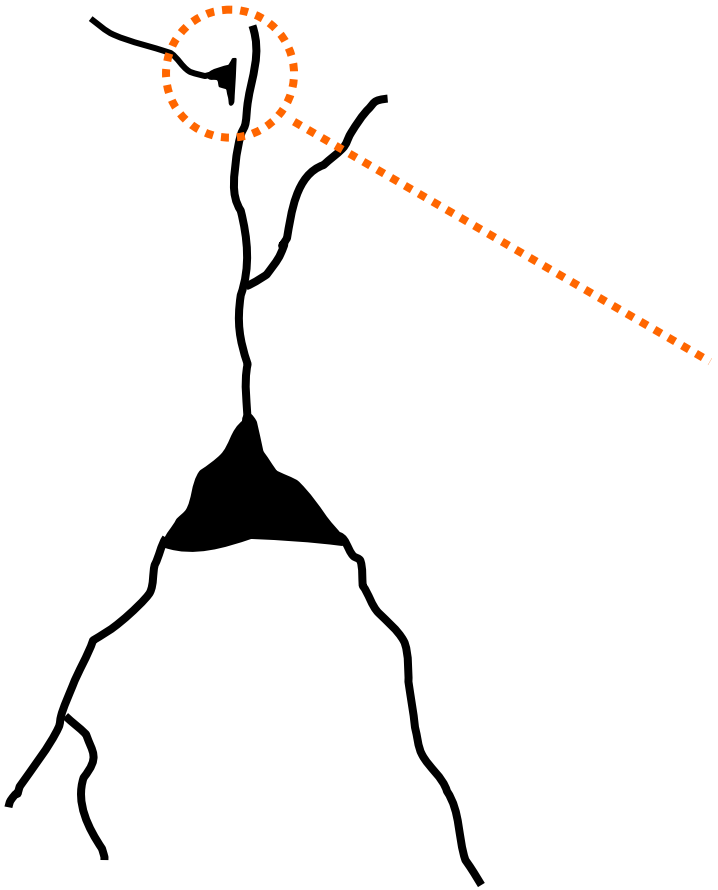
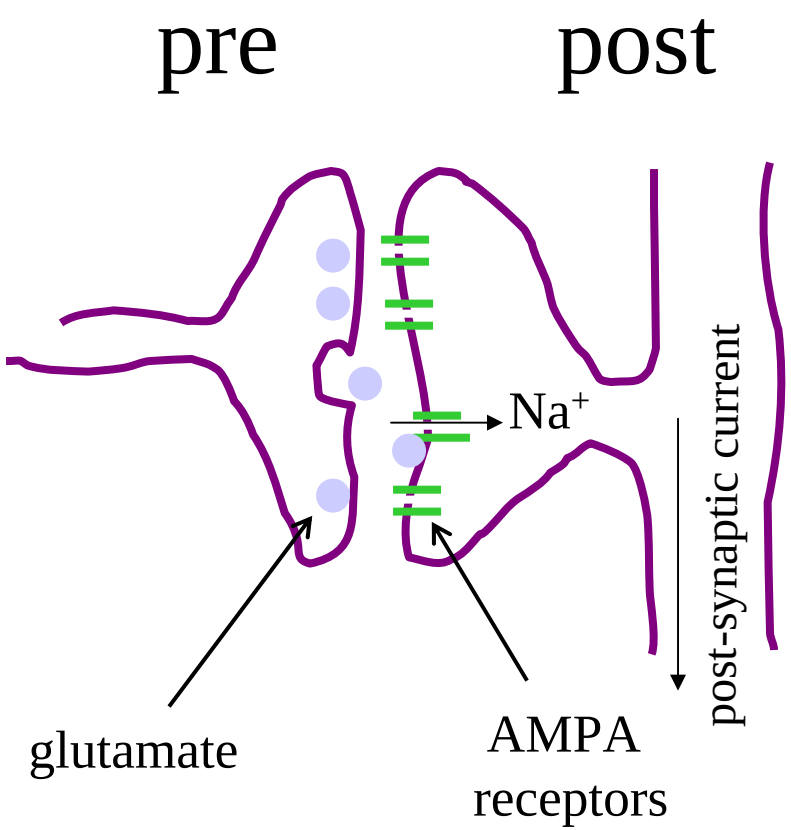


The Physiology of EEG/MEG



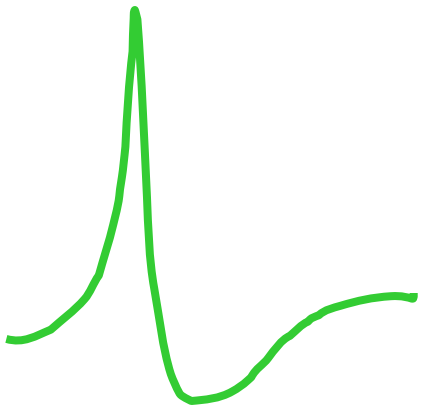


The Physiology of EEG/MEG

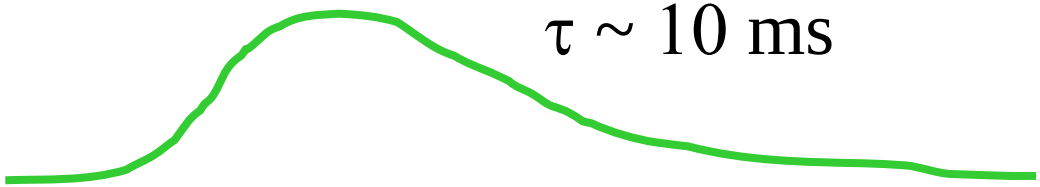
Post-synaptic currents, not action potentials generate the field

~ 2 ms

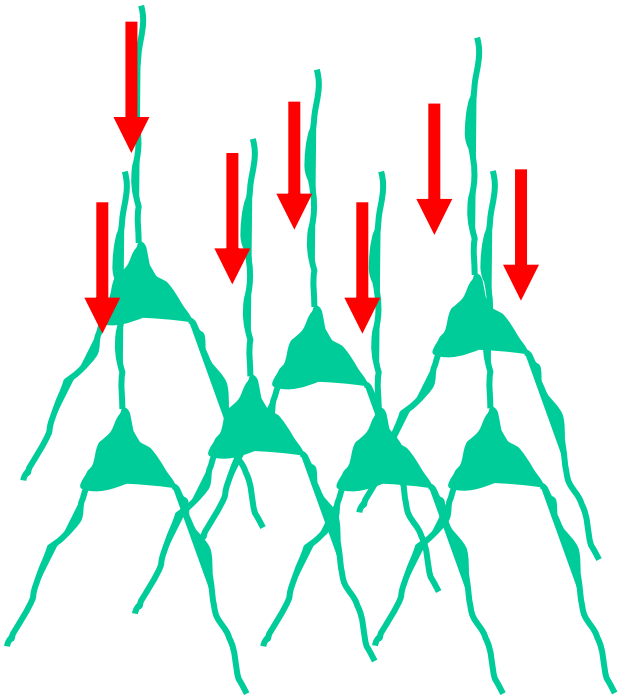
Action potential:



Post-synaptic current:

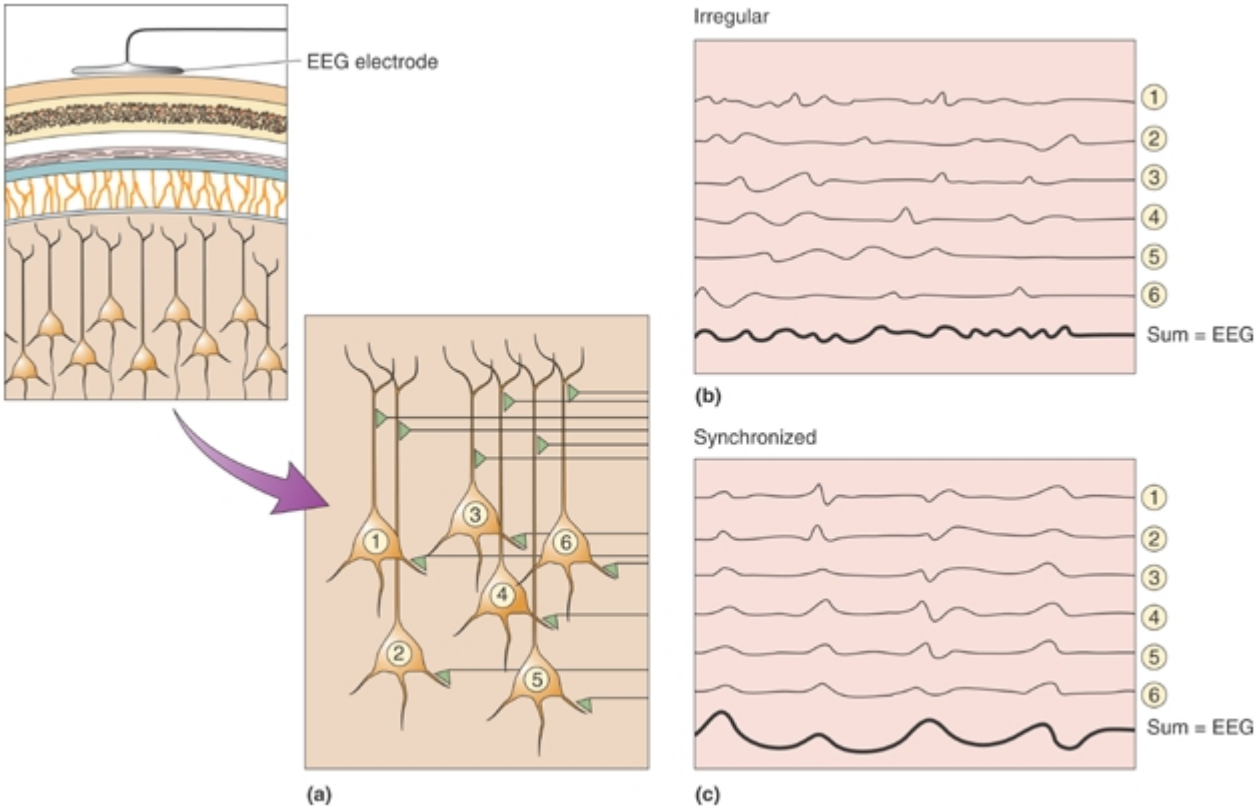


The Physiology of EEG/MEG

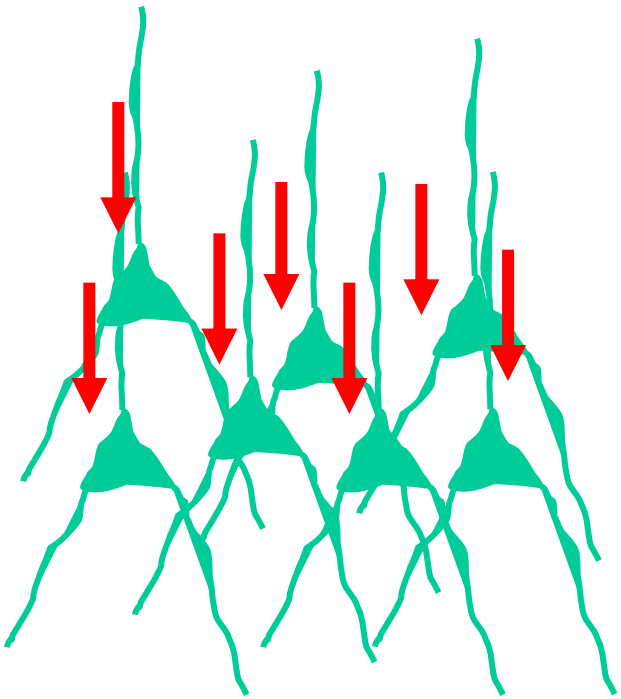


Synchronized activity is required to produce a measurable field

The Physiology of EEG/MEG



The Physiology of EEG/MEG



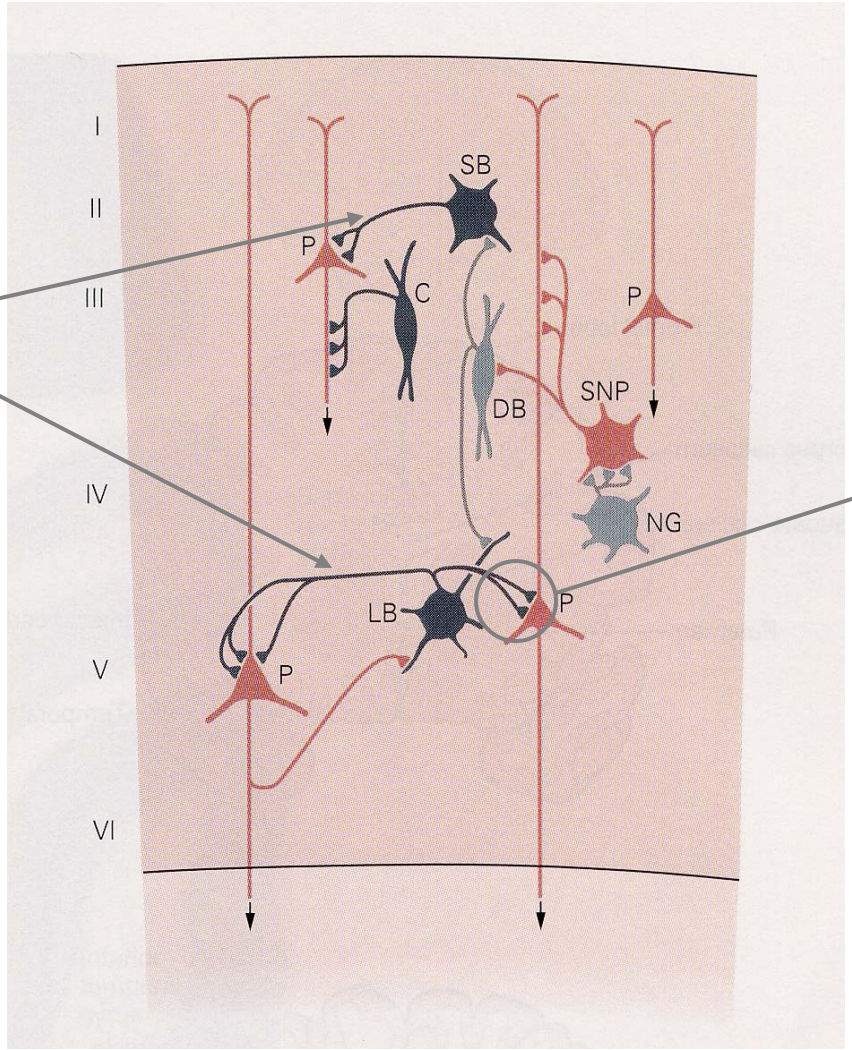
Synchronized activity manifests itself in two ways:

1) Evoked responses (e.g. auditory evoked fields)

2) Spontaneous oscillations (e.g. 9-13 Hz alpha rhythm)

The Physiology of EEG/MEG

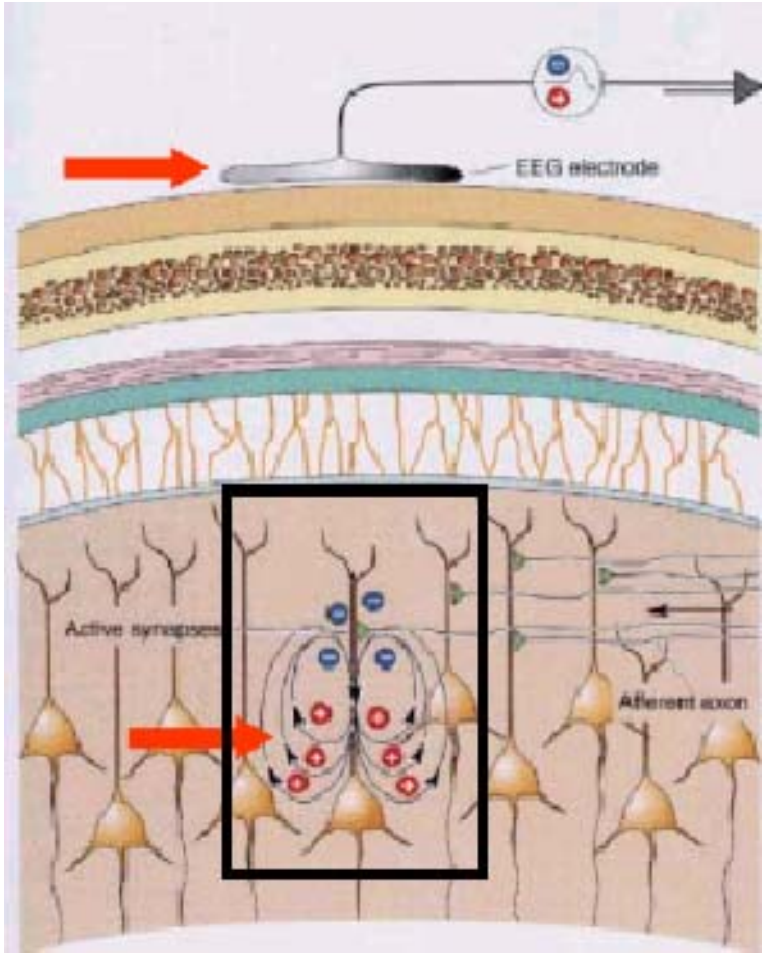
Dendrites of inhibitory neurons are not aligned



Inhibitory synapses close to the soma

Pyramidal neurons generate the field!

The Physiology of EEG/MEG



When the apical dendrites are aligned, then the neurophysiological generator consists of

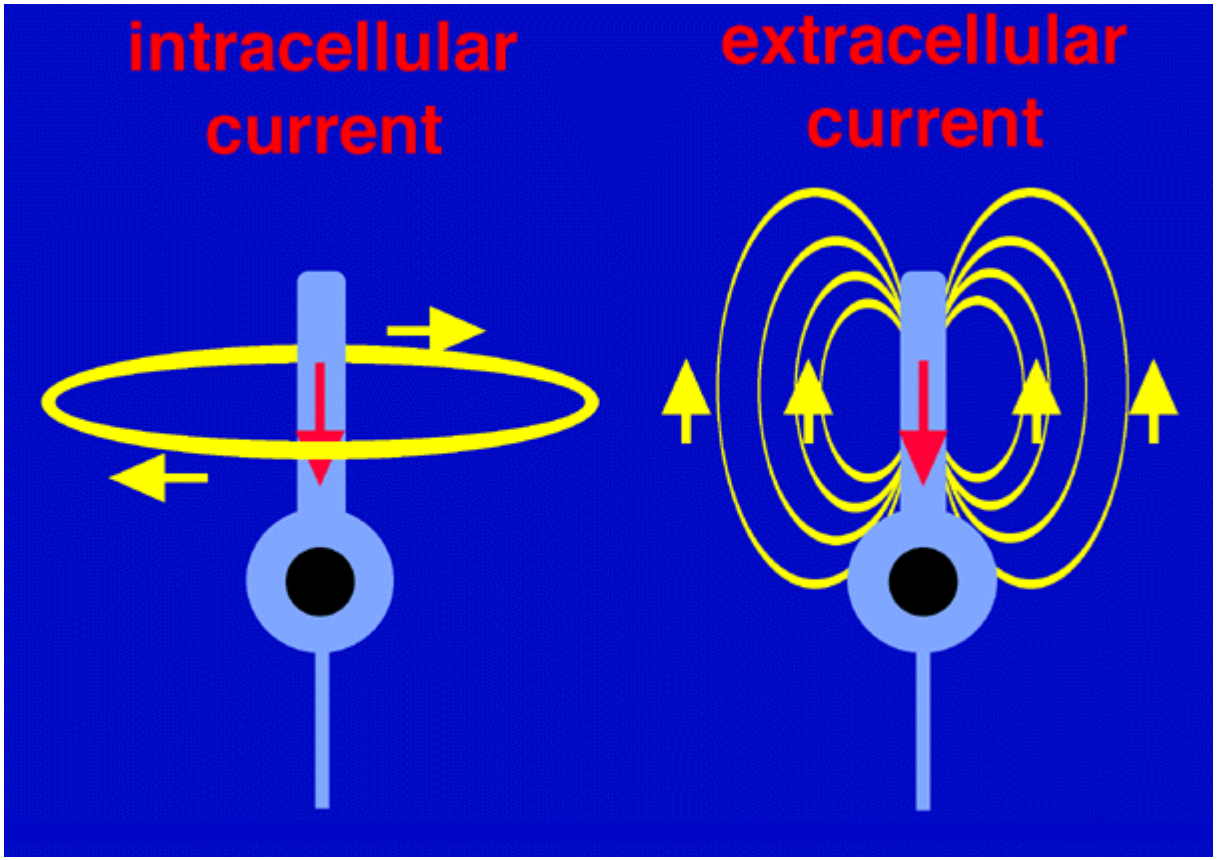
1. a source region
2. a sink region
3. electrical current from source to sink

The *dipole* is a good mathematical model for the current that is produced by this type of generator

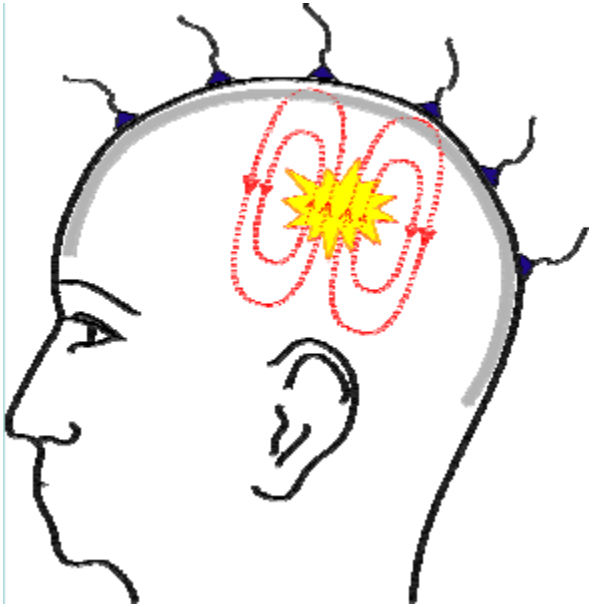
EEG vs MEG

MEG only

EEG and MEG



EEG vs MEG

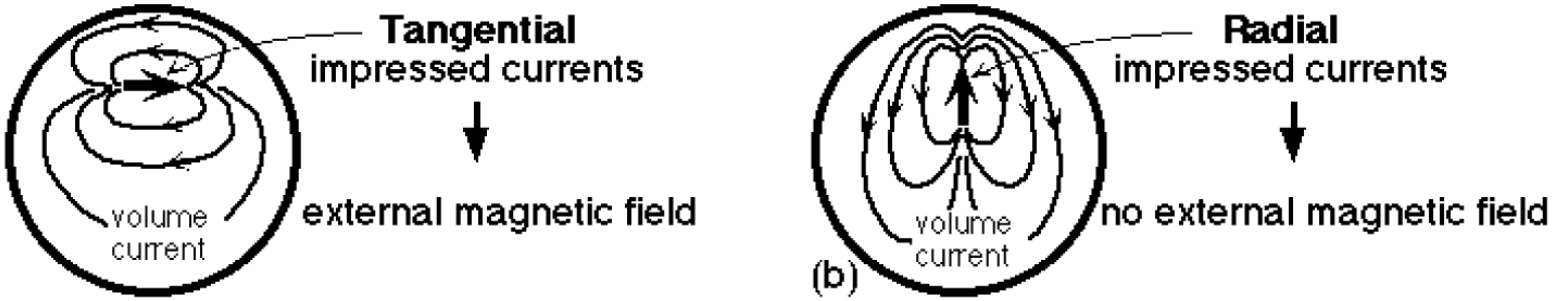


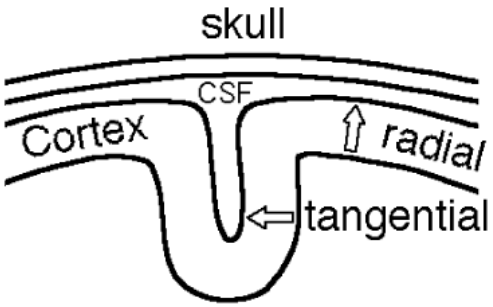
Two components in the EEG/MEG:

1. Primary currents (intracellular) produced by the neural generator
   - in MEG only
2. Secondary currents (extracellular)
   - in EEG and MEG

EEG vs MEG

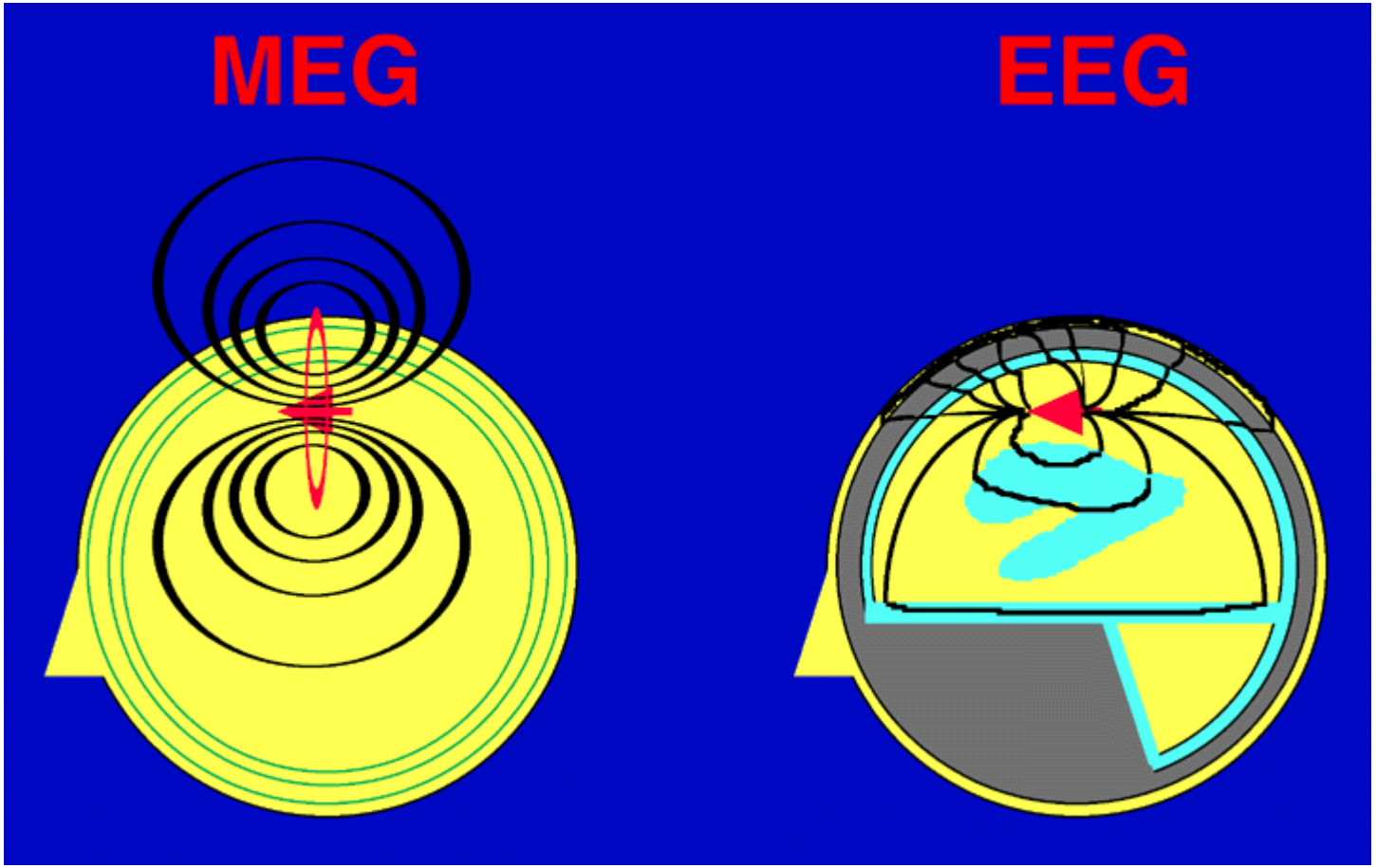
The external magnetic field of a radial source is zero because the magnetic fields of the primary and the secondary currents cancel out.





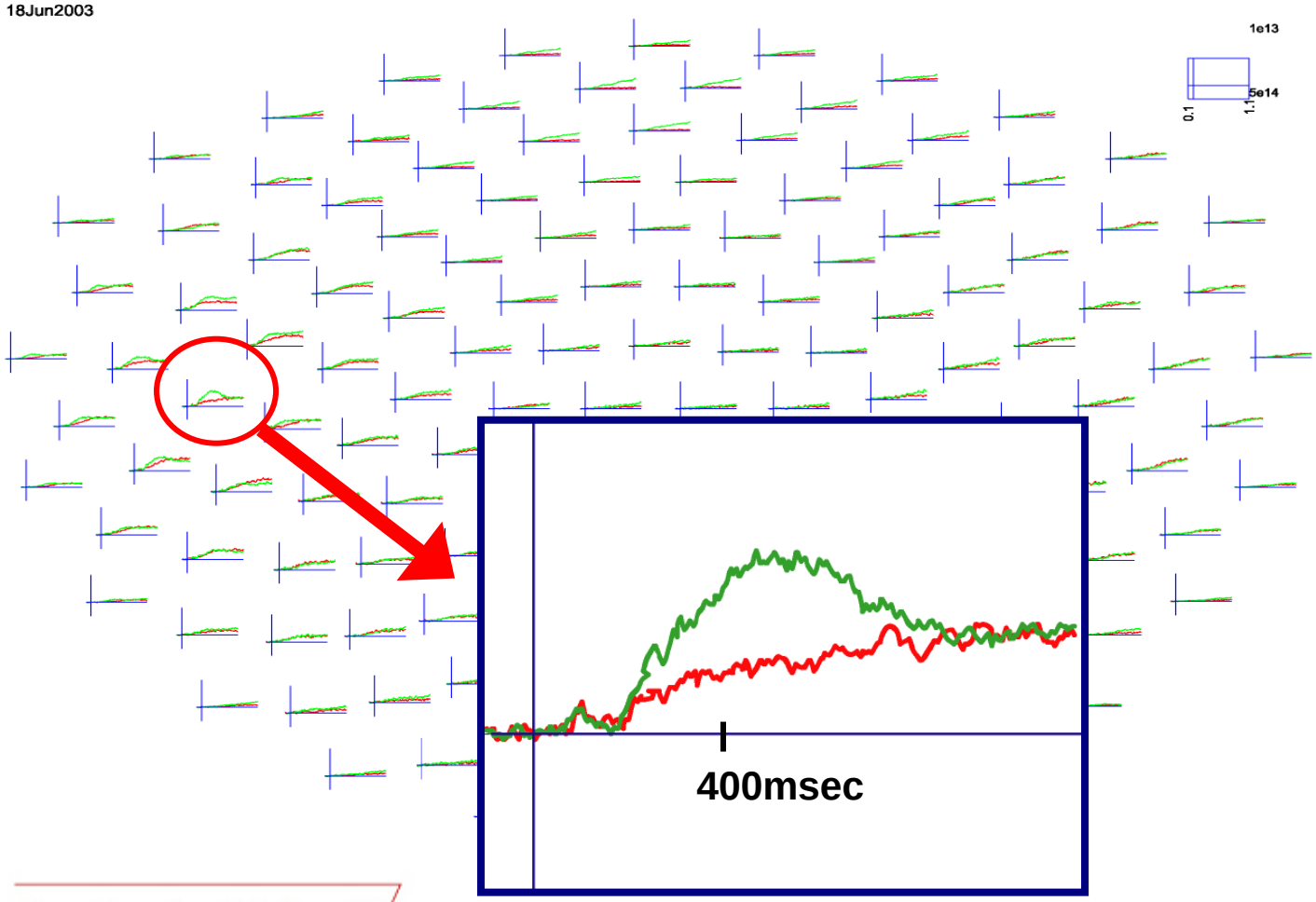
EEG vs MEG

MEG is less spatially smeared than EEG

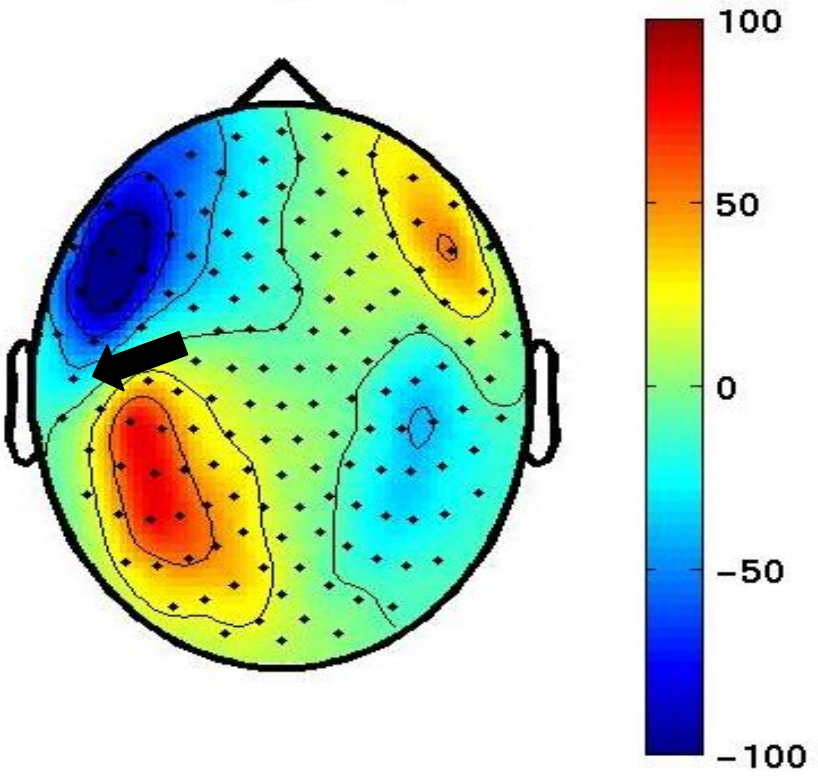


EEG vs MEG

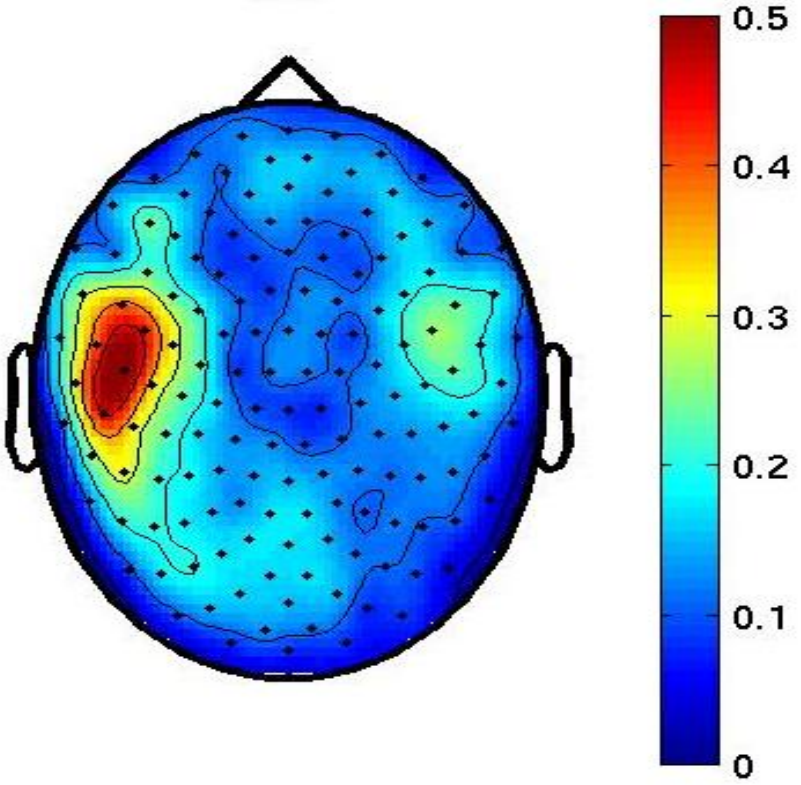
Example: the magnetic N400



EEG vs MEG



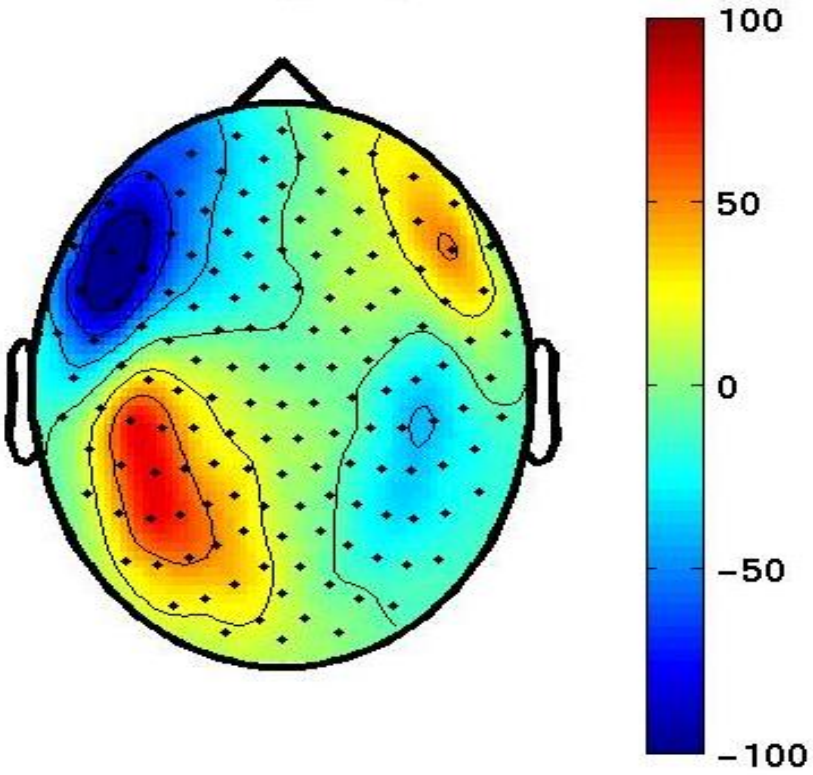
MEG Field map



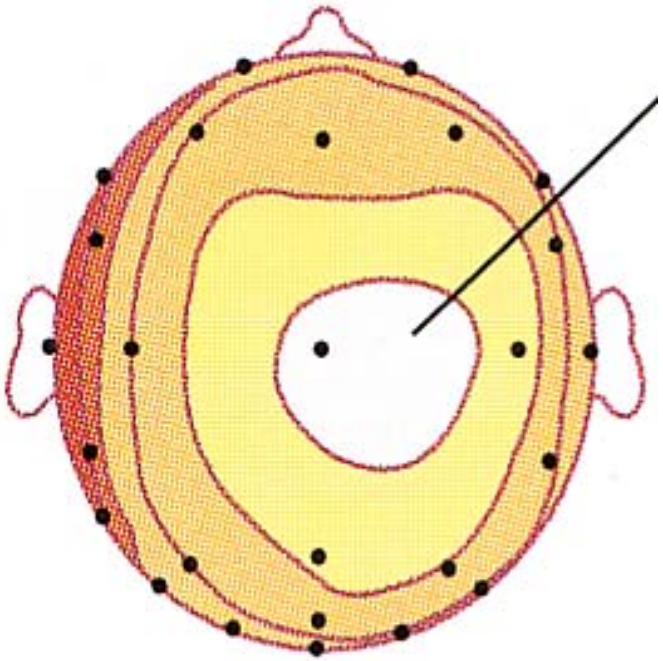
1st order planar gradient

Time: 300 – 500 ms

EEG vs MEG



MEG Field map



ERP Field map

From Extracranial EEG/MEG to the Intracranial Potential Distribution?

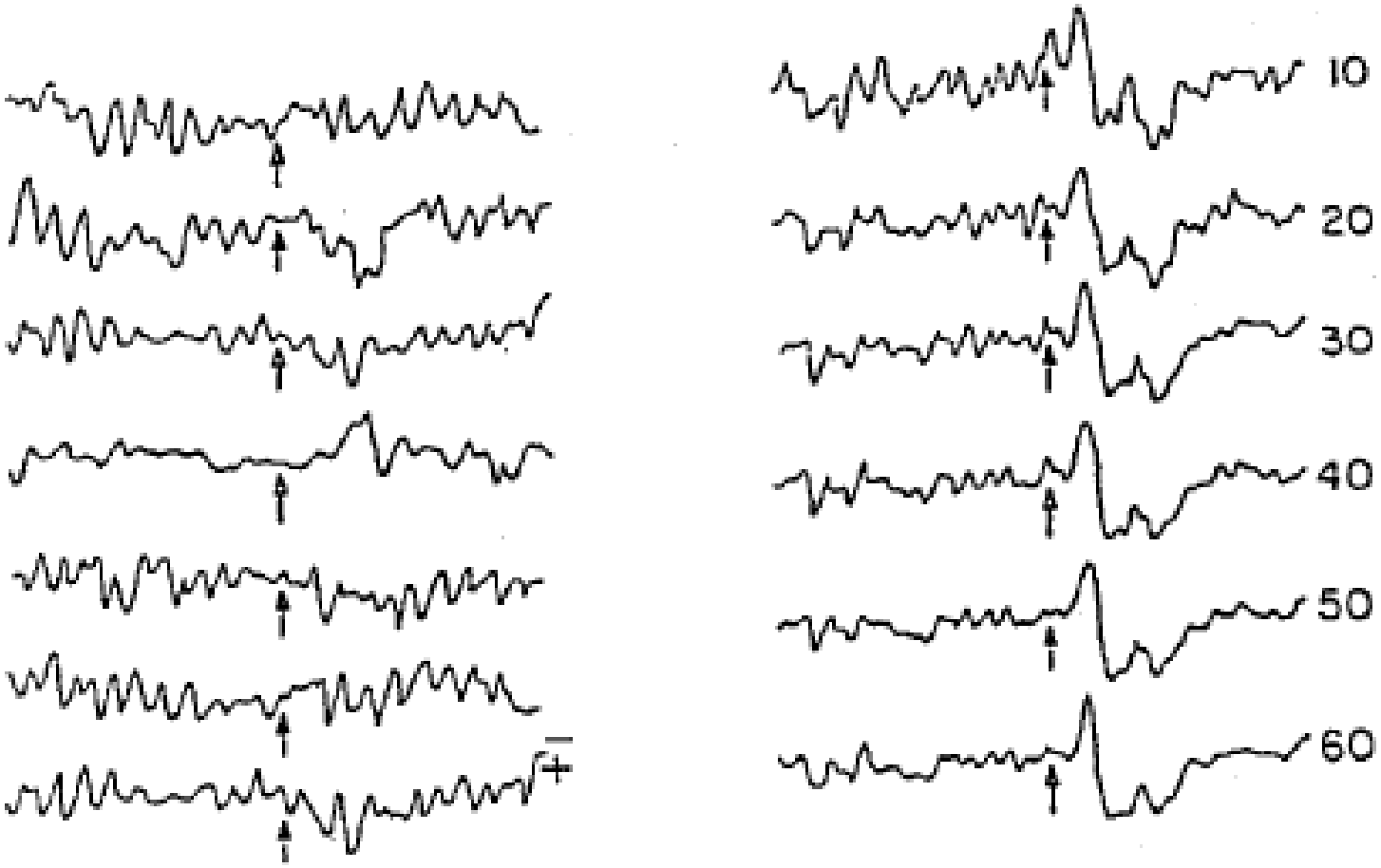
There is an infinite number of current distributions within the head that gives rise to the same external EEG/MEG observation

Hermann Ludwig Ferdinand von Helmholtz

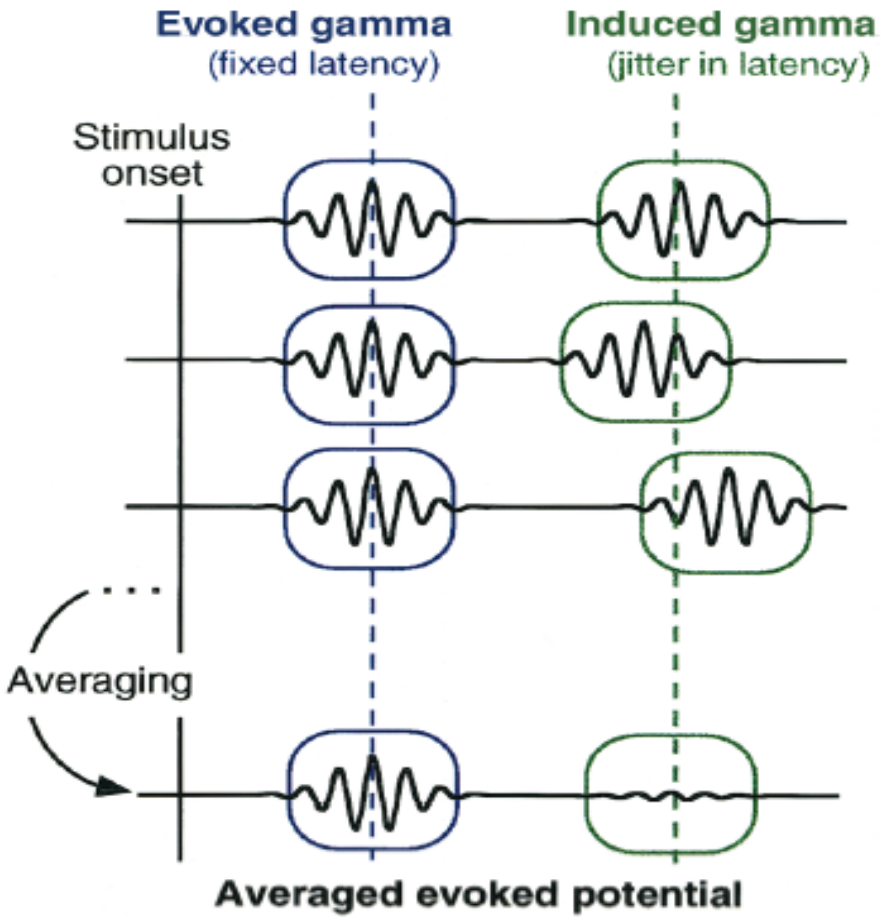
Über einige Gezetze der Verteilung elektrischer Ströme in körperliche Leitern mit Anwendung auf die thierisch-elektrischen Versuche

Pogg Ann Physik und Chemie, 89:211-233, 1853.

Evoked Responses



Induced Oscillations



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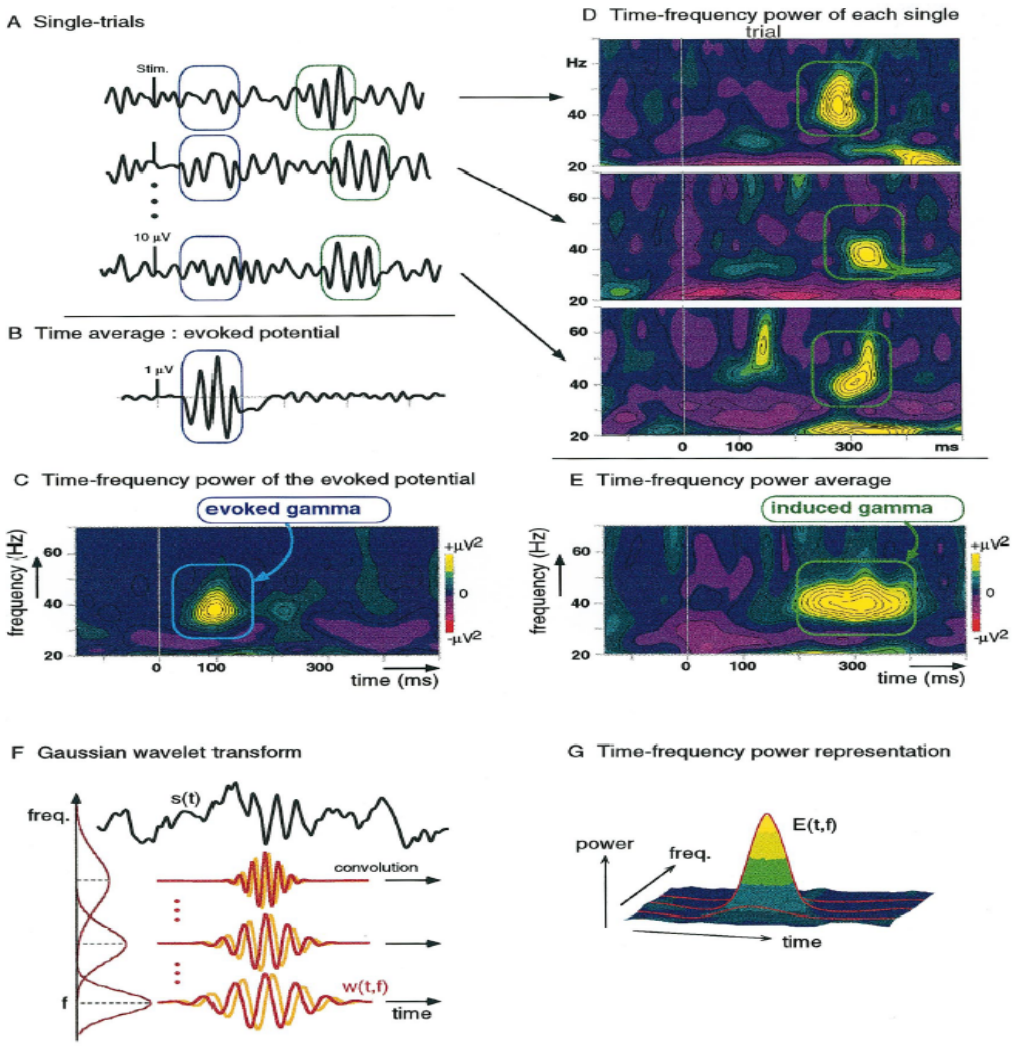

To Remember

- There are four types of electrophysiological data: EEG, MEG, ECoG, and wire electrode recordings
- Electrophysiological data have a *spatial* and a *temporal* dimension
- Electrophysiological data reflect electrical potential distributions in the brain (but not only that!)
- fMRI data reflect haemodynamic processes in the brain

To Remember

- The EEG/MEG is produced by synchronized post-synaptic currents in the pyramidal neurons
- When the apical dendrites are aligned, then the neurophysiological generator of the EEG/MEG can be modeled as a current dipole
- MEG measures both primary and secondary currents, whereas EEG measures only secondary currents

To Remember

- MEG is less spatially smeared than EEG
- There is an infinite number of current distributions within the head that gives rise to the same external EEG/MEG observation (von Helmholtz, 1853)
- Evoked responses are obtained by time-locked averaging (to stimulus- or response onset) of the raw EEG/MEG

To Remember

- Induced oscillations are obtained by convolving the raw EEG/MEG with a filter that passes the signal components in a particular frequency band