MRC Cognition and Brain Sciences Unit

UNIVERSITY OF CAMBRIDGE

EEG/MEG 1:

History, Measurement, Signal Generation

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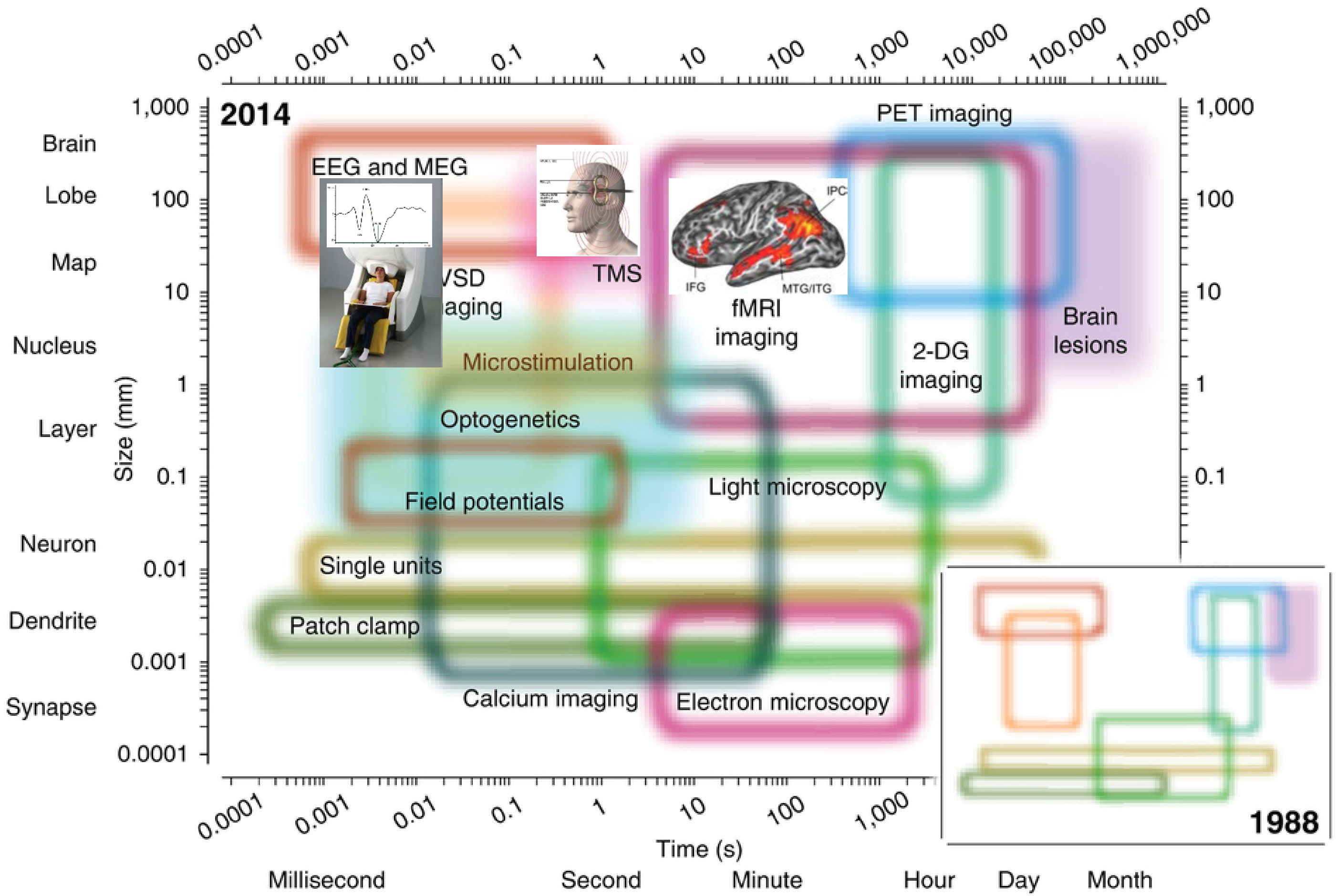
COGNESTIC 2022

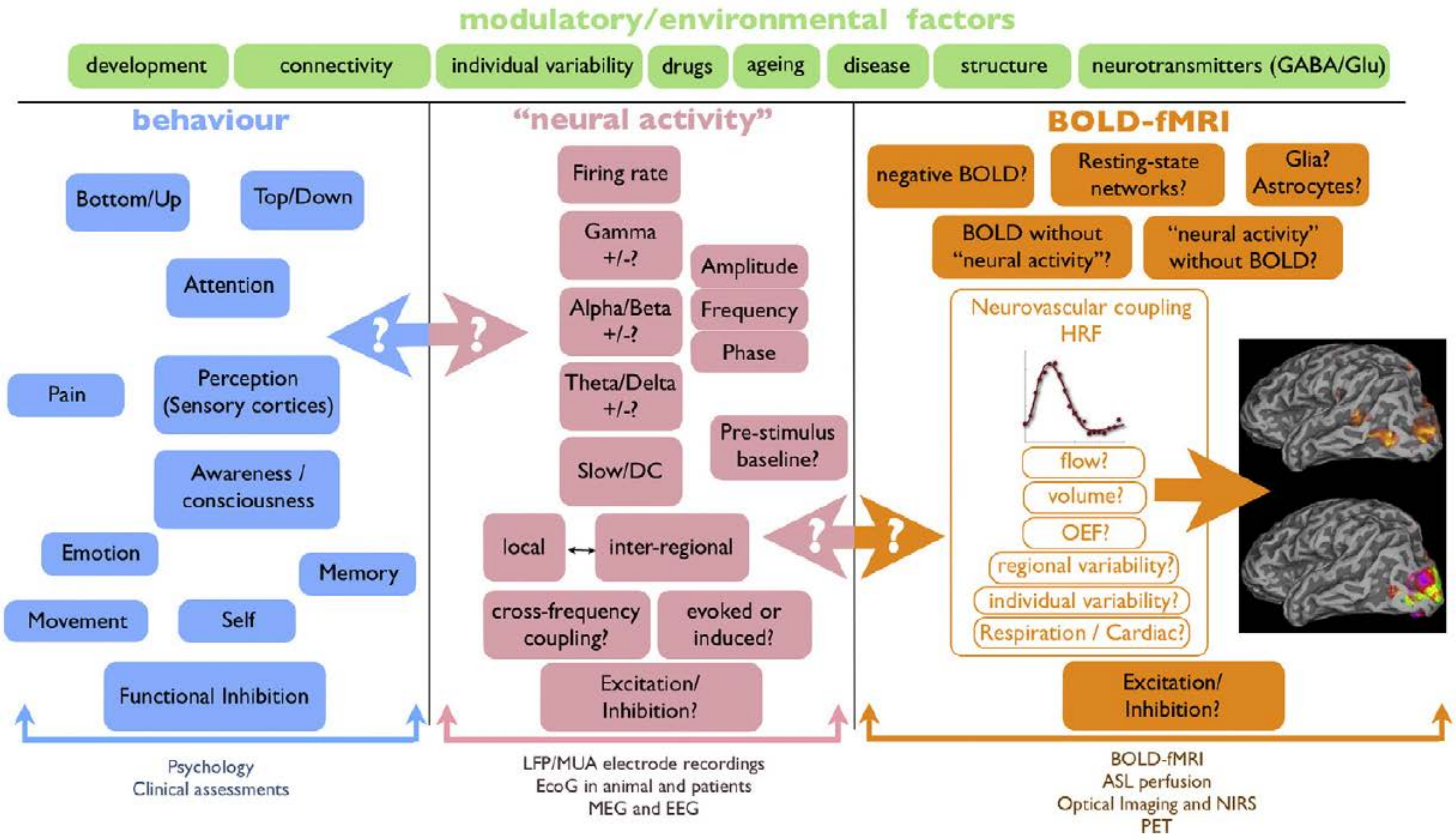
Neuroimaging Methods Vary With Respect To Spatial and Temporal Resolution

(and their invasiveness, physiology, etc.)



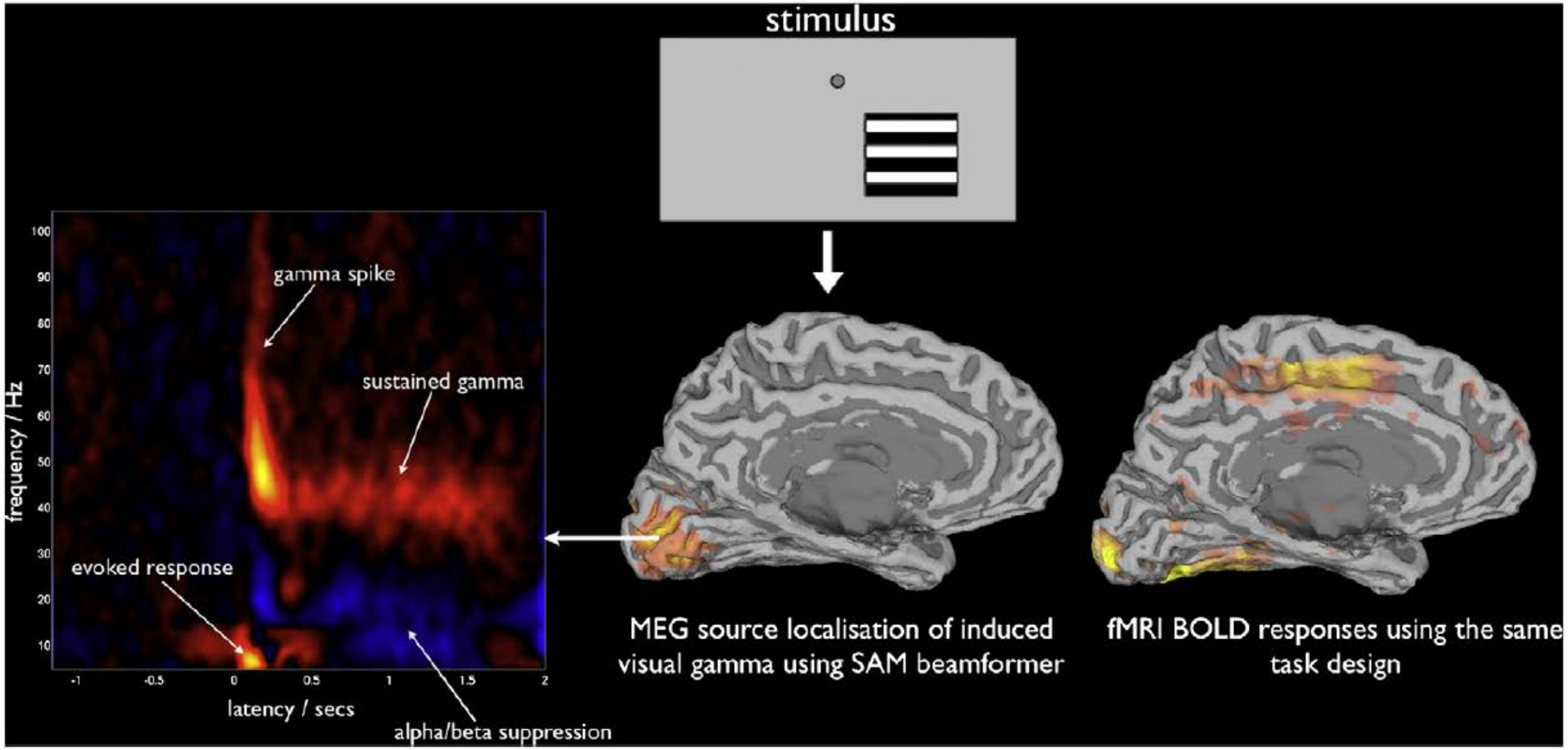
Seijnowki, Churchland, Movshon, Nat Nsc 2014

Which “Neural Activity” Do You Mean?



Singh, NI 2012

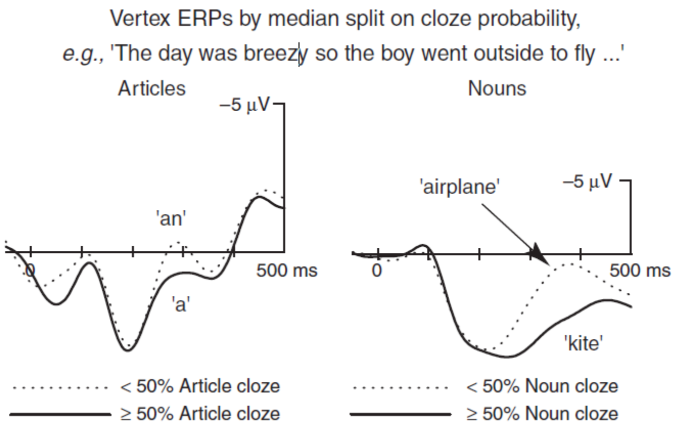
Which “Neural Activity” Do You Mean?



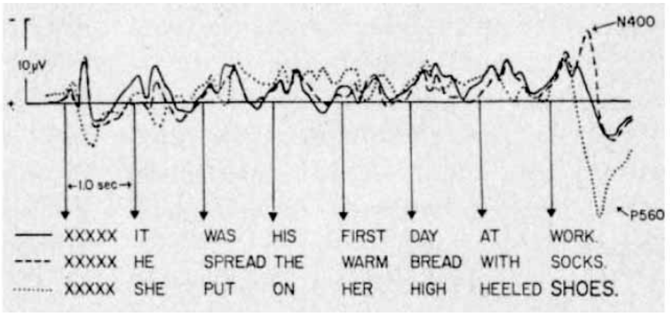
Singh, NI 2012

EEG/MEG “Activity” Can Be Analysed In A Number Of Ways, e.g.

Event-Related Potentials

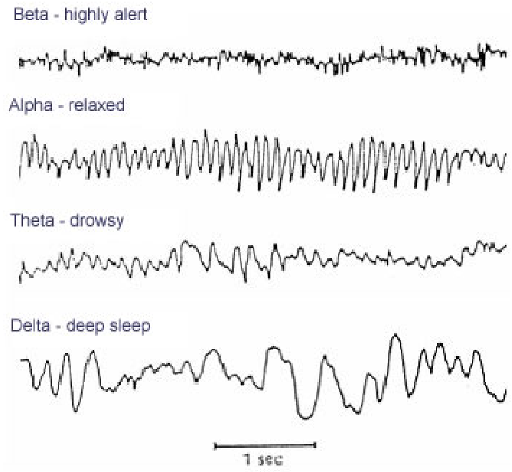


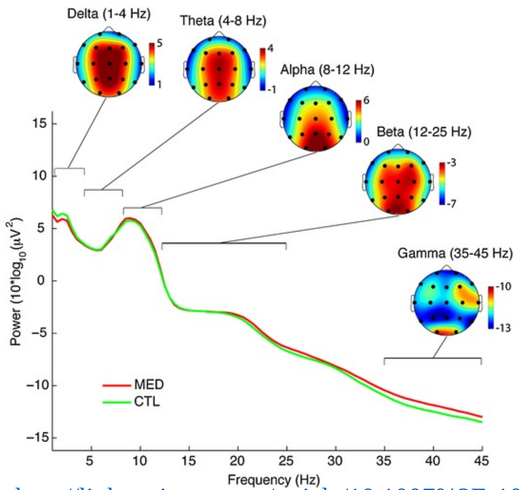
deLong, Urbach, Kutas, Nat Nsc 2005



Kutas&Hillyard, Science 1980

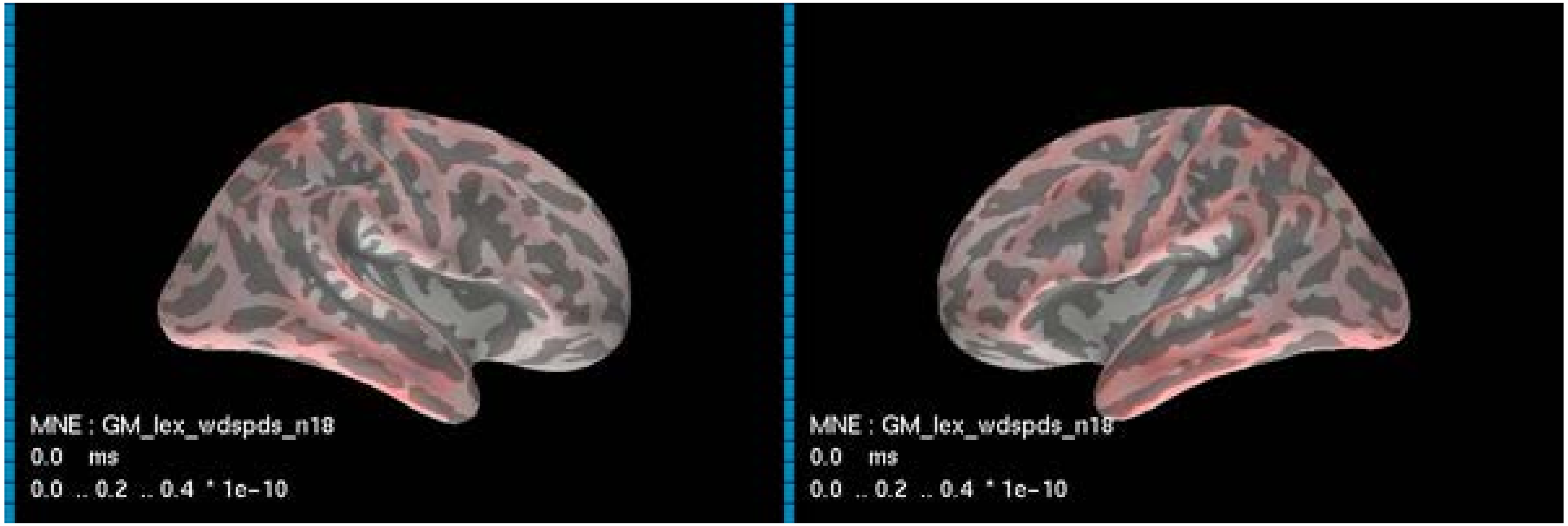
Brain “Rhythms”/”Oscillations”





http://link.springer.com/article/10.1007%2Fs10339-009-0352-1/

What We Really Want:
Spatio-Temporal Brain Activity
(Movies rather than pictures)



EEG/MEG Literature

Books:

- Supek & Aine: “Magnetoencephalography (2nd)”, Springer 2019
- Ilmoniemi & Sarvas: Brain Signals – Physics and Mathematics of MEG and EEG”, MIT 2019
- Hari R, Puce A. “MEG-EEG Primer”. Oxford University Press 2017.
- Sekihara & Nagarajan: “Electromagnetic Brain Imaging”, Springer 2015.
- Cohen, Mike X; “Analyzing Neural Time Series Data”; MIT Press 2014.
- Hansen, Kringelbach, Salmelin: “MEG: An Introduction to Methods”, OUP 2010.
- Sekihara & Nagarajan: “Adaptive Spatial Filters For Electromagnetic Brain Imaging”. Springer 2008.
- SJ Luck: “An Introduction to The Event-Related Potential Technique”, MIT 2005.
- TC Handy: “Event-Related Potentials”, MIT 2004.
- http://imaging.mrc-cbu.cam.ac.uk/meg/IntroEEGMEG

Guidelines for MEG and EEG research:

- Gross et al., “Good practice for conducting and reporting MEG research.“, Neuroimage 2013.
- Picton et al., “Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria.“, Psychophysiology 2000.

Demos of some open software packages:
https://www.frontiersin.org/research-topics/5158/from-raw-megeeg-to-publication-how-to-perform-megeeg-group-analysis-with-free-academic-software

Plus software tutorials, online talks, etc. etc.
Plus specialised papers etc. etc.

A Brief History Of Bioelectromagnetism

Ancient Egypt, 2750 BC:

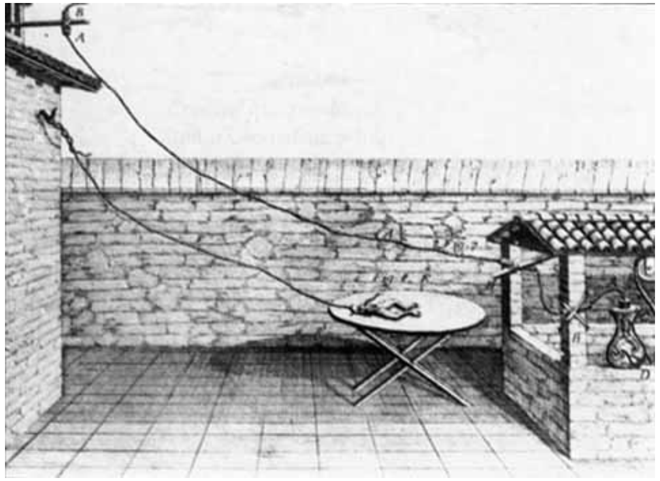
Electric Fish ("Thunderer of the Nile")
Some Roman writers mention electric shocks as an ailment for headaches (~ 0 AC)...

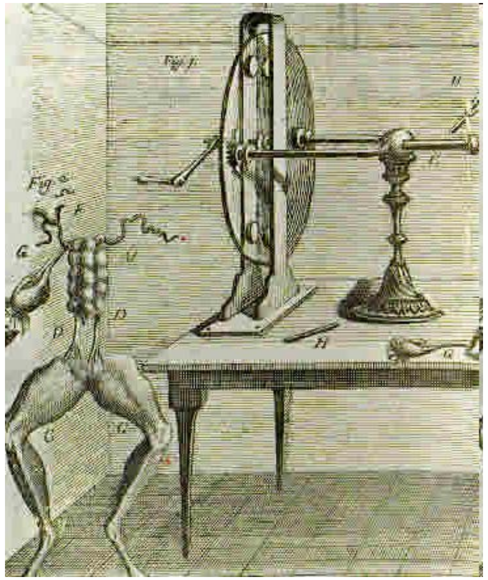
Ancient Greece, 600 BC:

Thales describes static electricity
"electron"

Early Science

1771
Luigi Galvani, Bologna
“animal electricity”

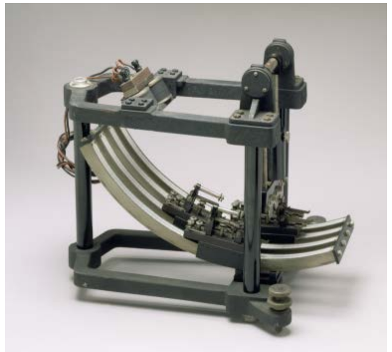




In 1803:
“On the first application of the process to the face, the jaws of the deceased criminal began to quiver, and the adjoining muscles were horribly contorted, and one eye was actually opened. …
Mr Pass, the beadle of the Surgeons’ Company, who was officially present during this experiment, was so alarmed that he died of fright soon after his return home.”
http://www.executedtoday.com/2009/01/18/1803-george-foster-giovanni-aldini-galvanic-reanimation/

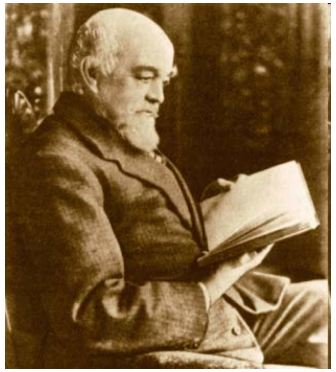
Early Electrophysiology

1842: Du Bois-Reymond, Berlin
nerve action potentials neurons



1852: Helmholtz, Berlin
speed of action potentials in frogs neurons

1875: Richard Caton, Liverpool
first "ECoG" from animals



http://www.sciencemuseum.org.uk/broughttolife/objects/display.aspx?id=4360

Early EEG

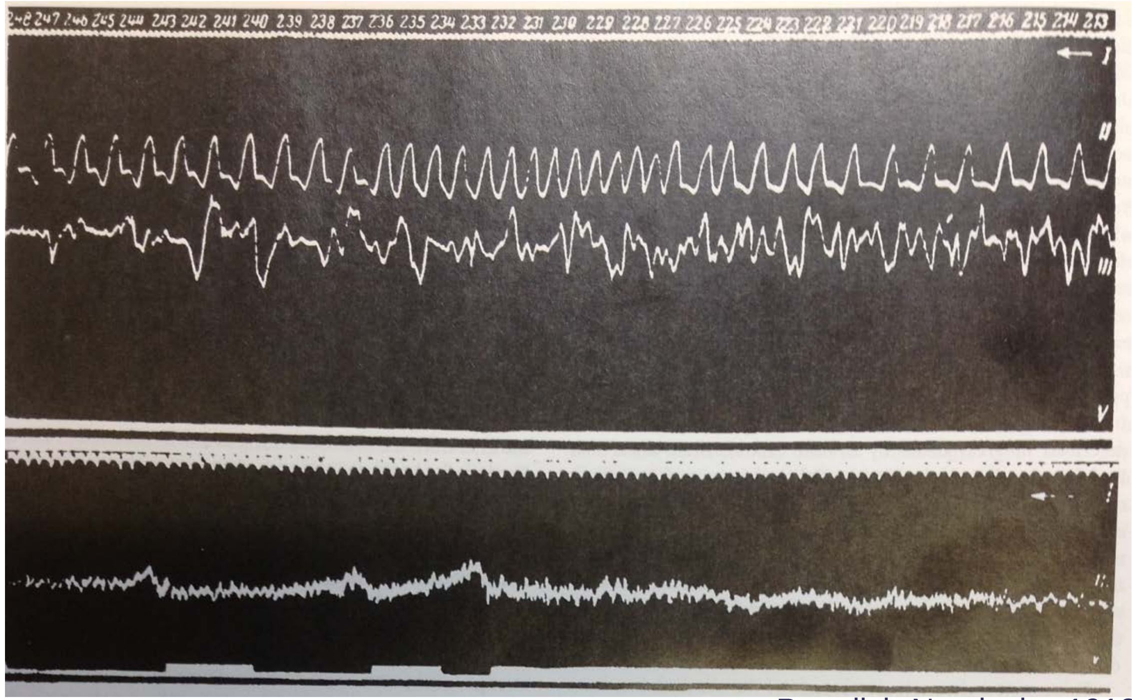
Time marker

Artery pulsation

Brain potential

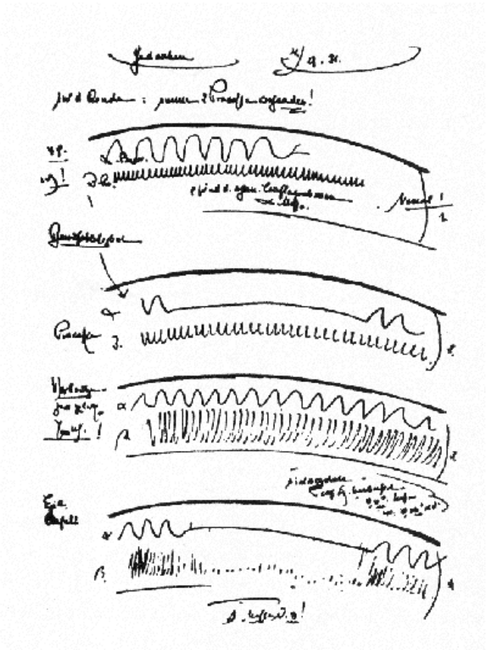
Response to sciatic nerve stimulation

Stimulation signal



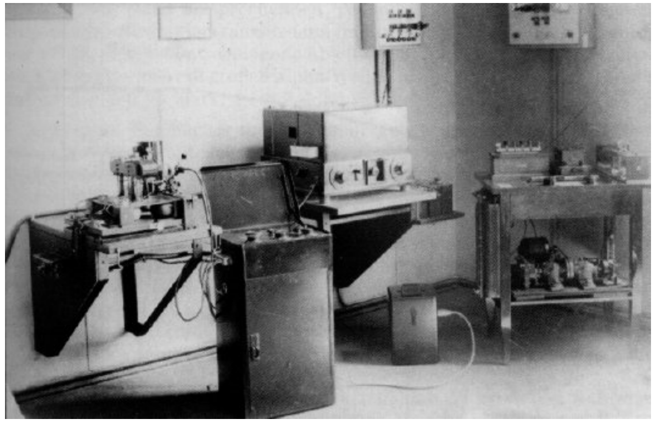
Pravdich-Neminsky, 1913

Early EEG

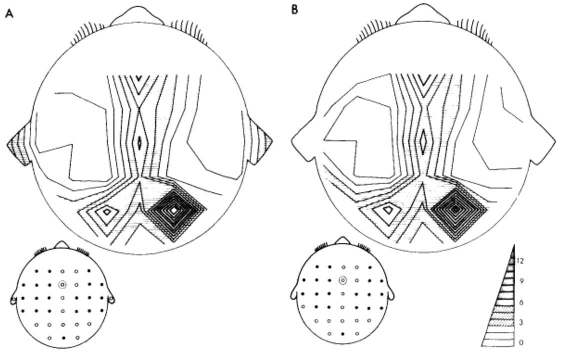


Hans Berger, Jena 1924

First Fourier Analysis of EEG: Berger&Dietsch 1931



1969/70: 32/48-channel EEG, “generators”



Lehmann, 1971

Early ERPs

A summation technique for detecting small signals in a large irregular background. By G. D. Dawson. *Neurological Research Unit, Medical Research Council, National Hospital, Queen Square, London, W.C.* 1

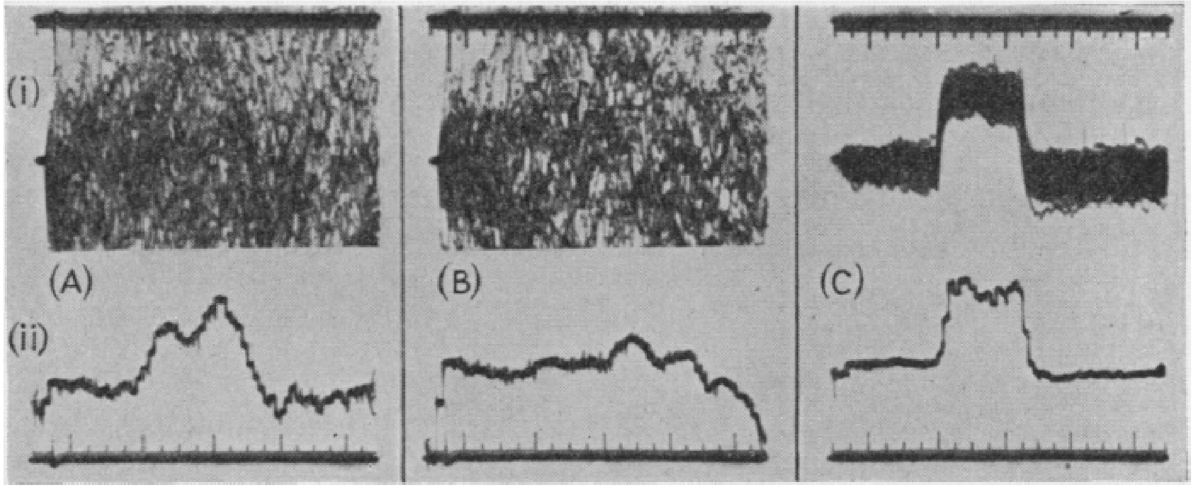


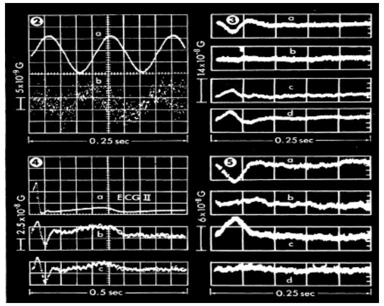
Fig. 1. An experiment to detect cerebral responses when the left ulnar nerve was stimulated at the wrist once per second. The upper line of traces shows sets of 55 records superimposed and the lower line the averages of these given by the machine. In A, from the contralateral scalp, there was one electrode on the midline and one over the right central sulcus. In B, from the ipsilateral scalp, the record was taken from the same midline electrode and one over the left central sulcus. In C is shown the result of making the electrode over the central sulcus positive to that on the midline by 5 μV. The largest spikes in the time scales show intervals of 20 msec., and the stimulus was applied 5 msec. after the start of each sweep.

Dawson, Proceedings of the Physiological Society, 1951

First MEG: Pre-SQUID age

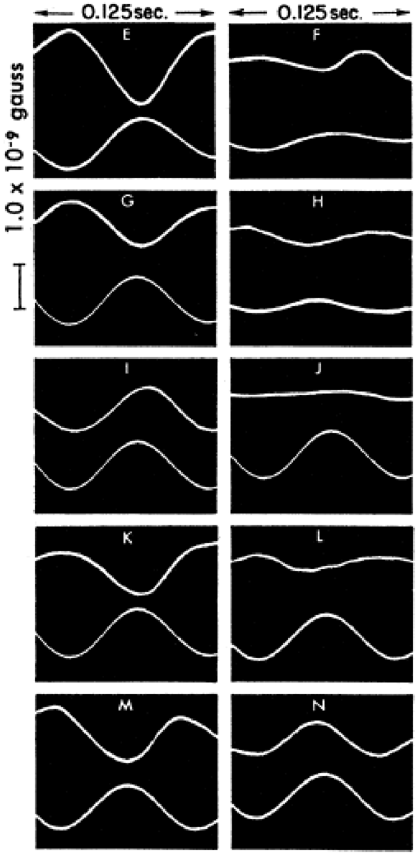
MEG pioneers MIT

MCG, 1967/(63)



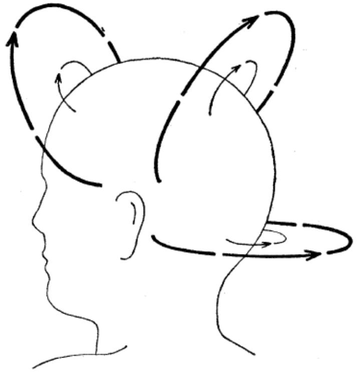
Cohen, Science 1967

MEG, 1968



Cohen, Science 1968

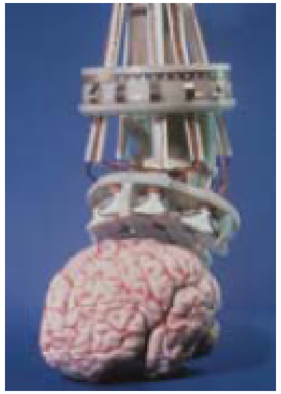
Alpha Rhythm



The Fast Evolution of MEG

1983
by HUT
4 channels
30 mm in diameter
(coverage: 7 cm^2)
Axial

1986
by HUT
7 channels
93 mm in diameter
(coverage: 68 cm^2)
Axial



1989
by HUT
24 channels
125 mm in diameter
(coverage: 123 cm^2)
Planar

1991
by Neuromag
122 channels
whole head
(coverage: 1100 cm^2)
Planar
12 Deliveries

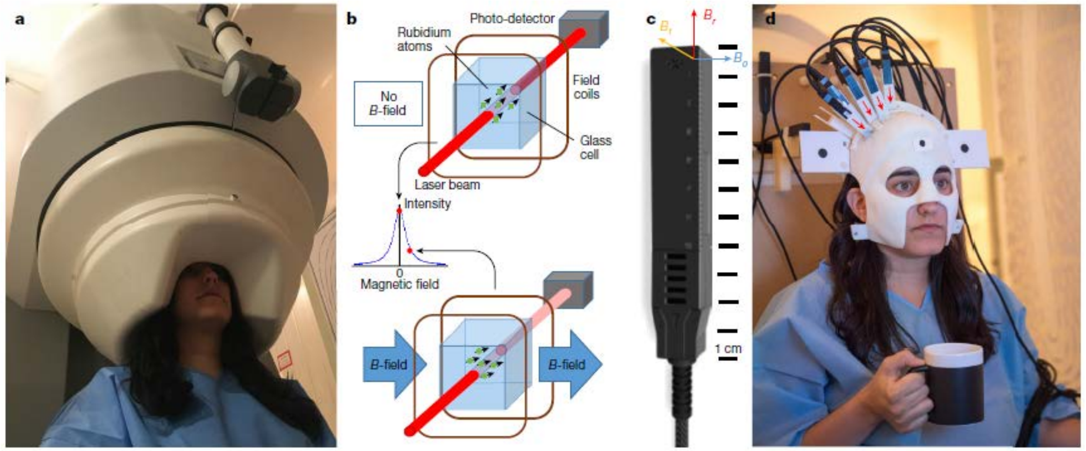
1997
by Neuromag
306 channels
whole head
(coverage: 1220 cm^2)
Planar &
Magnetometers

MEG – The Present

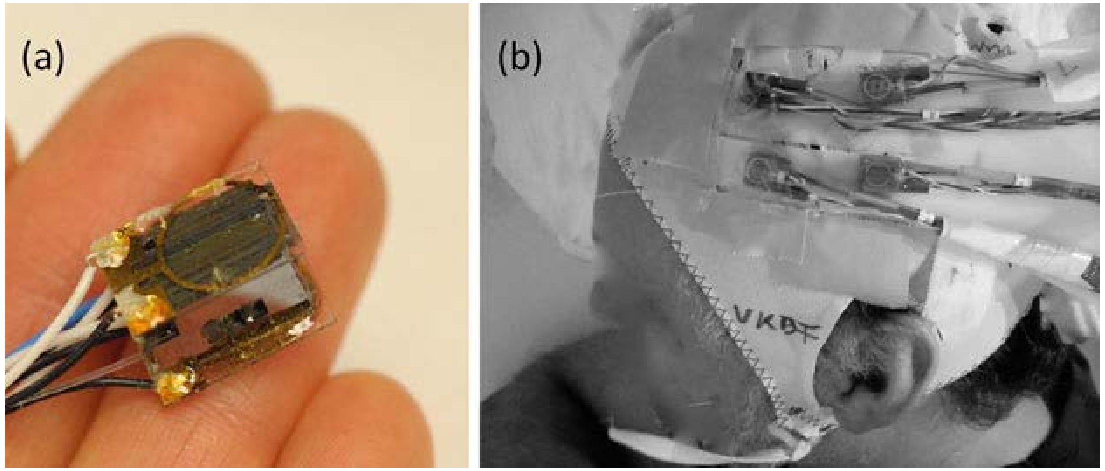
e.g. MEGIN Triux System
306 MEG sensors (102 magnetometers, 204 gradiometers)
64 EEG electrodes

MEG – The (Near) Future

On-Scalp Optically Pumped Magnetometers



https://twitter.com/wellcometrust/status/976534659436703744 Boto et al., Nature 2018

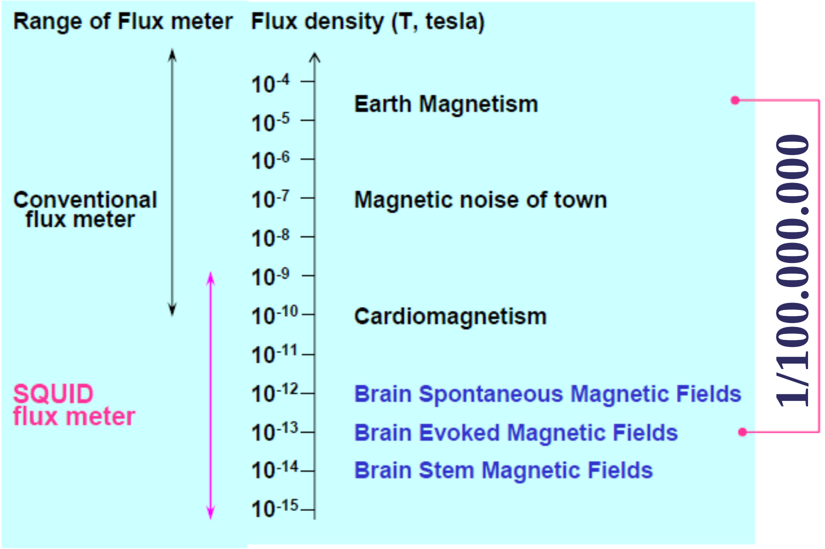


Knappe, Sander, Trahms, chapter in “Magnetoencephalography” by Supek & Aine (edts)

The Measurement Of EEG/MEG Signals

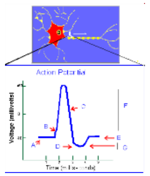
What EEG/MEG Are Measuring

Magnetoencephalography (MEG)



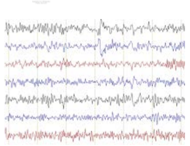
Electroencephalography (EEG)

Household Batteries
~ 1-12 V



Cell Membrane Potentials
~ 70 mV

ECG:
~ 1mV

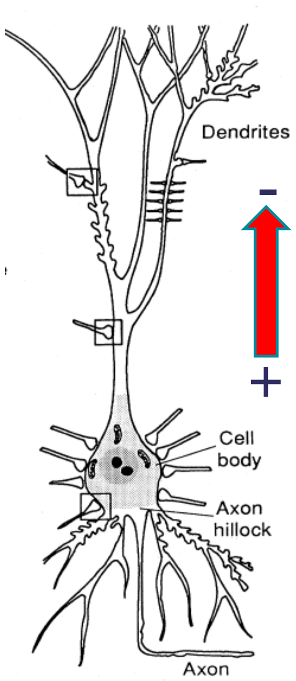


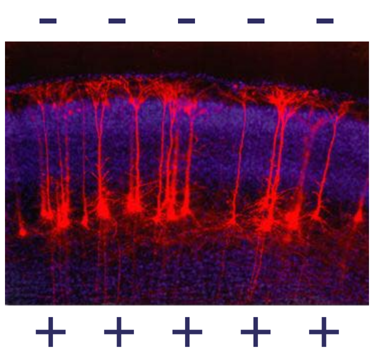
Raw EEG: ~ 30 μV
Eye blinks: > 100 μV

ERPs: ~ 0-10 μV

Main Generators of Electrical Activity in the Brain

- **Apical dendrites of pyramidal cells**
- **NOT action potentials** (too short-lived and quadrupolar)
- **EEG/MEG: same generators, different sensitivity**





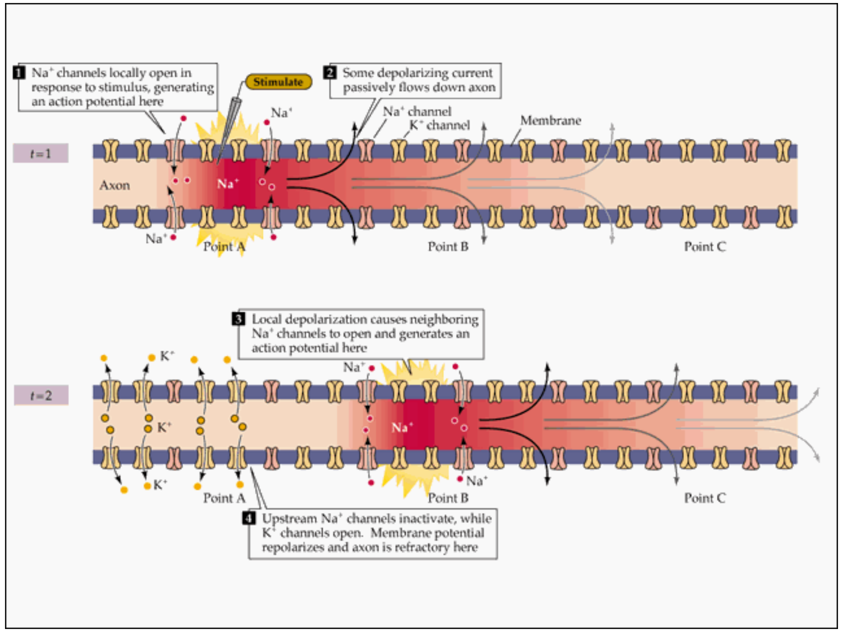
Dipolar currents

- ~ 1 Million synapses needed to activate simultaneously
- Luckily: ~10000 cells per mm^2, ~ 1000 synapses per cell

=> several mm^2 can produce measurable signal

EEG/MEG Are Mostly Insensitive To Action Potentials

Action potentials are caused by active cellular mechanisms,
not passive “Ohmic” currents.
(Very different speeds)



http://www.arts.uwaterloo.ca/~bfleming/psych261/lec4se21.htm

Action potentials are quadupolar

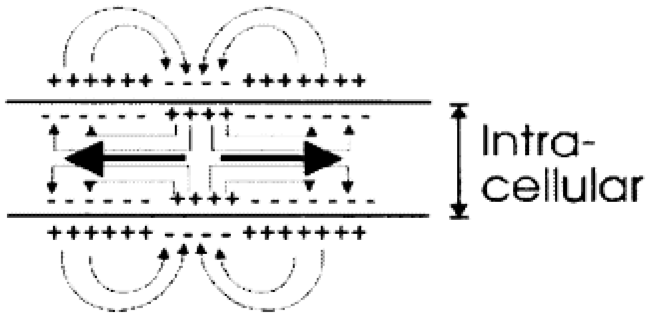


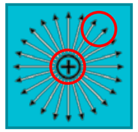
Figure I.1: *Schematic representation of an action potential*
Wieringa thesis, http://www.medcat.nl/megeeg/chap1.htm

Currents due to action potentials are very short-lived and asynchronous as well as “quadrupolar” (i.e. two opposing dipoles).

The Physics of EEG/MEG:
Quasi-Static Approximations of Maxwell’s Equations

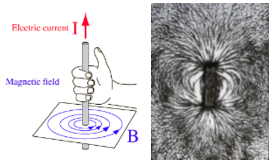
- The summed electric flux around a close surface is proportional to the total electric charge enclosed within this surface (Gauss’s Law)

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0} = 0 \; (for\ dipoles)$$



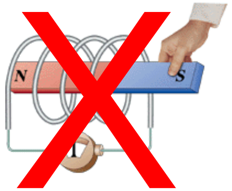
- *Magnetic field lines are closed (Gauss’s Law for magnetism)*

$$\nabla \cdot \boldsymbol{B} = 0$$



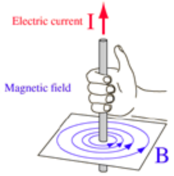
- *We do not consider any inductive effects (Faraday’s Law):*

$$\nabla \times \boldsymbol{E} = 0$$



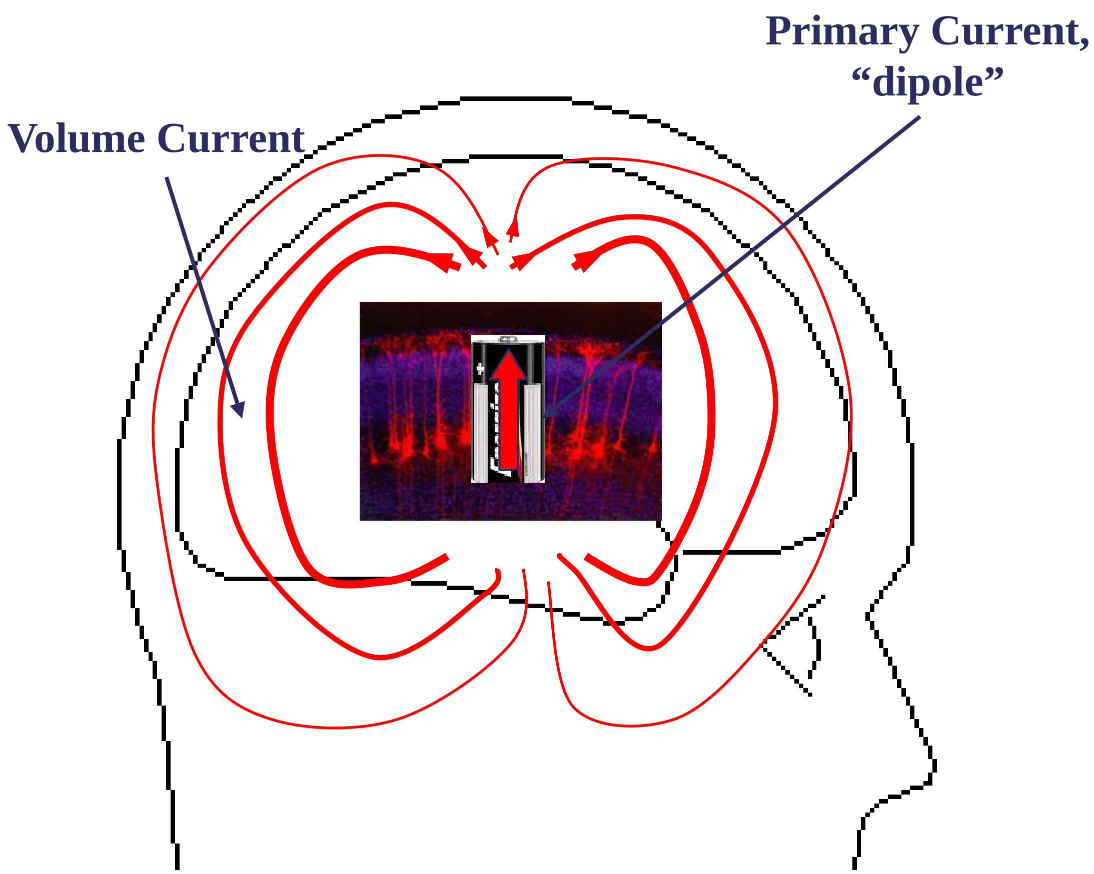
- *Magnetic fields are only caused by static currents (Ampere’s Law):*

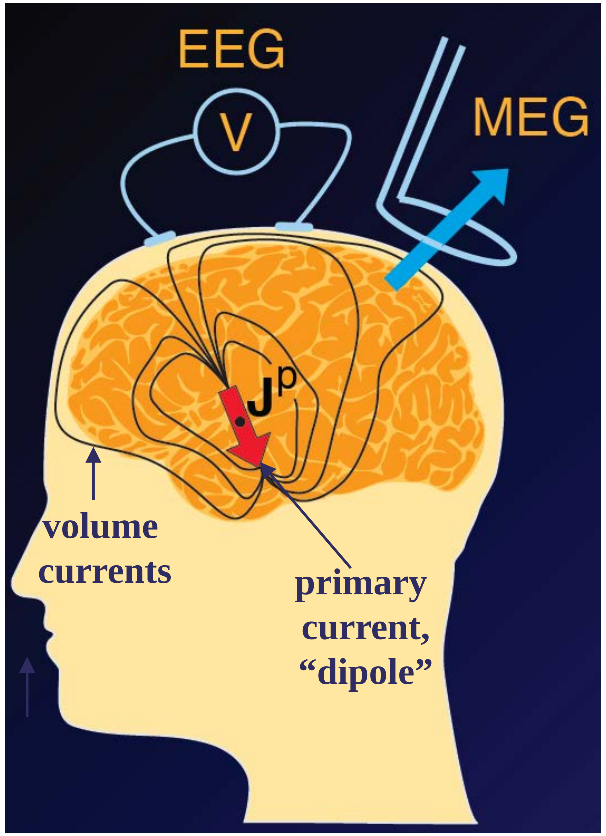
$$\nabla \times \boldsymbol{B} = \mu_0 \mathbf{J}$$



The relationship between EEG/MEG measurements and their brain sources is instantaneous (no “waves”).

Current Flow in the Head





http://www.nmr.mgh.harvard.edu/meg/pdfs/talks/

Volume currents affect both EEG and MEG –

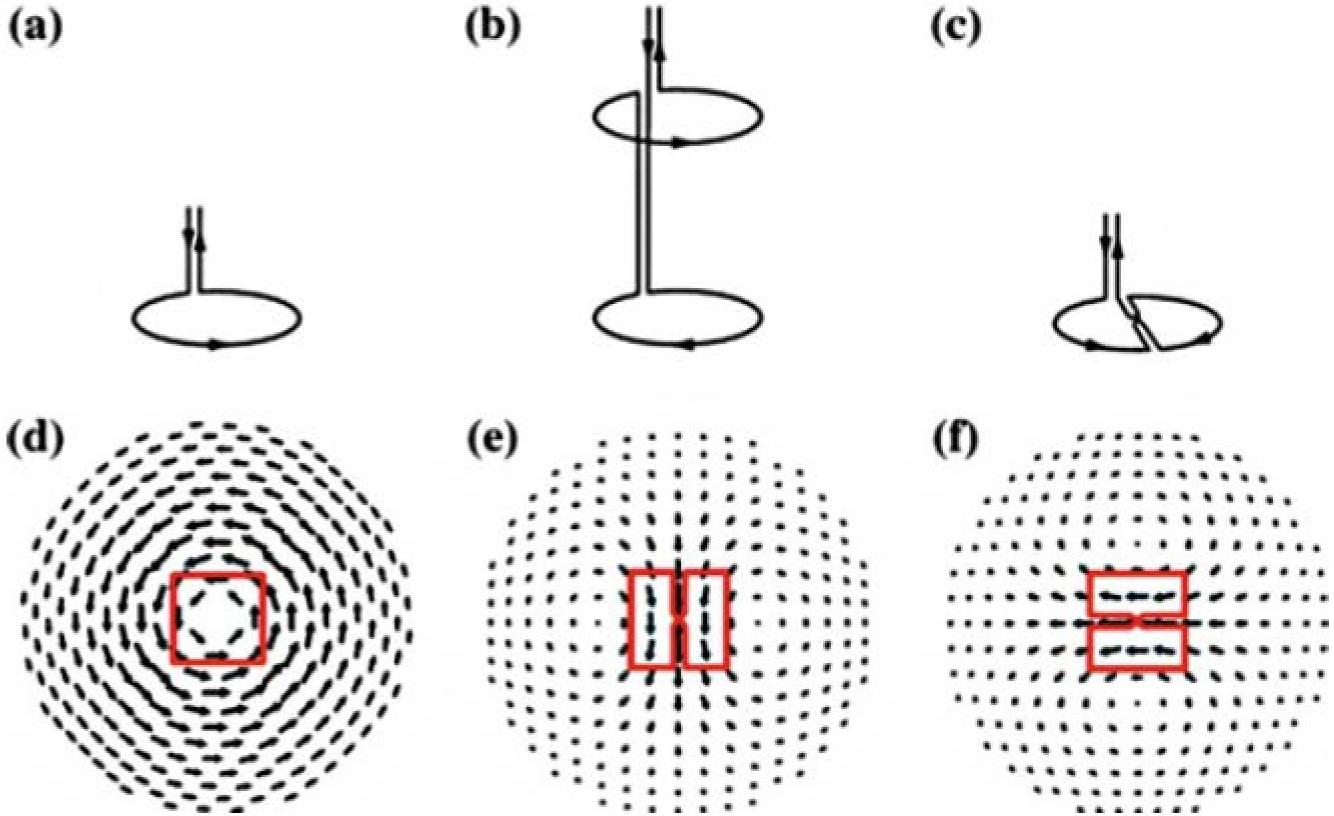
but EEG more than MEG

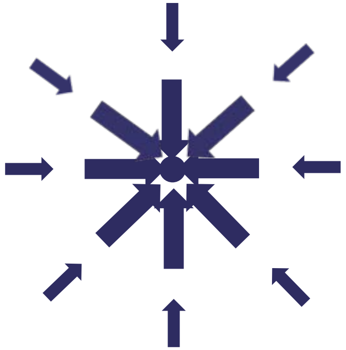
Different Sensors and their Sensitivities (Leadfields)

Leadfields are “sensitivity profiles” of individual sensors.

Each sensor is maximally sensitive to sources oriented along the arrows, and insensitive to sources perpendicular to the arrows.

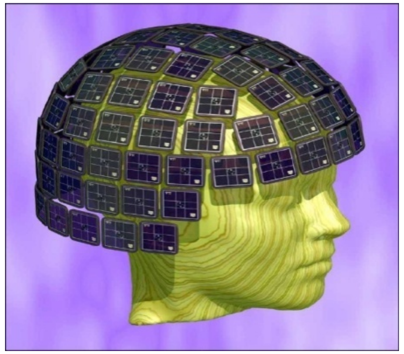
Magnetometer | Axial Gradiometer | Planar Gradiometer | EEG Electrode





The MEGIN Triux Neo System At CBU

306 channels in 102 locations



1 magnetometer and 2 planar gradiometers at each location

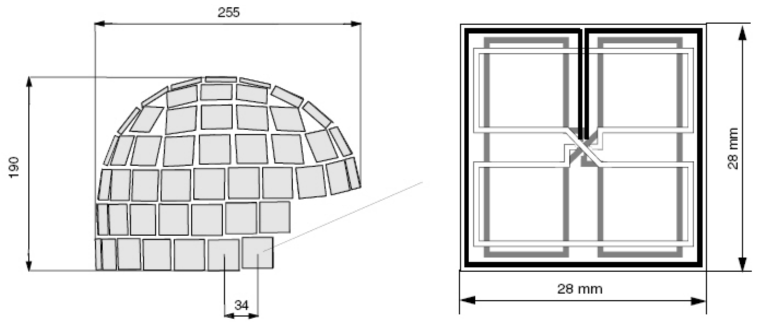
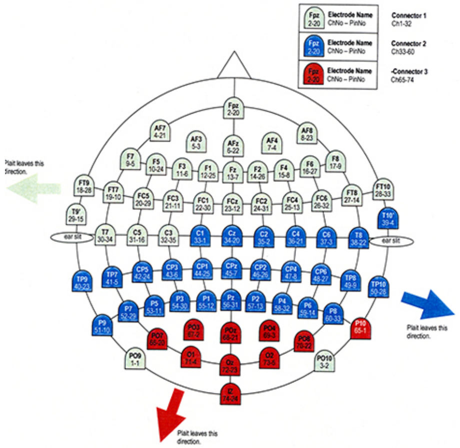


Figure 1.6. (left) Detector array, side view. Average distance between sensor elements : 34,6 mm. (right) Triple sensor detector unit.

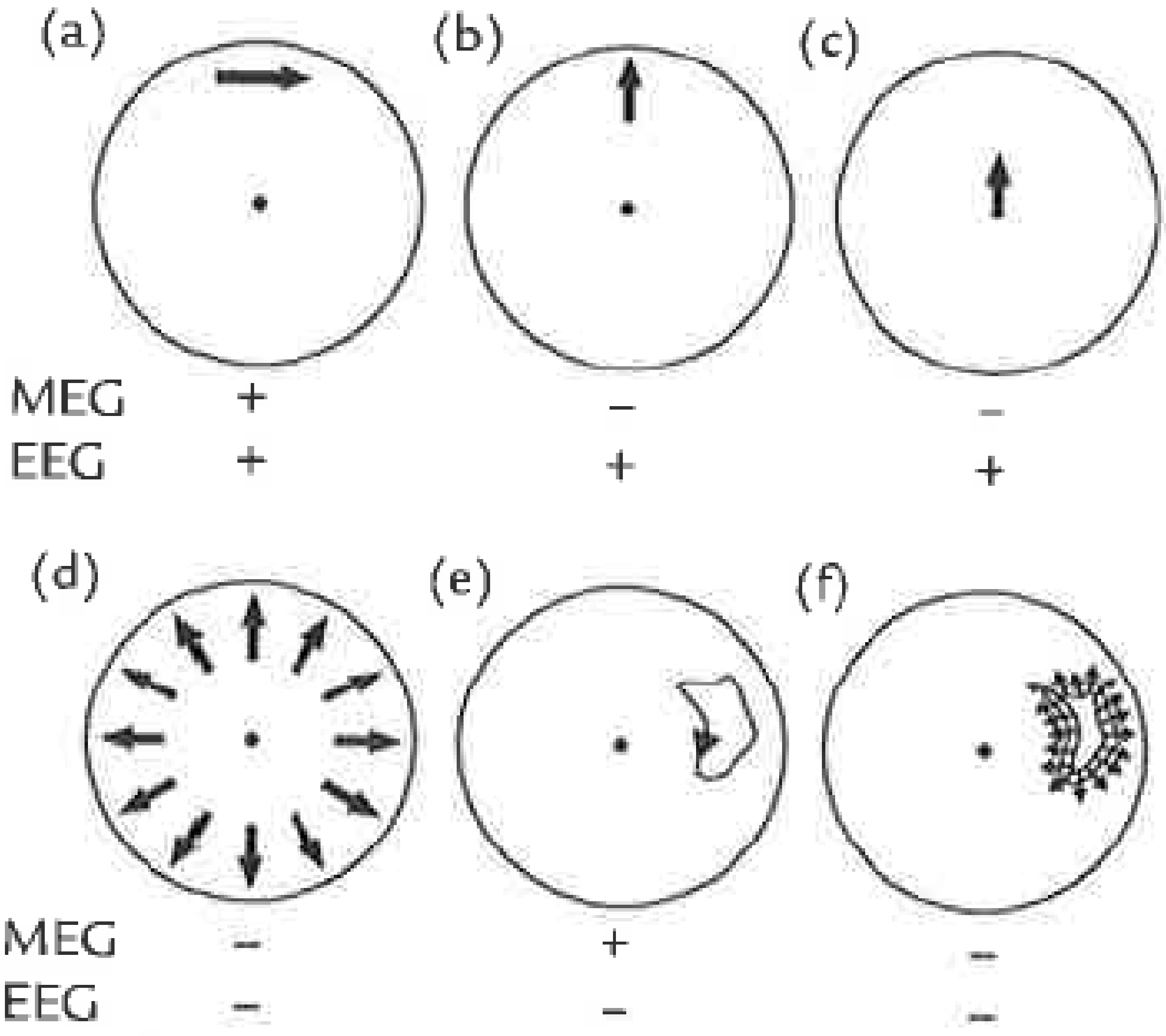
64 EEG electrodes

(plus EOG/ECG)



http://imaging.mrc-cbu.cam.ac.uk/meg/VectorviewDescription

EEG and MEG Are Differentially Sensitive To Radial and Tangential Sources



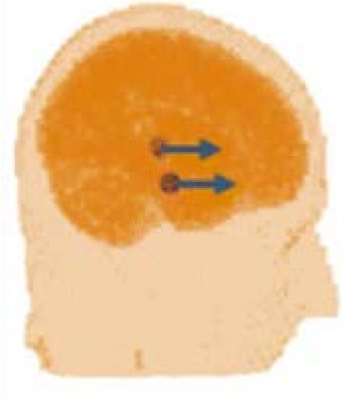
MEG is relatively insensitive to radial currents, and therefore also to deep currents.

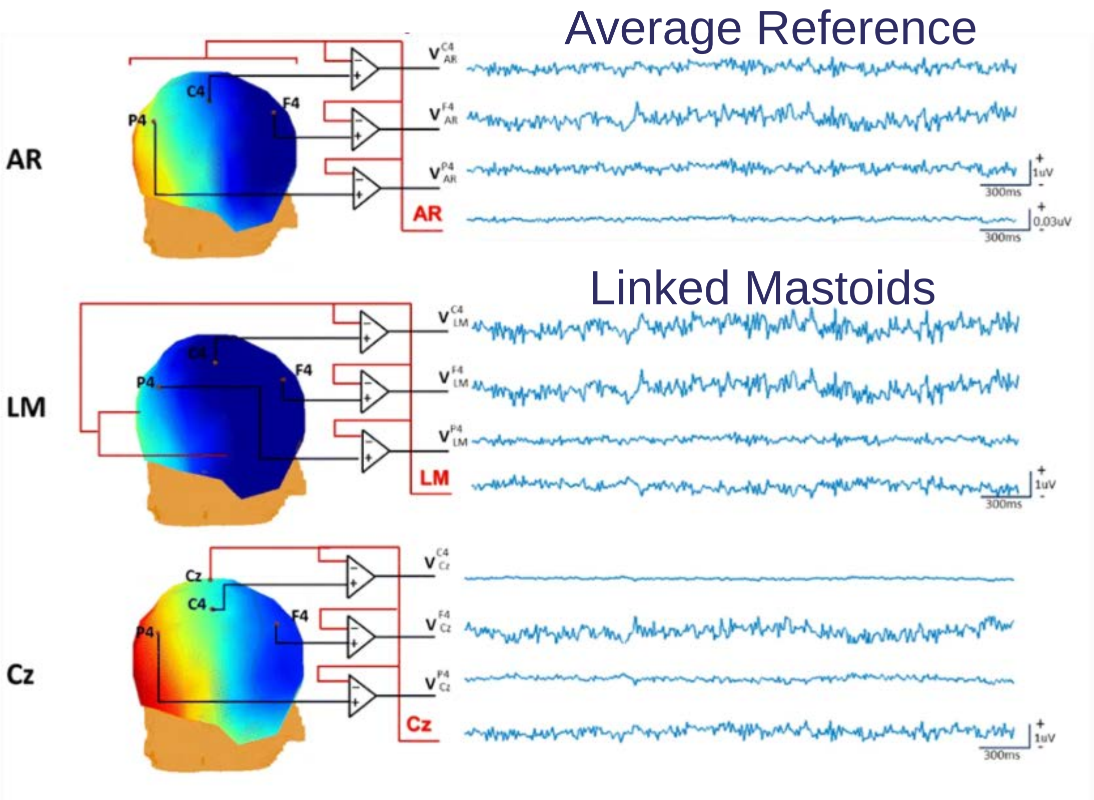
Some complex source distributions may not produce EEG or MEG signals.

MEG-EEG Primer, Hari & Puce, OUP 2017

EEG only: Choice of reference site

Data from
two simulated dipoles





The choice of reference changes time course and topography. For high-density recordings (> 65 channels), average reference is recommended.
Note: Source estimates do not depend on the reference.

Yao et al., Brain Topography 2019

Thank you