What are we measuring with M/EEG

(and what are we measuring with)

Gareth Barnes
UCL

SPM Course – May 2012 – London

Outline

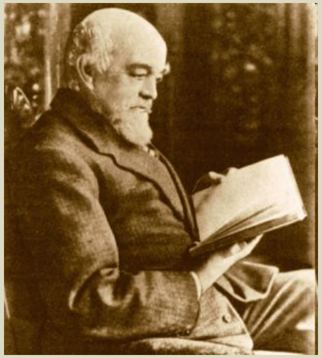
A brief history

The EEG & MEG instrumentation

Neuronal basis of the signal

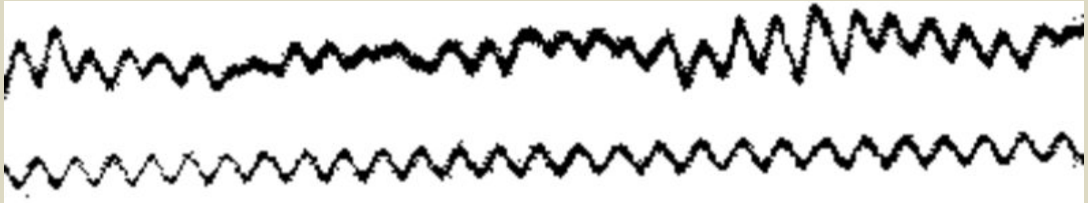
Forward models

EEG history

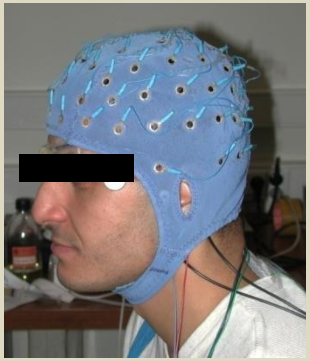


1875: Richard Caton (1842-1926) measured currents inbetween the cortical surface and the skull, in dogs and monkeys

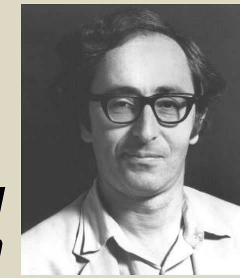
1929: Hans Berger (1873-1941) first EEG in humans (his young son), description of alpha and beta waves



1950s. Grey Walter (1910 – 1977). Invention of topographic EEG maps.



MEG history



Brian-David Josephson

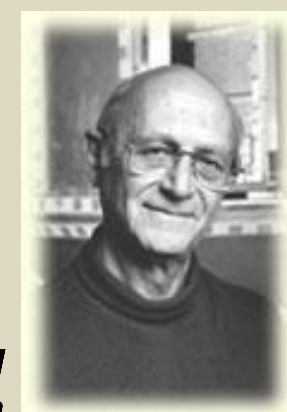
1962: Josephson effect

1968: first (noisy) measure of a magnetic brain signal *[Cohen, Science 68]*

1970: James Zimmerman invents the '*Superconducting quantum interference device*' (SQUID)

1972: first (1 sensor) MEG recording based on SQUID *[Cohen, Science 1972]*

1973: Josephson wins the Nobel Prize in Physics
- *And goes on to study paranormal activity…*



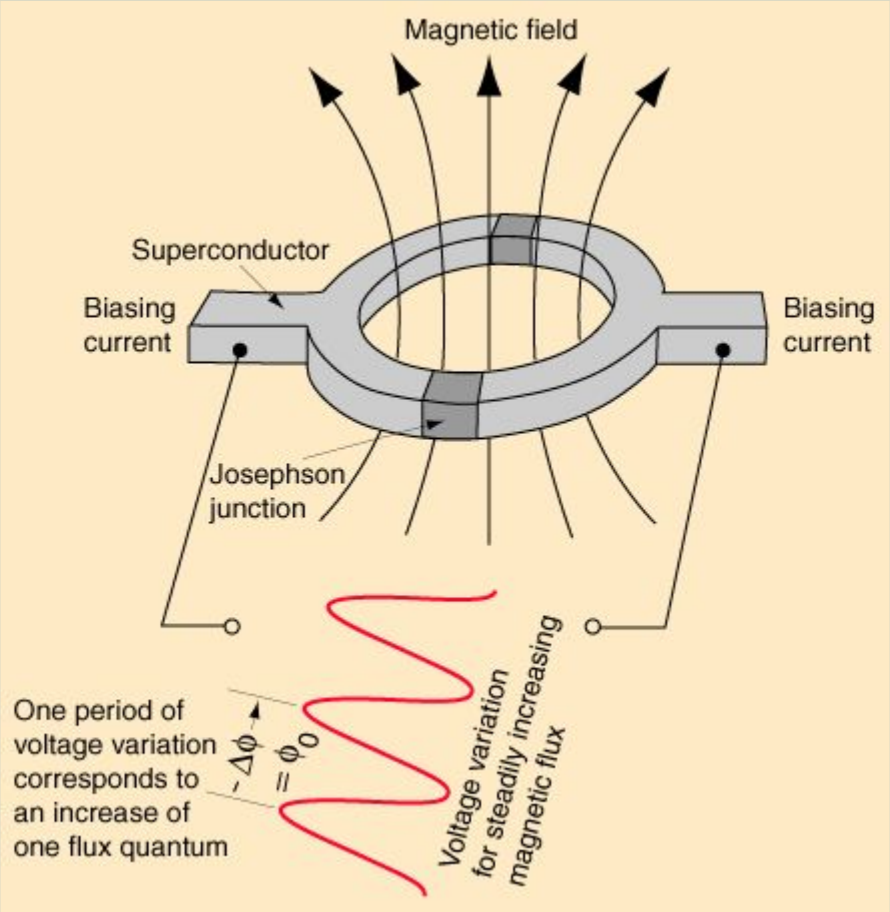
David Cohen

SQUIDS

It is an ultrasensitive detector of magnetic flux.
It is made up of a superconducting ring interrupted by one or two Josephson Junctions.

Can measure field changes of the order of 10^-15 (femto) Tesla

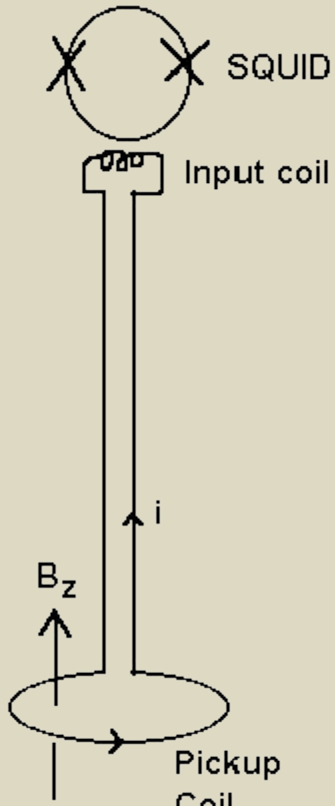
(compare to the earth's field of 10^-4 Tesla)



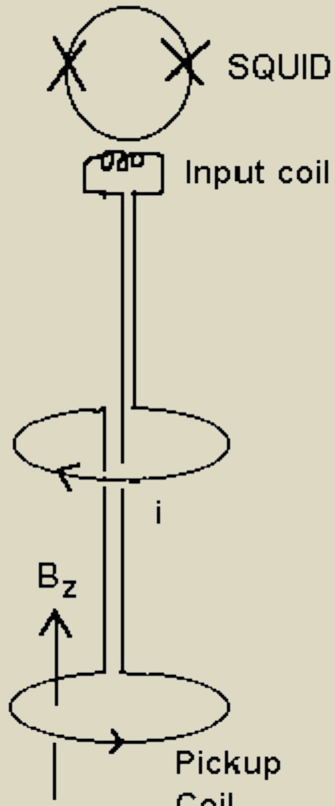
Flux transformers

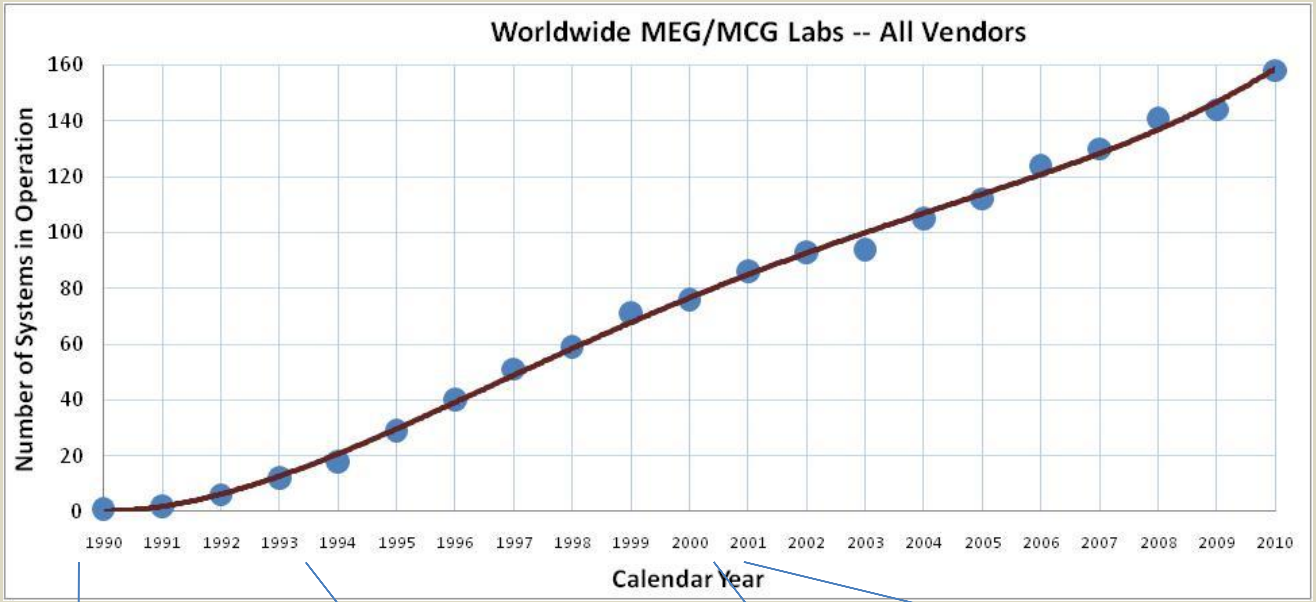
There are different types of sensors

Magnetometers: measure the magnetic flux through a single coil



Gradiometers: when more flux passes through the lower coil (near the head) than the upper get a net change in current flow at the inut coil.




Worldwide MEG/MCG Labs -- All Vendors
Number of Systems in Operation
0
20
40
60
80
100
120
140
160
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
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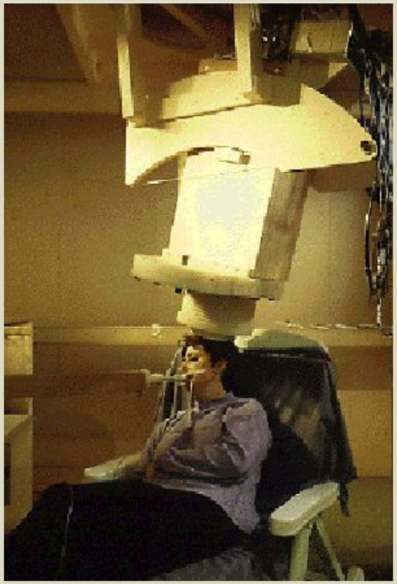
2007
2008
2009
2010
Calendar Year

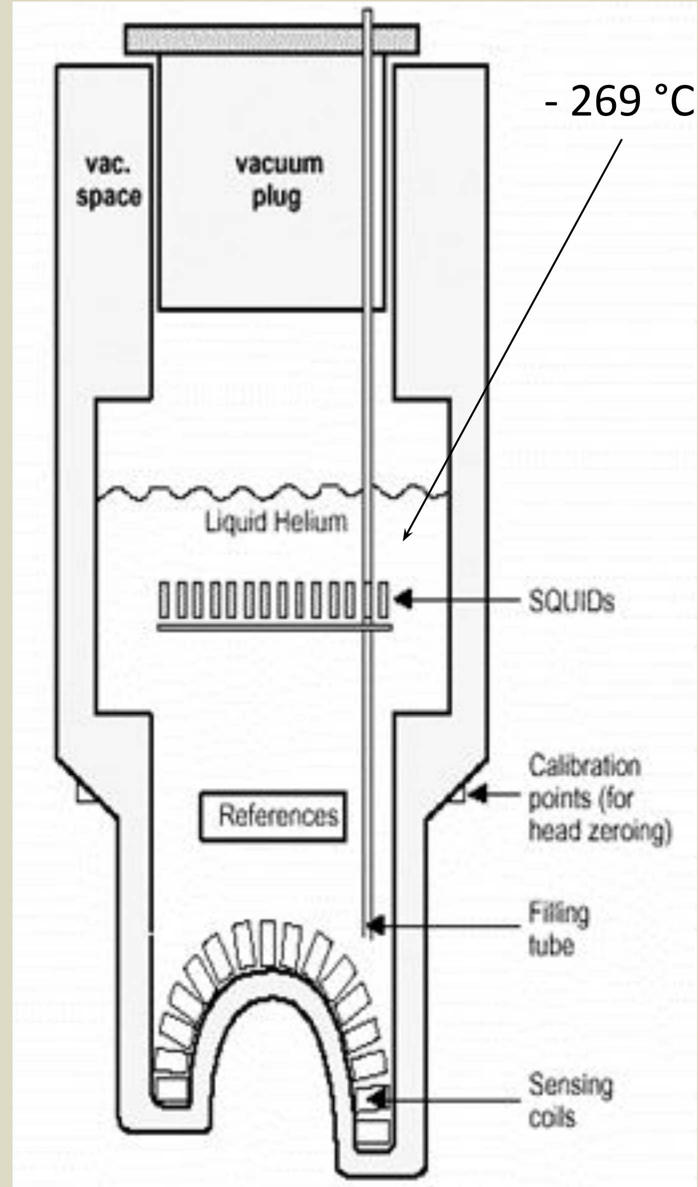


The EEG & MEG instrumentation

MEG

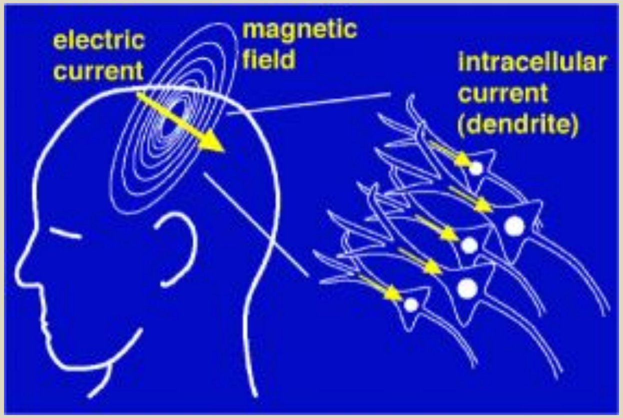
SQUIDs

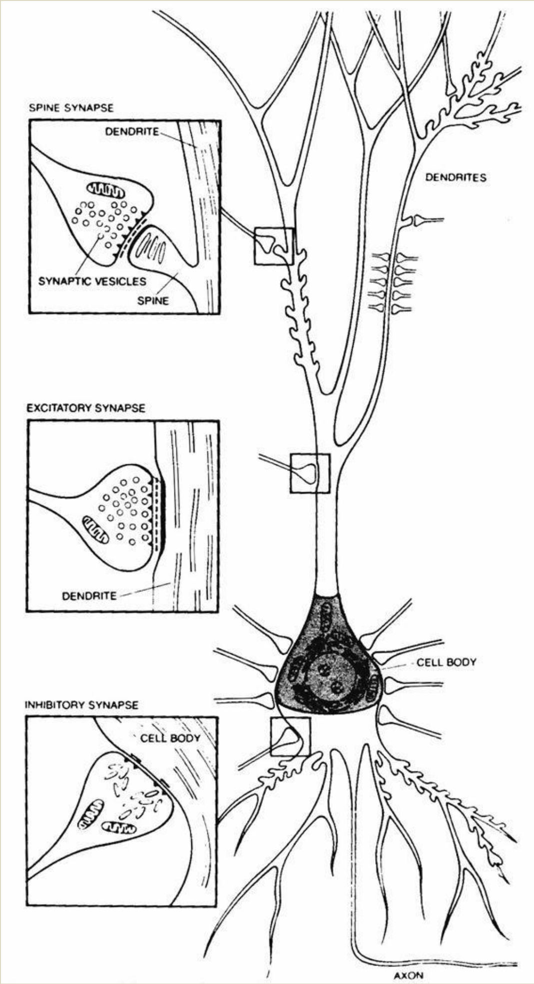
Sensors
(Pick up coil)



What do we measure with EEG & MEG ?

From a single neuron to a neuronal assembly/column



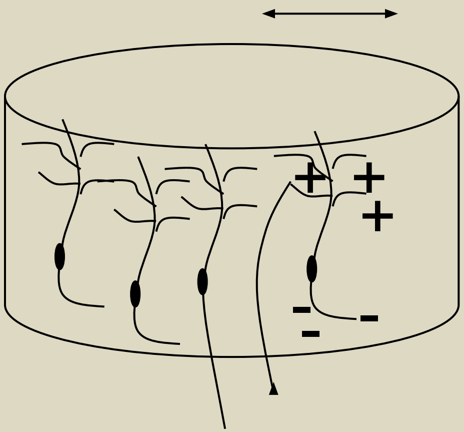


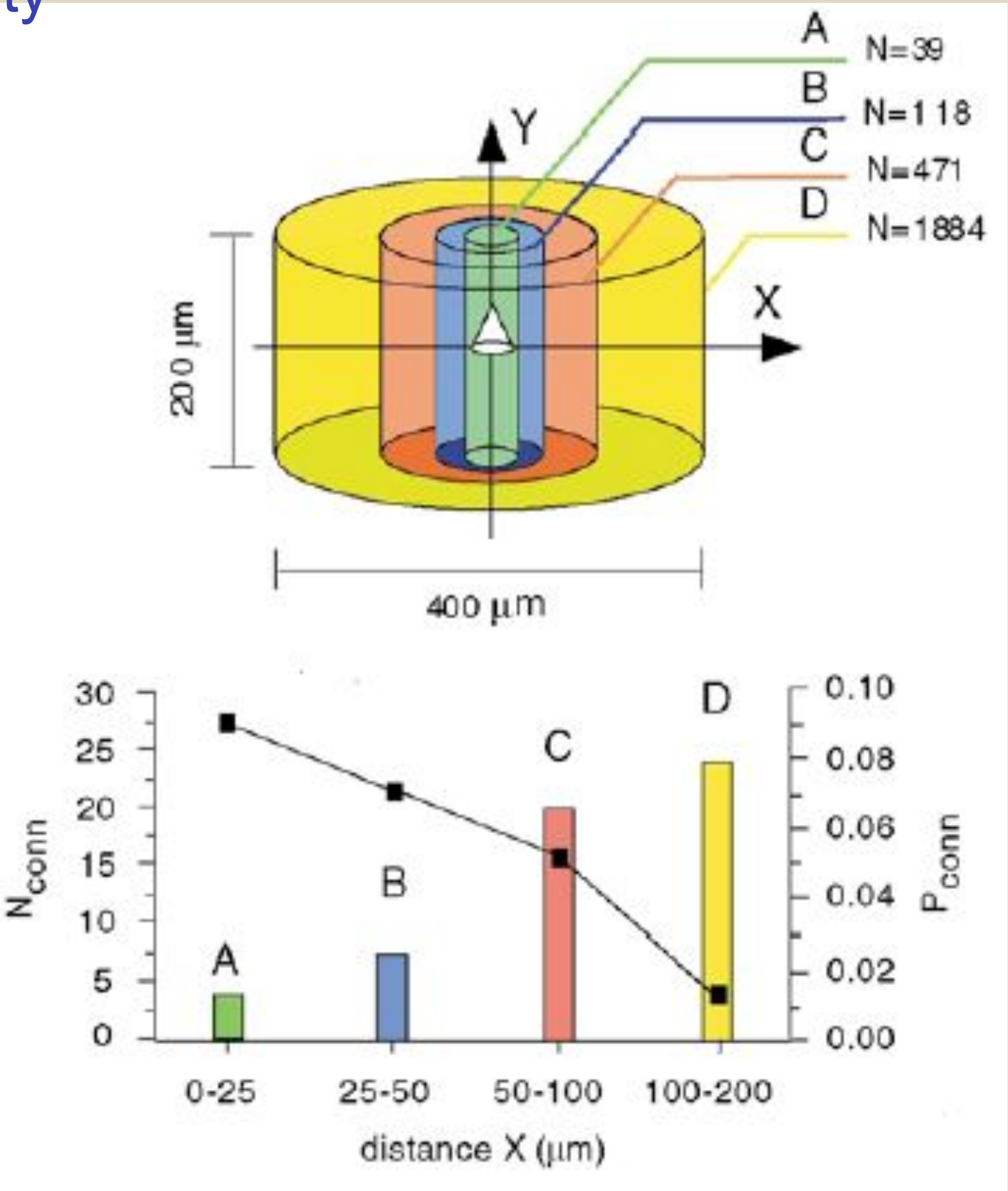
- A single active neuron is not sufficient. ~100,000 simultaneously active neurons are needed to generate a measurable M/EEG signal.

- Pyramidal cells are the main direct neuronal sources of EEG & MEG signals.

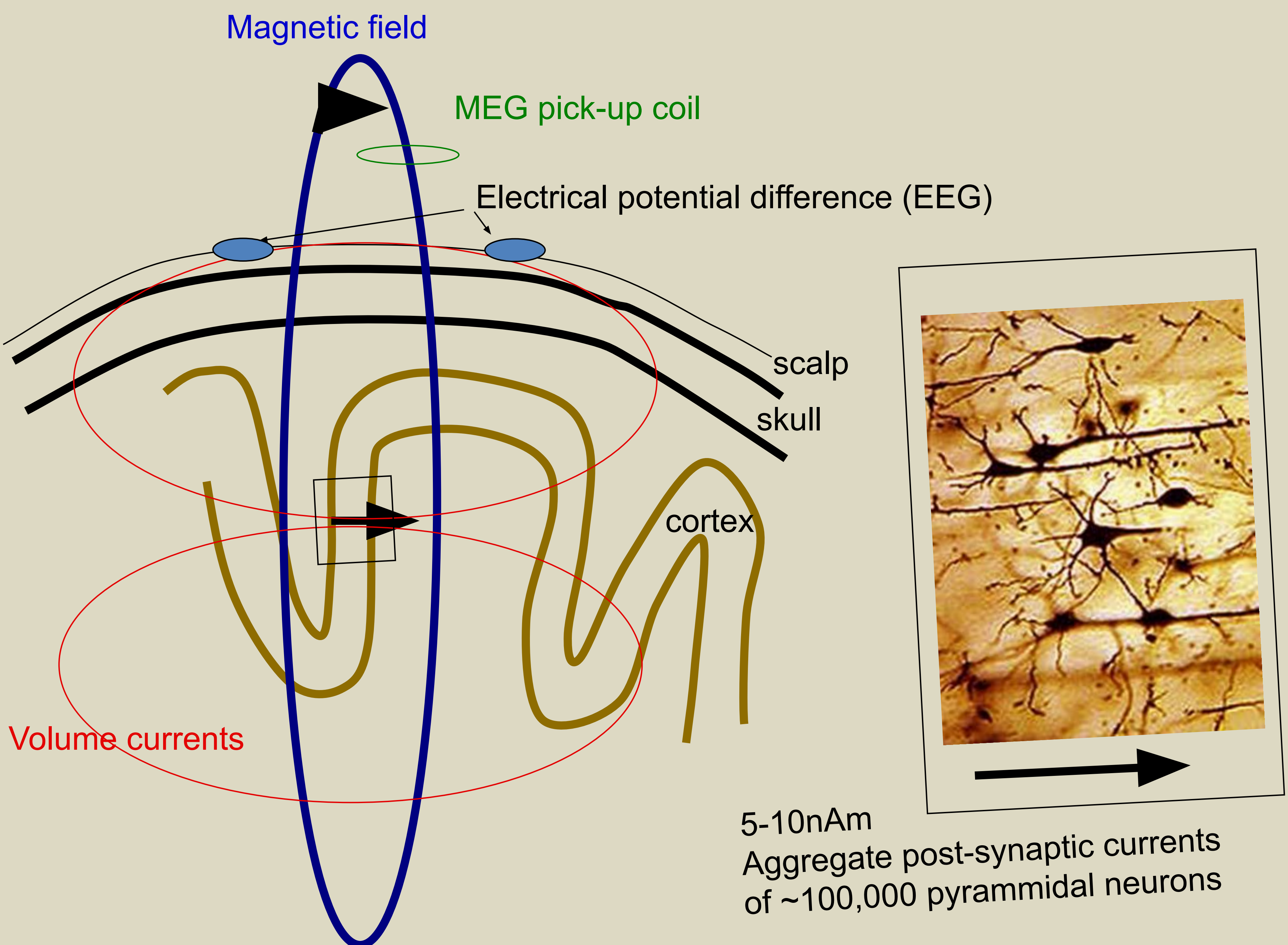
- Synaptic currents but not action potentials generate EEG/MEG signals

Lateral connectivity
-local





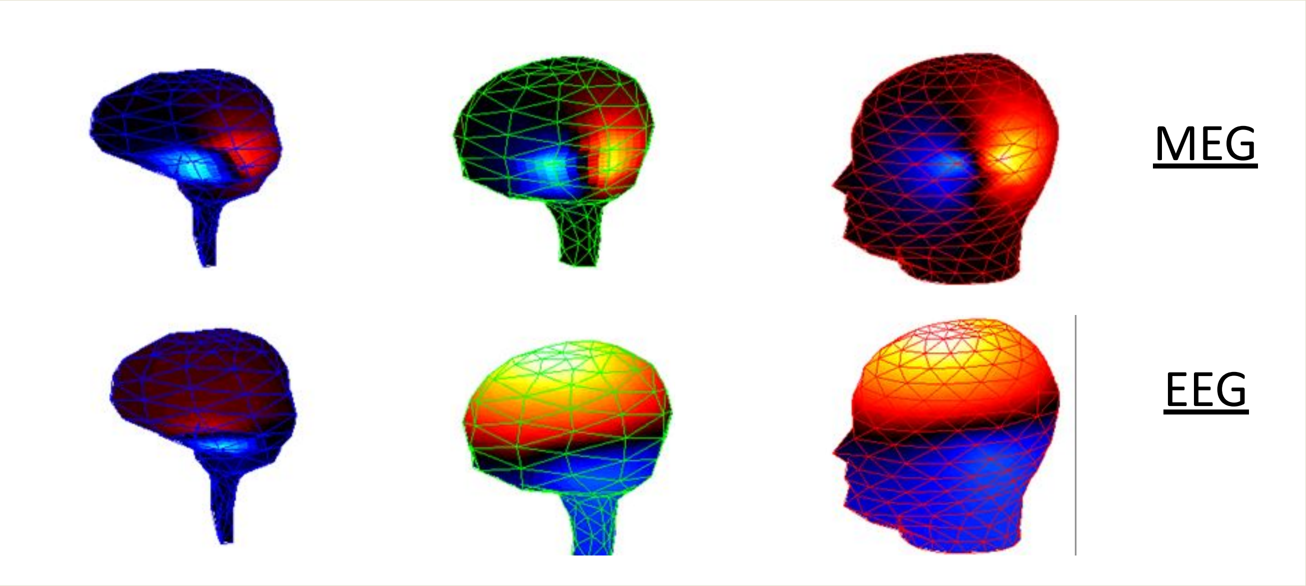
Holmgren et al. 2003

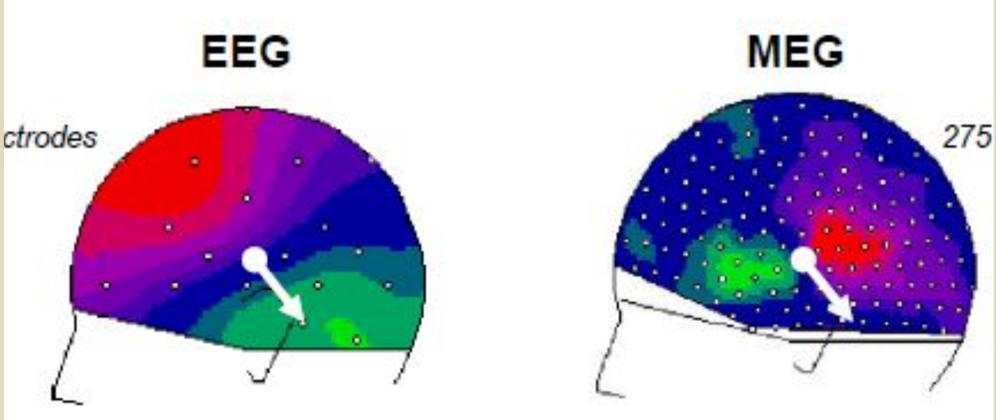


Magnetic field
MEG pick-up coil
Electrical potential difference (EEG)
scalp
skull
cortex
Volume currents
5-10nAm
Aggregate post-synaptic currents
of ~100,000 pyrammidal neurons

What do we measure with EEG & MEG ?

From a single source to the sensor: MEG





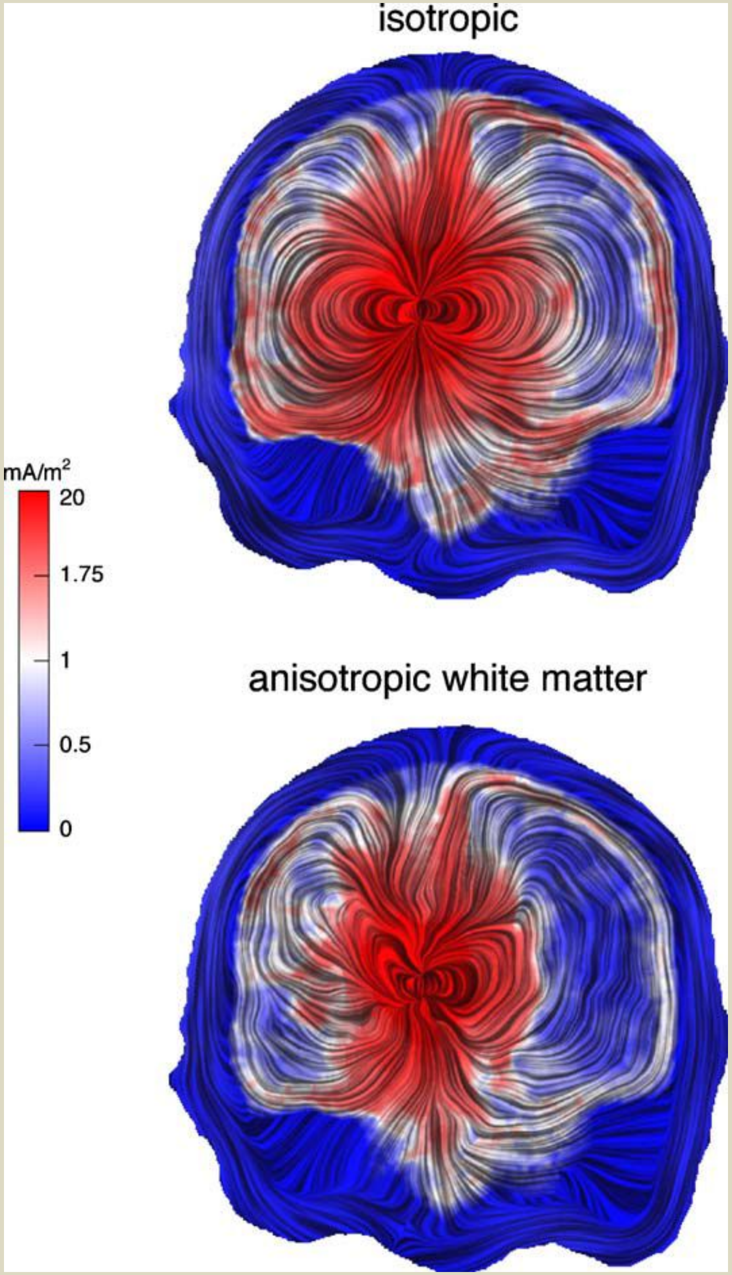
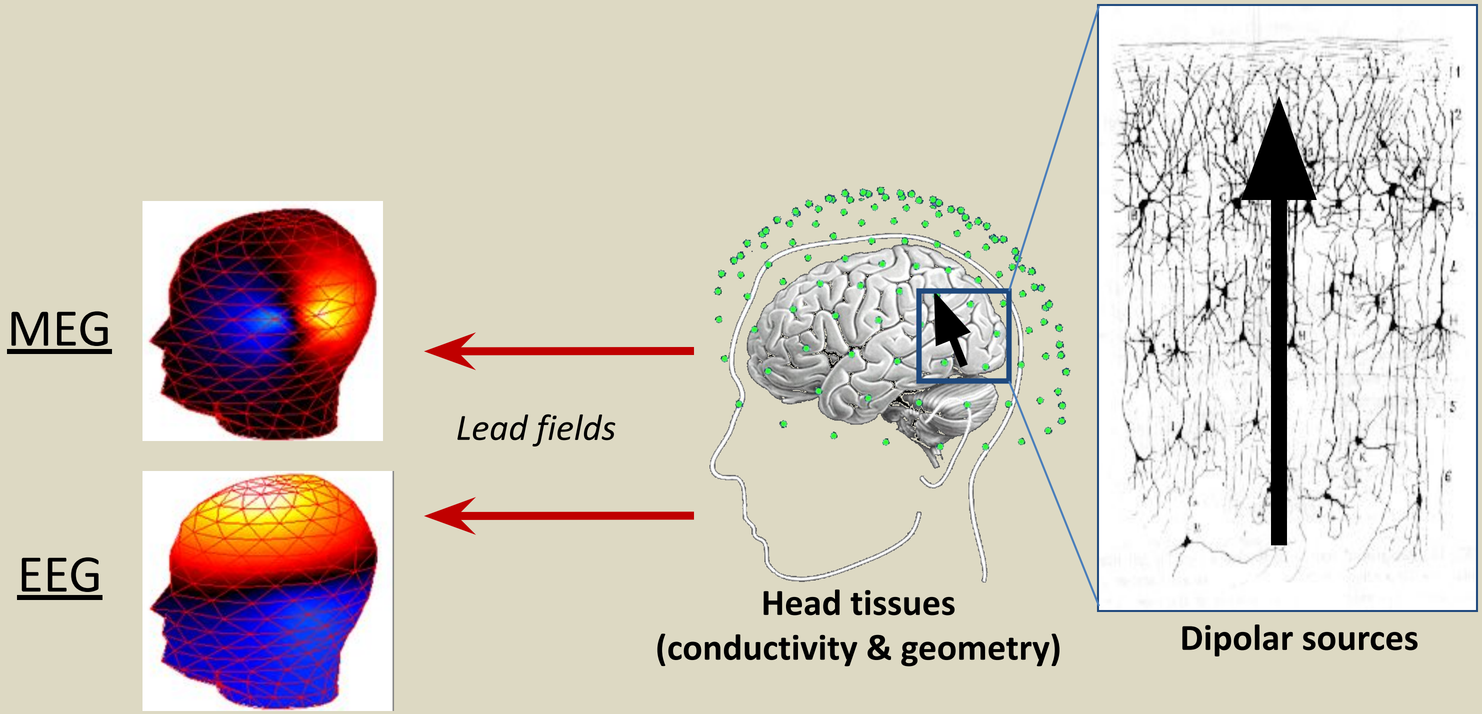


Fig. 14. Return currents for the left thalamic source on a coronal cut through the isotropic model (top row) and the model with 1:10 anisotropic white matter compartment (volume constraint, bottom row): the return current directions are indicated by the texture and the magnitude is color coded.

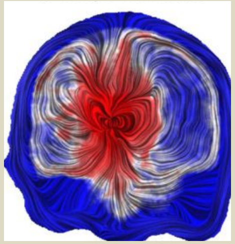
C.H. Wolters et al. / NeuroImage 30 (2006) 813– 826

The forward problem

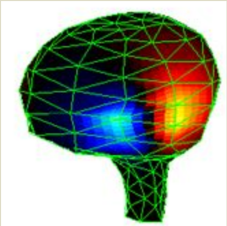


Different head models (lead field definitions) for the forward problem

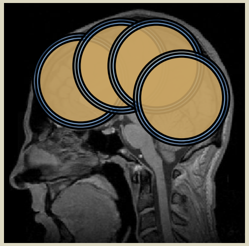
- Finite Element



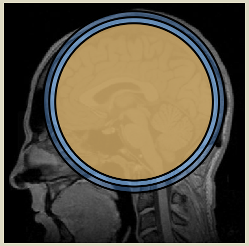
- Boundary Element



- Multiple Spheres

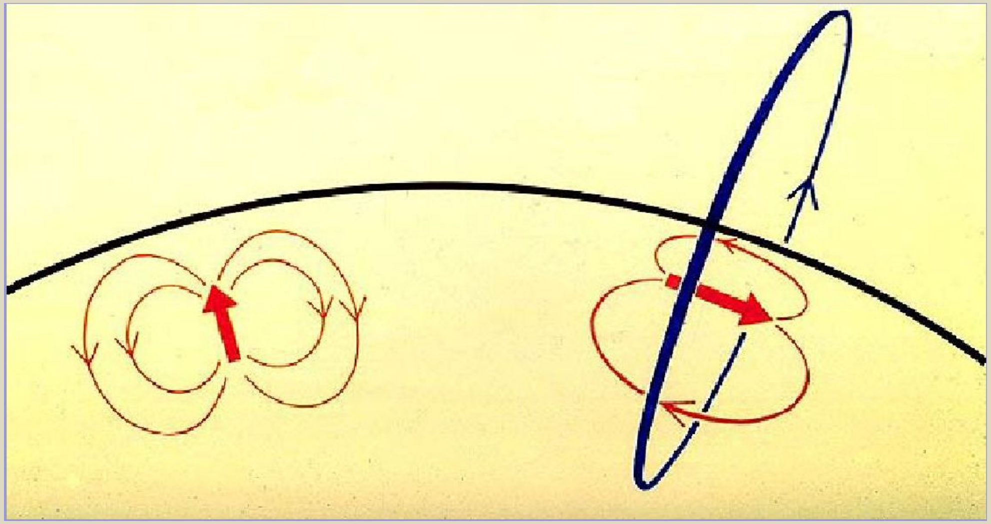


- Single Sphere



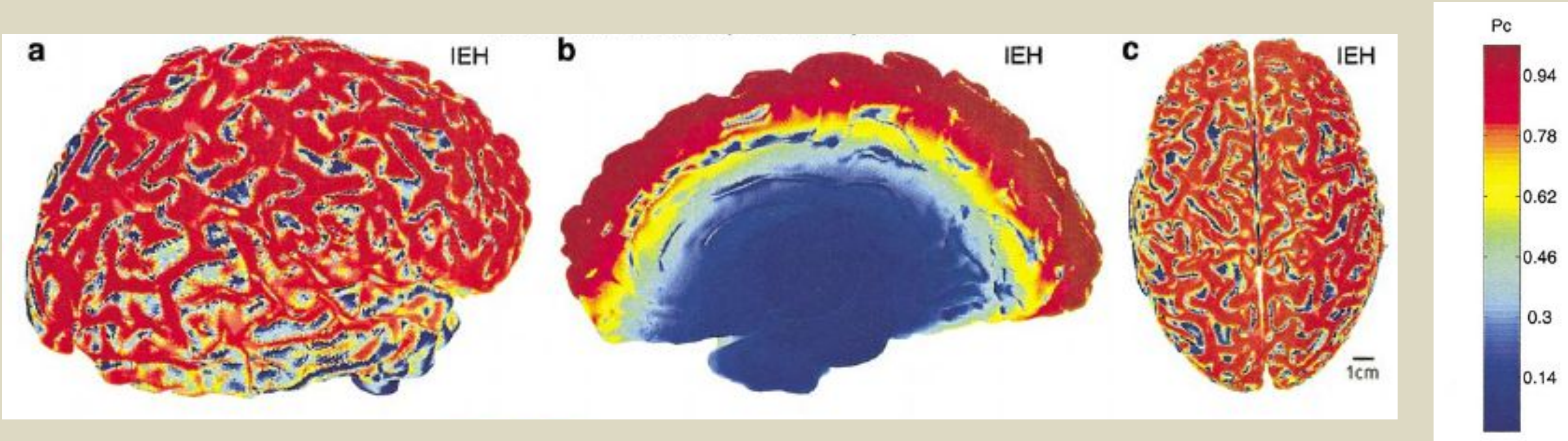
Simpler models

Can MEG see gyral sources ?



A perfectly radial source in a spherical conductor produces no external magnetic field.

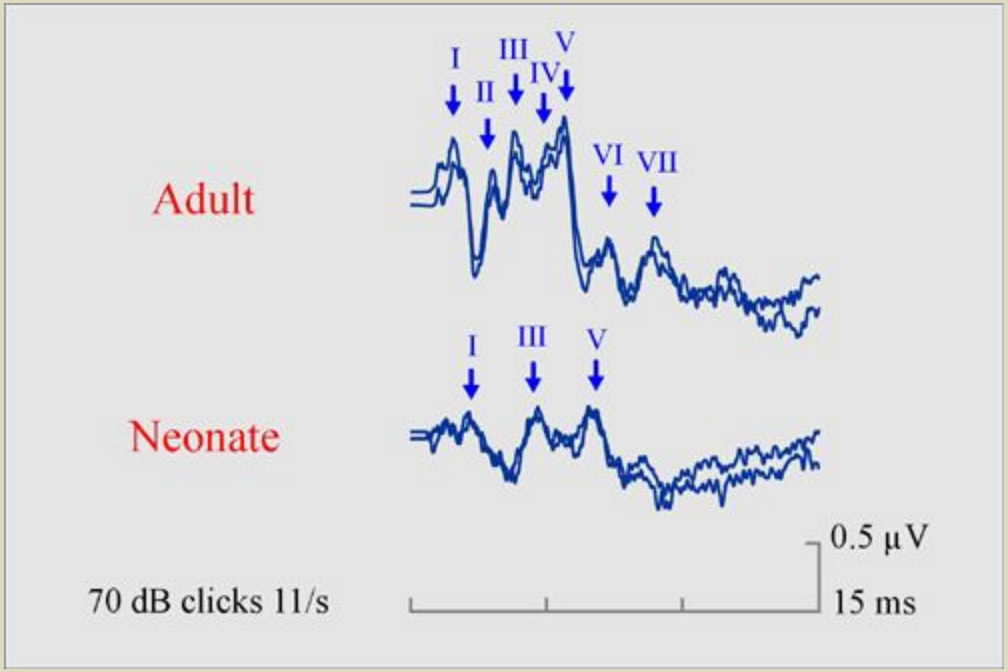
Can MEG see gyral sources ?

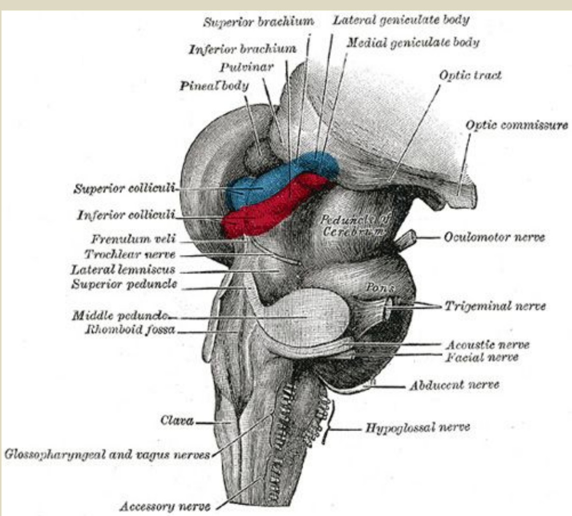


Source depth, rather than orientation, limits the sensitivity of MEG to electrical activity on the cortical surface. There are thin strips (approximately 2mm wide) of very poor resolvability at the crests of gyri, however these strips are abutted by elements with nominal tangential component yet high resolvability due to their proximity to the sensor array.

A quantitative assessment of the sensitivity of whole-head MEG to activity in the adult human cortex. Arjan Hillebrand et al. , NeuroImage 2002

EEG Auditory Brainstem Response





Wave I/II (<3ms) generated in auditory nerve or at entry to brainstem+ cochlear nucleus
Wave III. Ipsilateral cochlear nucleus / superior olivary complex
Wave IV. Fibres leaving cochlear nucleus and/or superior olivary complex
Wave V. Lateral lemniscus

THE LANCET
Volume 295, Issue 7654, 9 May 1970, Pages 976-979

IS ALPHA RHYTHM AN ARTEFACT?

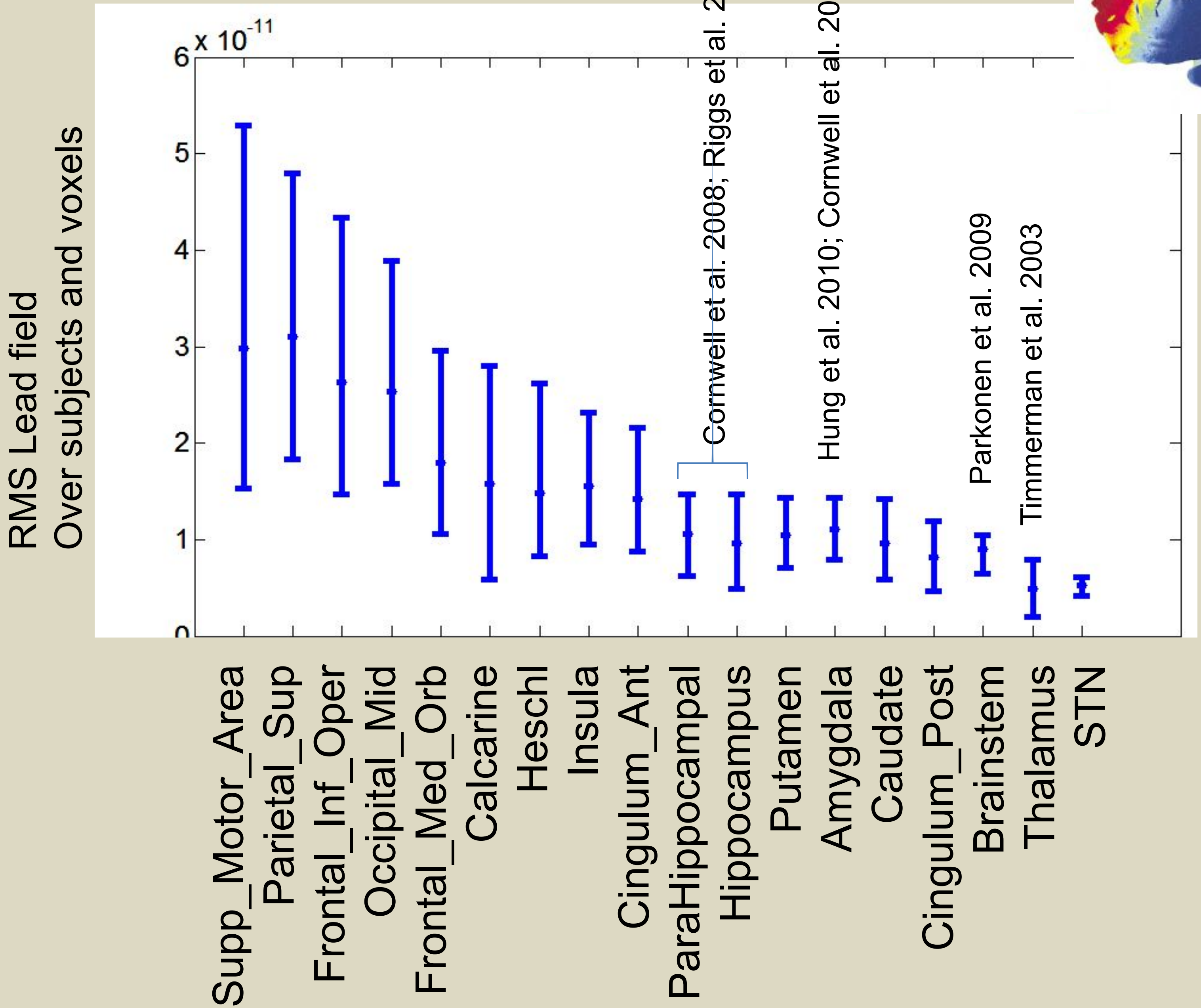
O. C. J. Lippold and G. E. K. Novotny
Department of Physiology, University College, London, W.C.1, United Kingdon

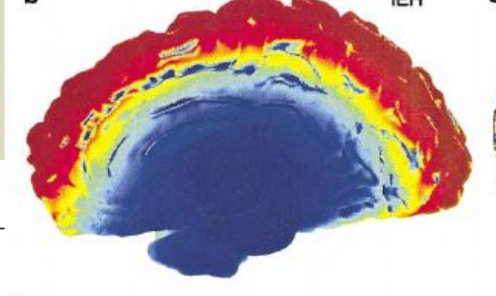
Abstract
It is postulated that occipital alpha rhythm in man is not generated in the occipital cortex, but by tremor of the extraocular muscles. It is thought that tremor modulates the corneoretinal potential and this modulation is recorded at the occiput because of the anatomical organisation of the orbital contents within the skull.

Summary

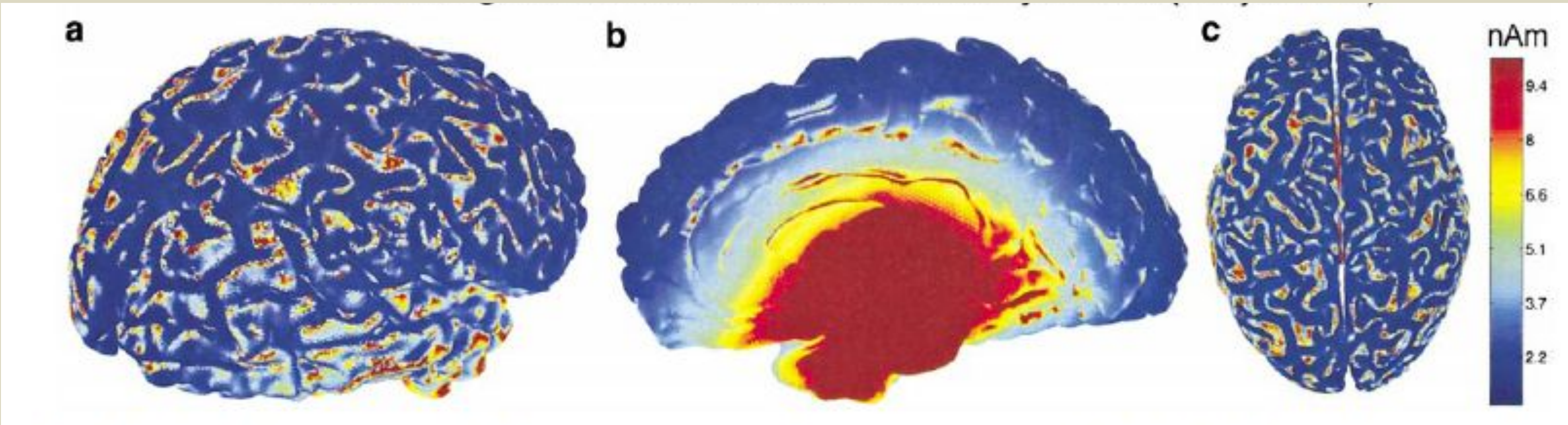
- EEG is sensitive to deep (and radial) sources but a very precise head model is required to get an accurate picture of current flow.
- MEG is relatively insensitive to deeper sources but forward model is simple.

MEG Sensitivity to depth



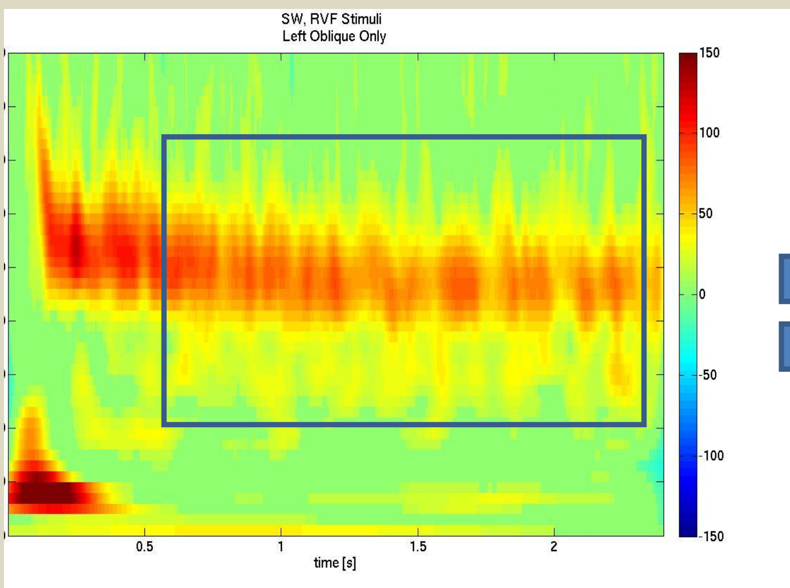


Sensitivity can be improved by knowing signal of interest

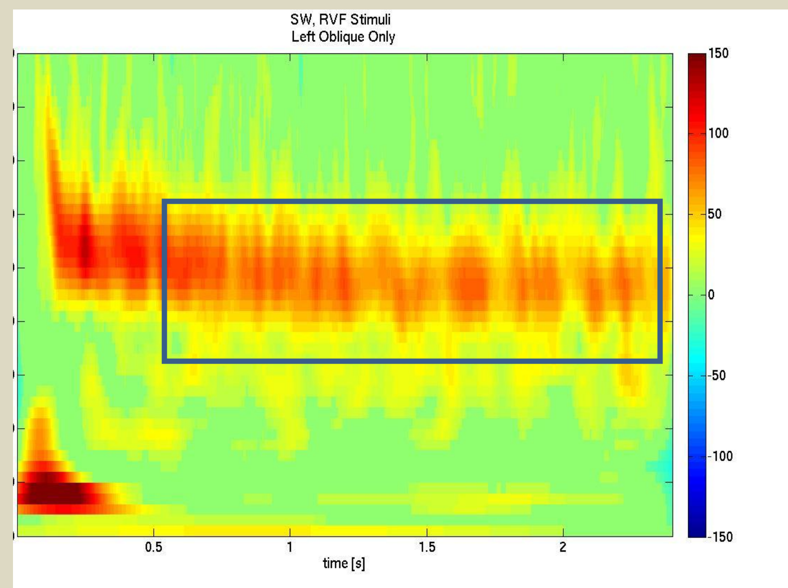


Sqrt(Trials)

sqrt(Noise Bandwidth)



400 Trials, 40Hz BW



200 Trials, 20 Hz BW

• Human Brain Mapping 30:1772–1782 (2009) •

Sources of Auditory Brainstem Responses Revisited: Contribution by Magnetoencephalography

Lauri Parkkonen,[1,2]* Nobuya Fujiki,[1] and Jyrki P. Mäkelä[3]

[1]*Brain Research Unit, Low Temperature Laboratory, Helsinki University of Technology, Finland*
[2]*Advanced Magnetic Imaging Centre, Helsinki University of Technology, Finland*
[3]*Biomag Laboratory, HUSLAB, Helsinki University Central Hospital, Helsinki, Finland*

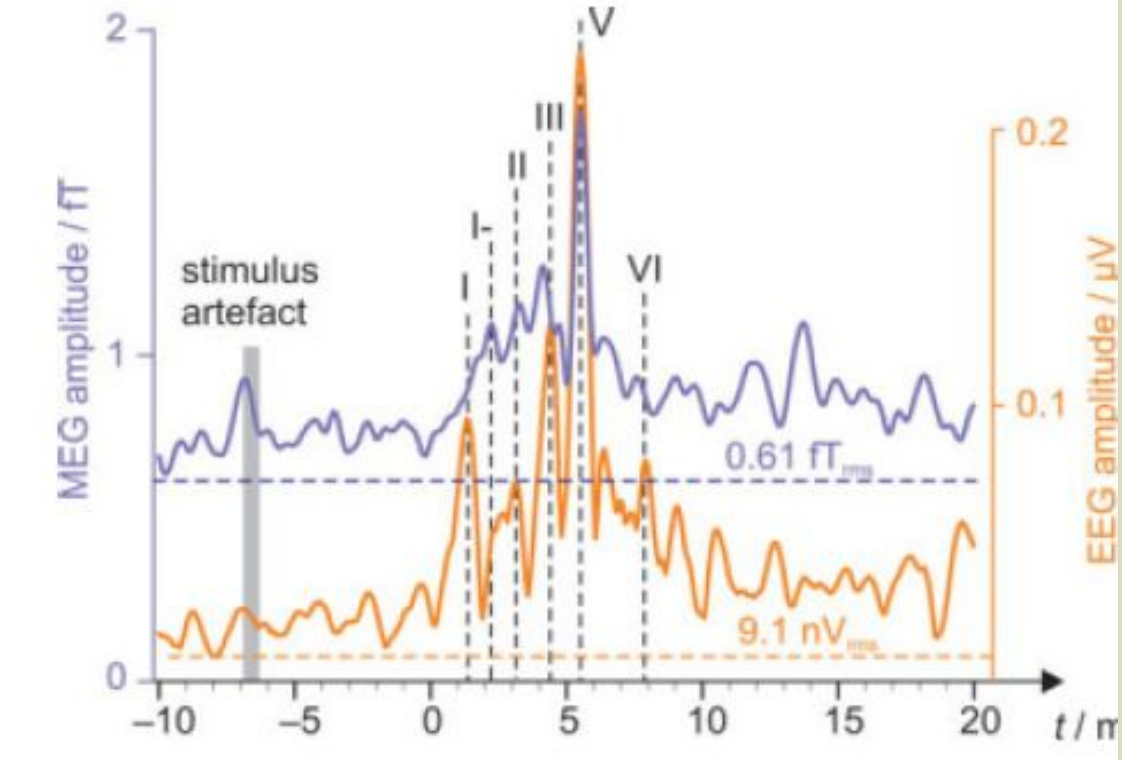
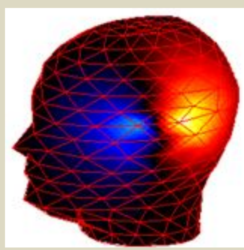


Figure 1.

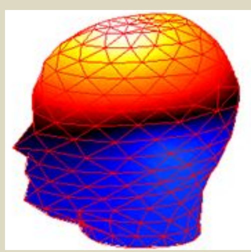
Lead fields

Forward problem

MEG

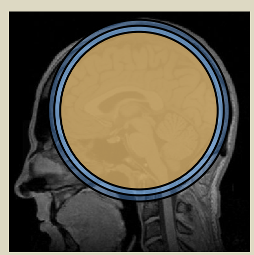


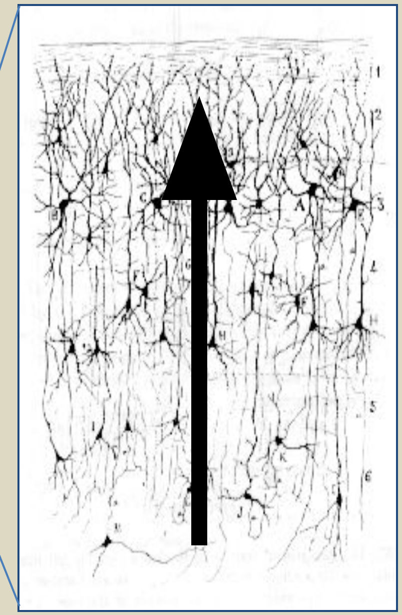
EEG



Lead fields

forward model





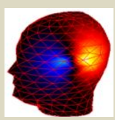
Dipolar sources

The inverse problem

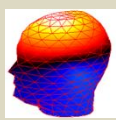
The inverse problem (estimating source activity from sensor data) is ill-posed. So you have add some prior assumptions

$$Y = g(\theta) + \varepsilon$$

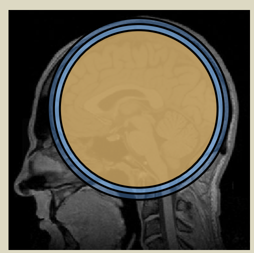
MEG

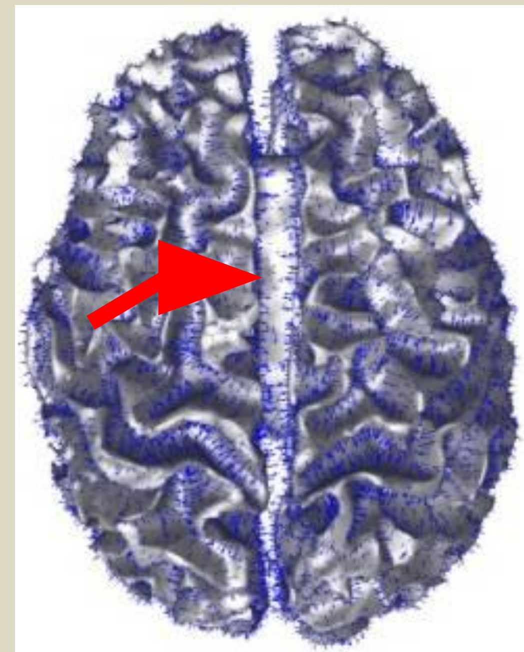


EEG



forward model



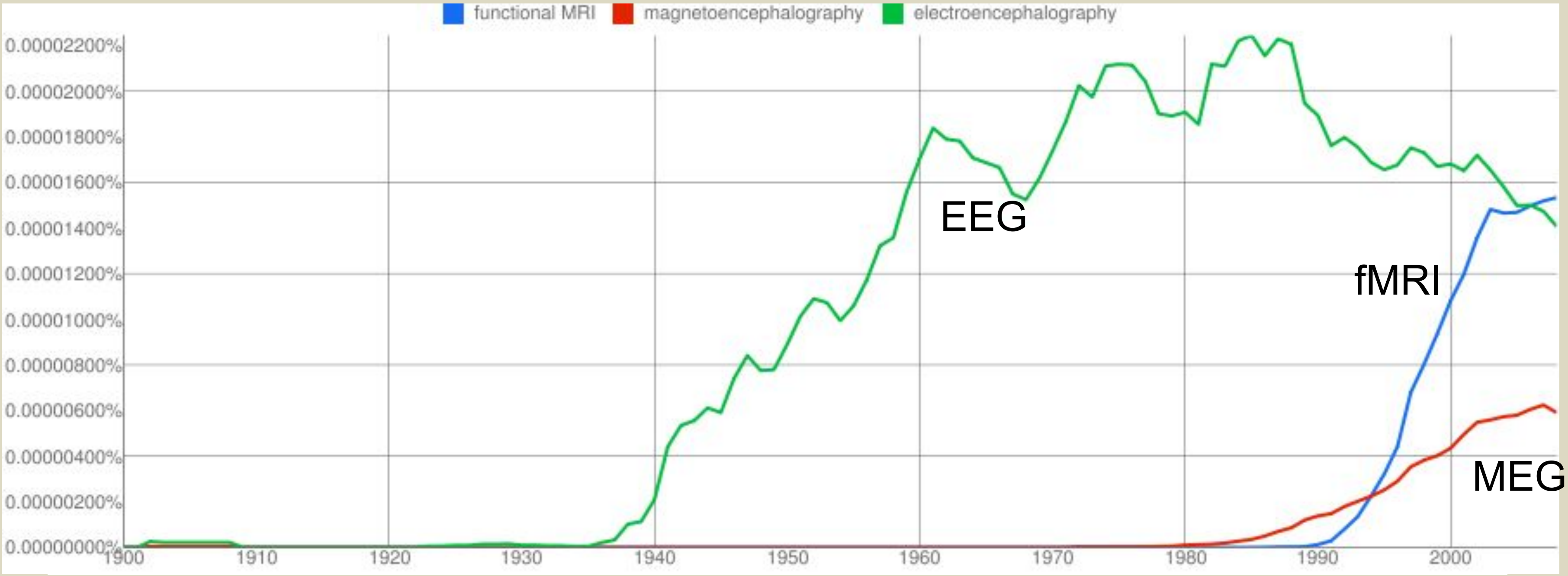


For example,
can make a good guess
at realistic orientation
(along pyrammidal cell bodies,
perpendicular to cortex)

Summary

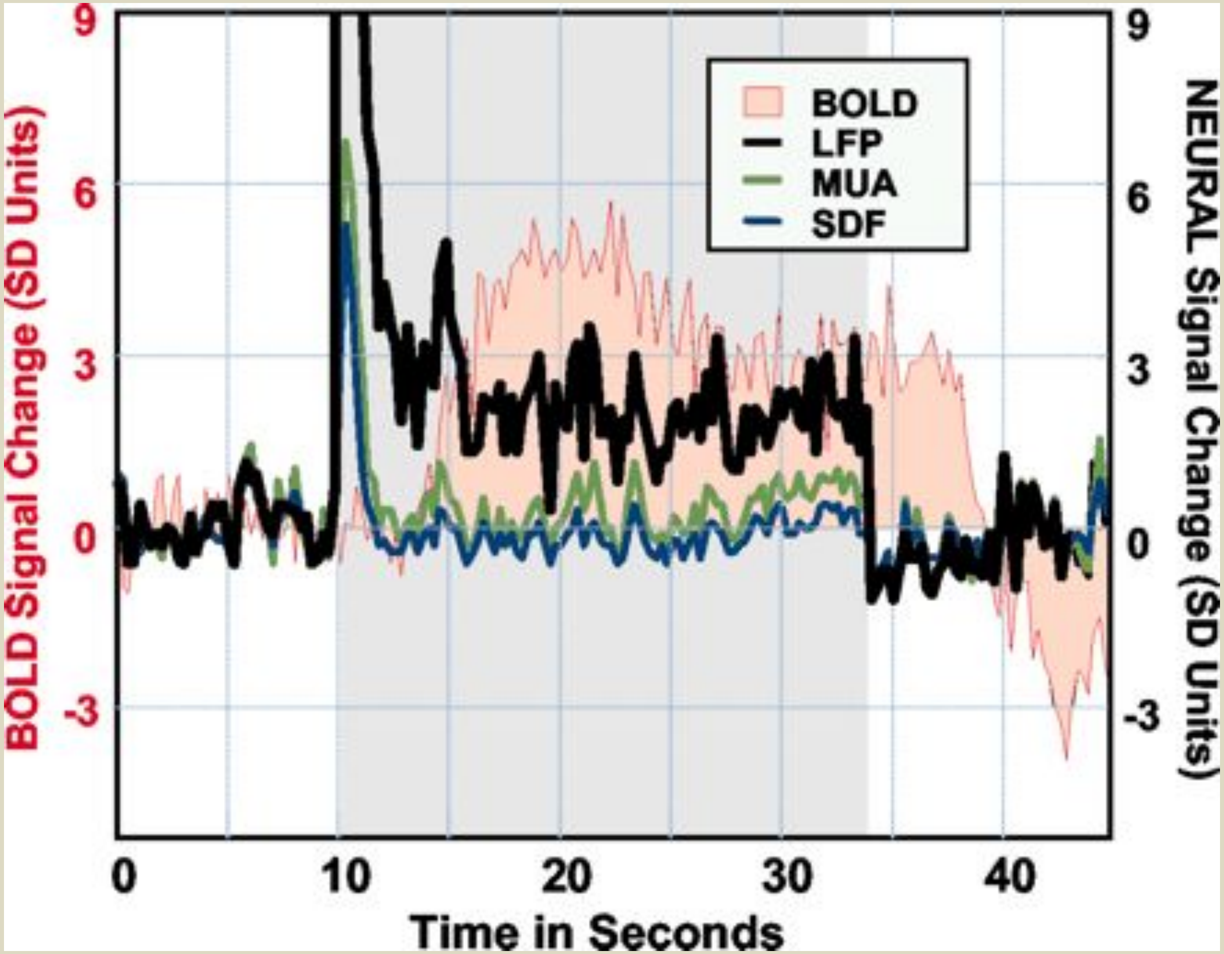
- Measuring signals due to aggregate post-synaptic currents (modeled as dipoles)
- Lead fields are the predicted signal produced by a dipole of unit amplitude.
- MEG is limited by SNR. Higher SNR= resolution of deeper structures.
- EEG is limited by head models. More accurate head models= more accurate reconstruction.

Occurrence in English language texts



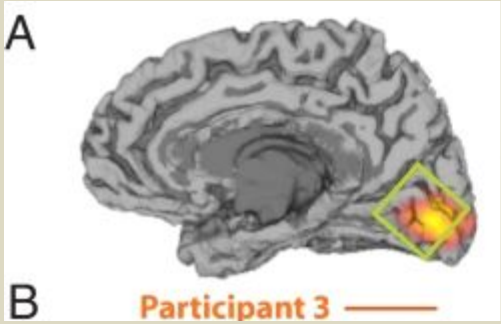
Google Ngram viewer
Thanks to Laurence Hunt and Tim Behrens

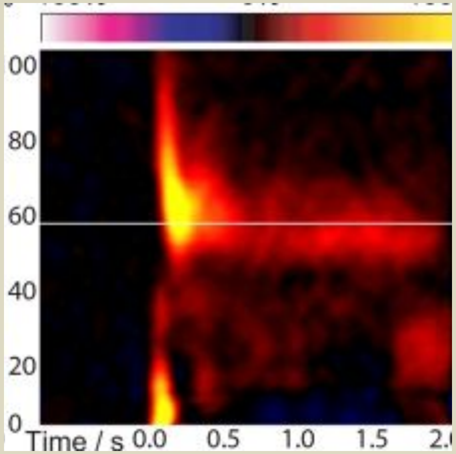
Local Field Potential (LFP) / BOLD

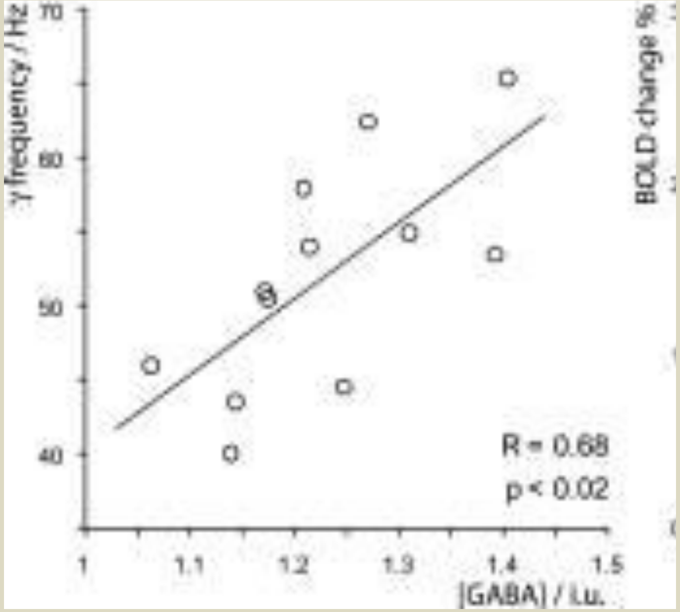


Logothetis 2003

- Note that the huge dimensionality of the data allows you to infer a lot more than source location.. (DCM talks tomorrow)
- For example, gamma frequency seems to relate to amount of GABA.

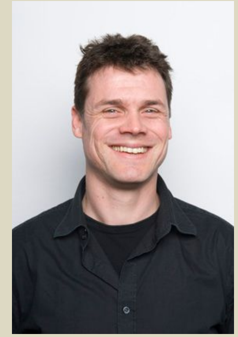






Muthukumaraswamy et al. 2009


Karl Friston


Arjan Hillebrand


Will Penny


Stefan Kiebel

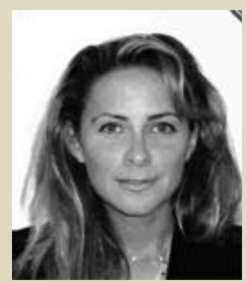

Marta Garrido


Jean Daunizeau


James Kilner


Vladimir Litvak


Guillaume Flandin


Rosalyn Moran


Rik Henson


Jérémie Mattout


JM Schoffelen


Christophe Phillips