Basis of the MEG/EEG Signal

19BMB301

DIAGNOSTIC AND THERAPEUTIC EQUIPMENT

UNIT - 1

Overview

EEG basics

MEG basics

EEG vs. MEG

Advantages & Disadvantages

Summary

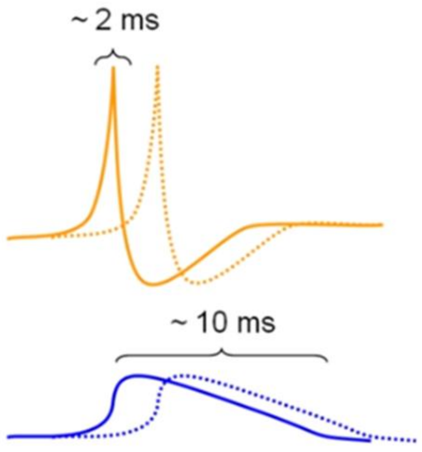
EEG: introduction

- **Electroencephalogram** (EEG) electrodes
- Scalp recording of **electrical activity** of cortex => waveform signals
- **Microvolts** (µV) – small!
- Role of EEG in neuroimaging:
  - Identify **neural correlates**
  - **Diagnose** epilepsy, sleep disorders, anaesthesia, coma, brain death

http://opencc.co.uk/blog/out-of-touch-manual-keypads-and-controllers-face-competition-from-new-hands-free-computer-interfaces/

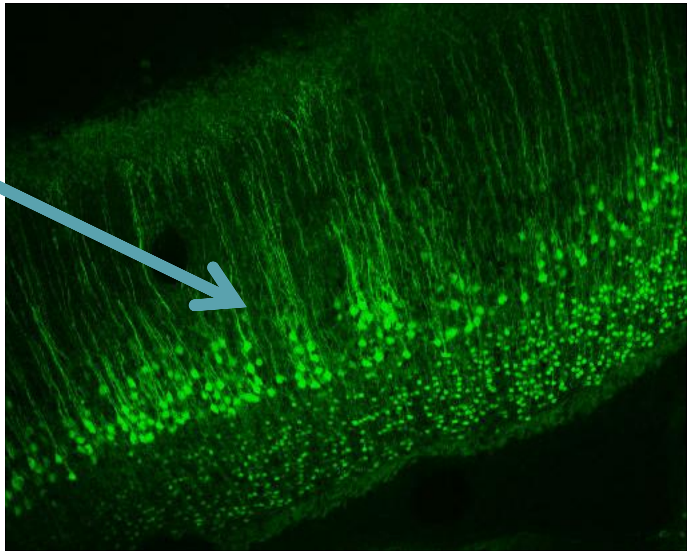
EEG: basis of the signal

- PSPs can be excitatory or inhibitory
- MEG/EEG reflects the **summation of synchronous PSPs** across a population of cells, at a point in time.
- **Large pyramidal neurons** in cortex layer V are:
  - ✓ arranged in parallel
  - ✓ similarly-oriented
  - ✓ perpendicular to surface
  - ✓ receive synchronous inputs



Action potentials are biphasic – do not summate

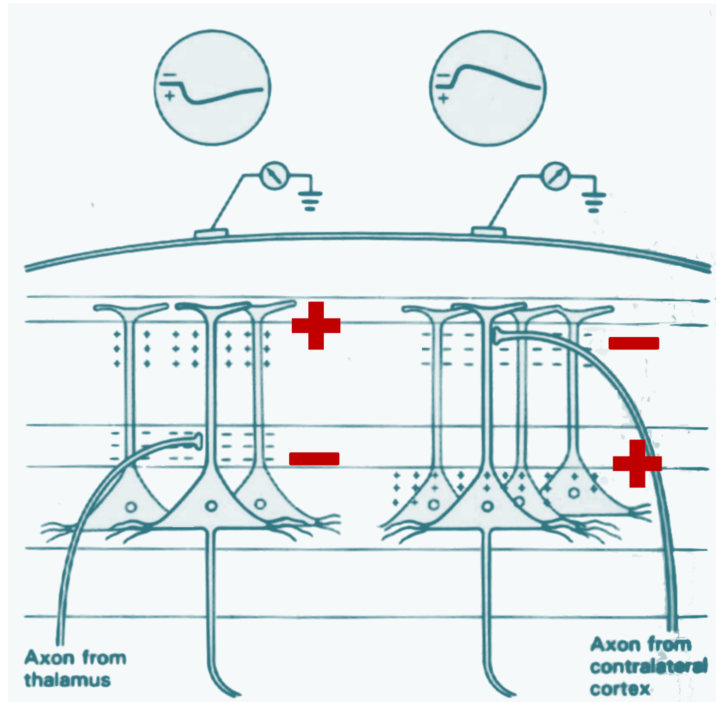
Postsynaptic potentials (PSPs) are monophasic – ideal for summation

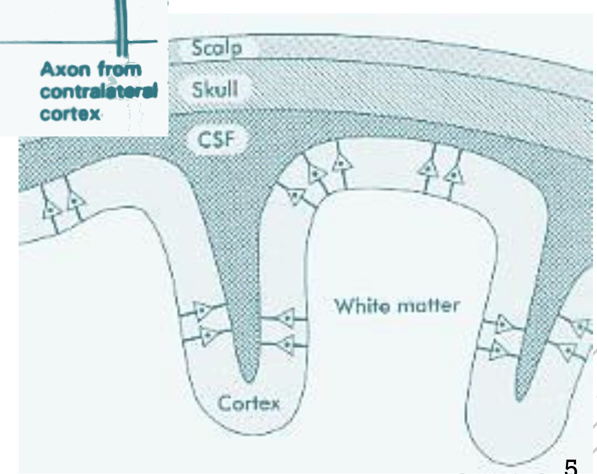


http://www.gensat.org/imagenavigator.jsp?imageID=29099

EEG: basis of the signal

- Dipole exists between soma and apical dendrites
- Potential behaves as if a **current flow**
- EEG electrodes on scalp detects net **positive** or net **negative** current flow from cortical neurons in both sulci and gyri

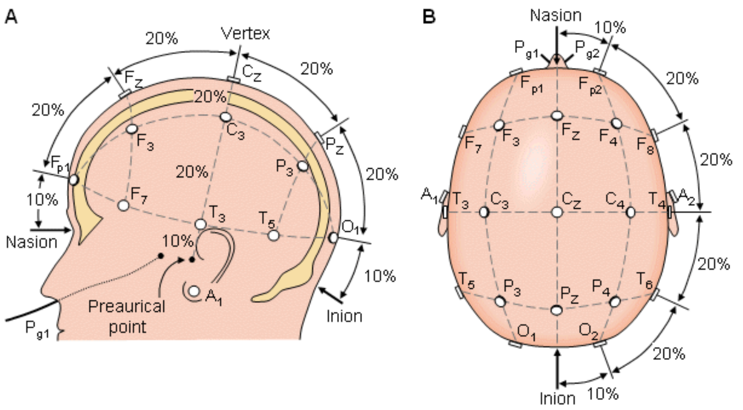


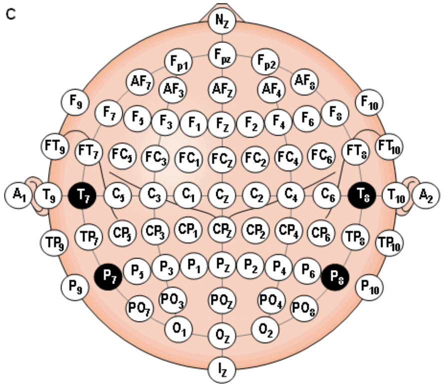


Kandel et al 1991. *Principles of Neural Science*

EEG: surface recordings

- **International** 10/20 or 10/10 system for placing electrodes:
  A: earlobes, **C:** central,
  P: parietal, **F:** frontal,
  O: occipital
- Low impedance 5-10kΩ
- Record **montages:**
  - **Bipolar** (electrodes connected to each other)
  - **Referential** (electrodes connected to one reference)



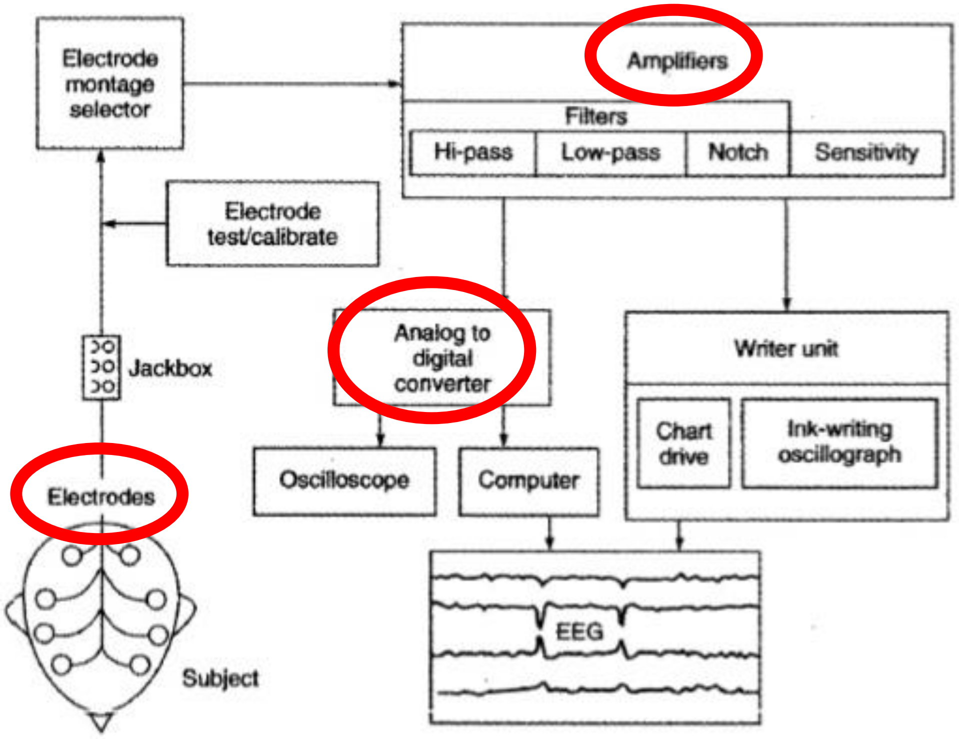


Malmivuo & Plonsey 1995.

http://www.lucid.ac.uk/news-and-events/blogs/how-to-study-language-why-do-we-put-electrodes-on-people-s-heads/

EEG: conducting studies

- **Digital**
  - **Electrode** array (32-256)
  - **Amplifier** (1 per pair of electrodes)
  - **Analogue-Digital Converter:** waveform into numerical values
  - Most digital systems sample at 240Hz
  - (Sampling rate should be 2.5x your frequency of interest)



Kallara 2012.

EEG: frequency spectrum

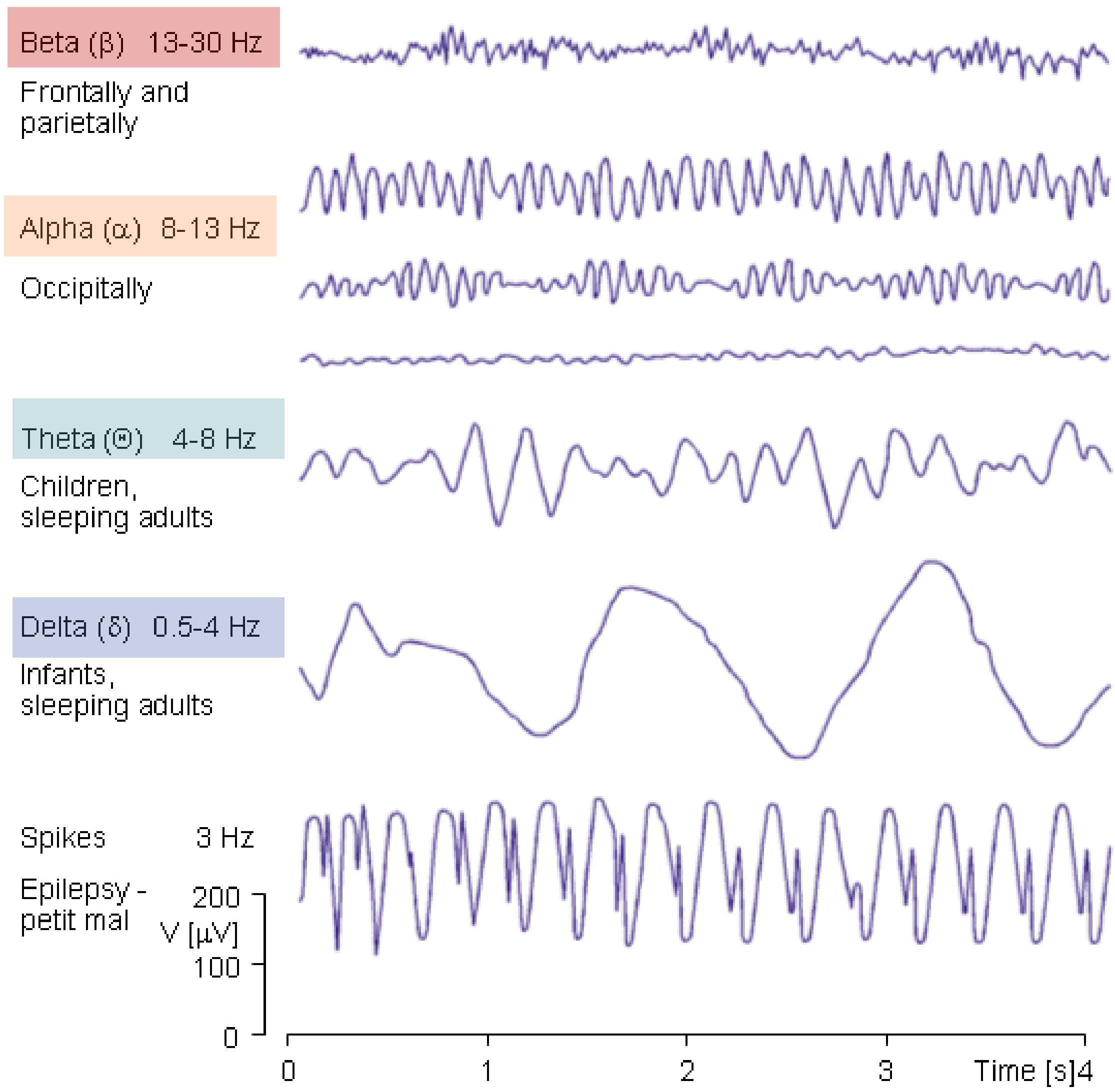
- **5-50 µV**, mostly below 30 µV
- Sharp spike-waves, **light sleep** stages

- **5-120 µV**, mostly below 50 µV
- **Awake**, eyes closed, mental inactivity, physical relaxation

- **20-200 µV**
- Strictly rhythmic or highly irregular
- Awake & drowsiness, **light sleep** stages
- LTP and phase-encoding

- **5-250 µV**
- Abnormality in waking adults, accompaniment of **deep sleep**

+ Gamma waves?
31-100 Hz, 10 µV
'binding of consciousness', unity of perception

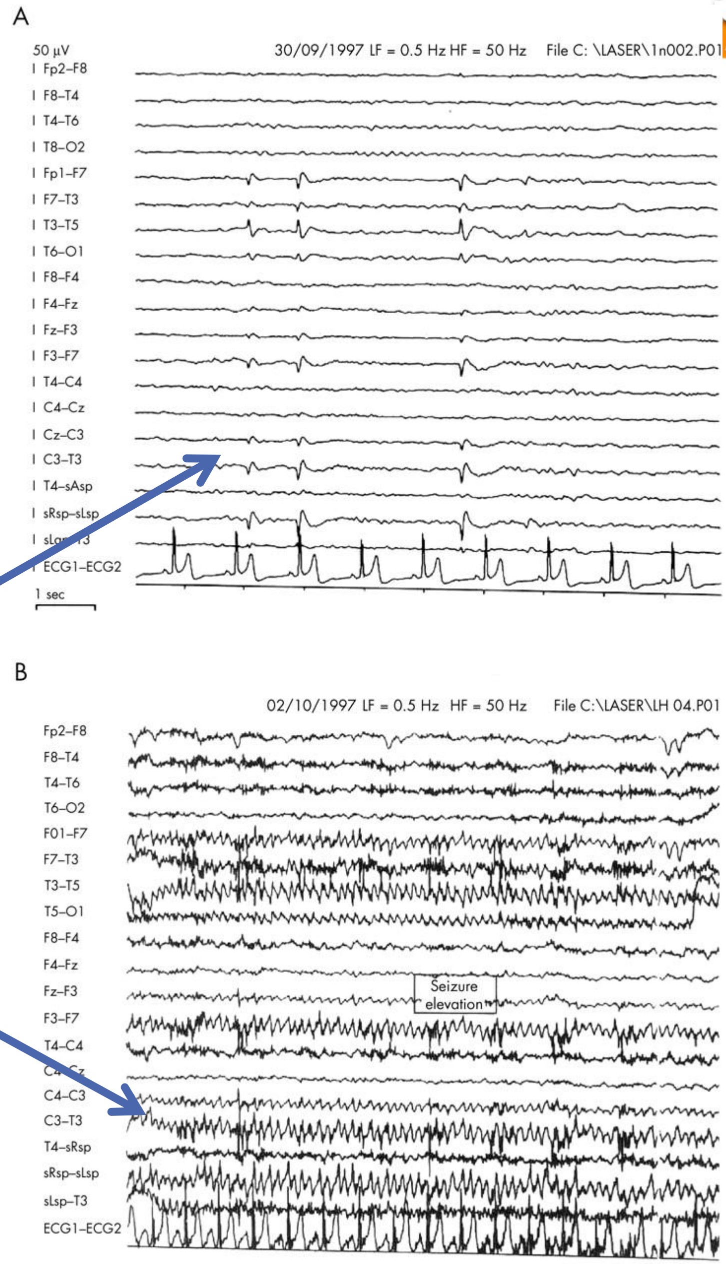


Tiege and Zlobinski, 2006

EEG studies

Smith (2005) **"EEG in the diagnosis, classification, and management of patients with epilepsy"** *BMJ*

- **Fig. 2:** mesial temporal lobe epilepsy associated with hippocampal sclerosis
  - **A**: **interictal spikes** over temporal lobe
  - **B:** characteristic rhythmic **ictal discharges** (theta, 5-7Hz) accompanying seizure



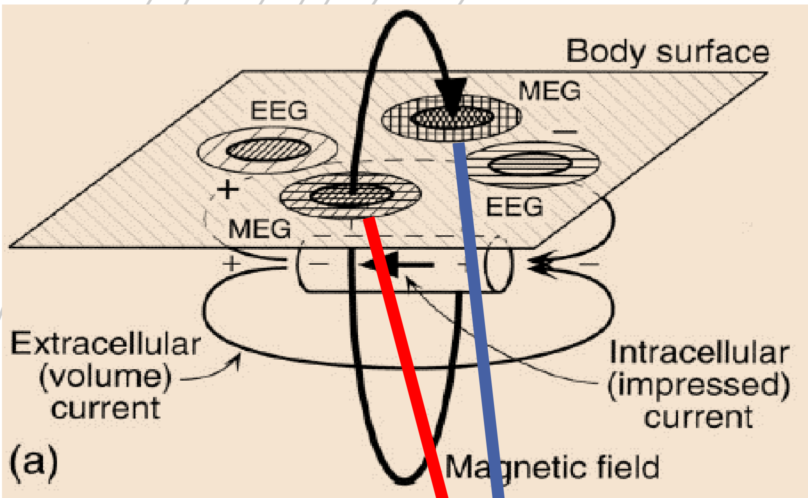
Smith 2005

MEG: introduction

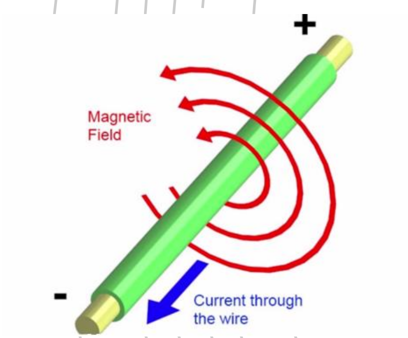
http://www.admin.ox.ac.uk/estates/capitalprojects/previouscapitalprojects/megscanner/

- **Magnetoencephalography**
- Direct external recordings of **magnetic fields** created by electrical currents in cortex
- Measured in **fT** to **pT**
- Role of MEG in neuroimaging:
  - **Neural correlates** of cognitive/perceptual processes
  - **Localise** affected regions before surgery(?), determine regional and network functionality

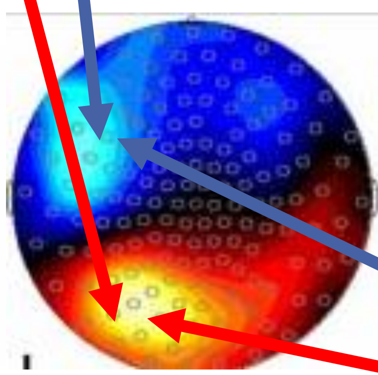
MEG: basis of the signal



Tiege & Zlobinski, 2006



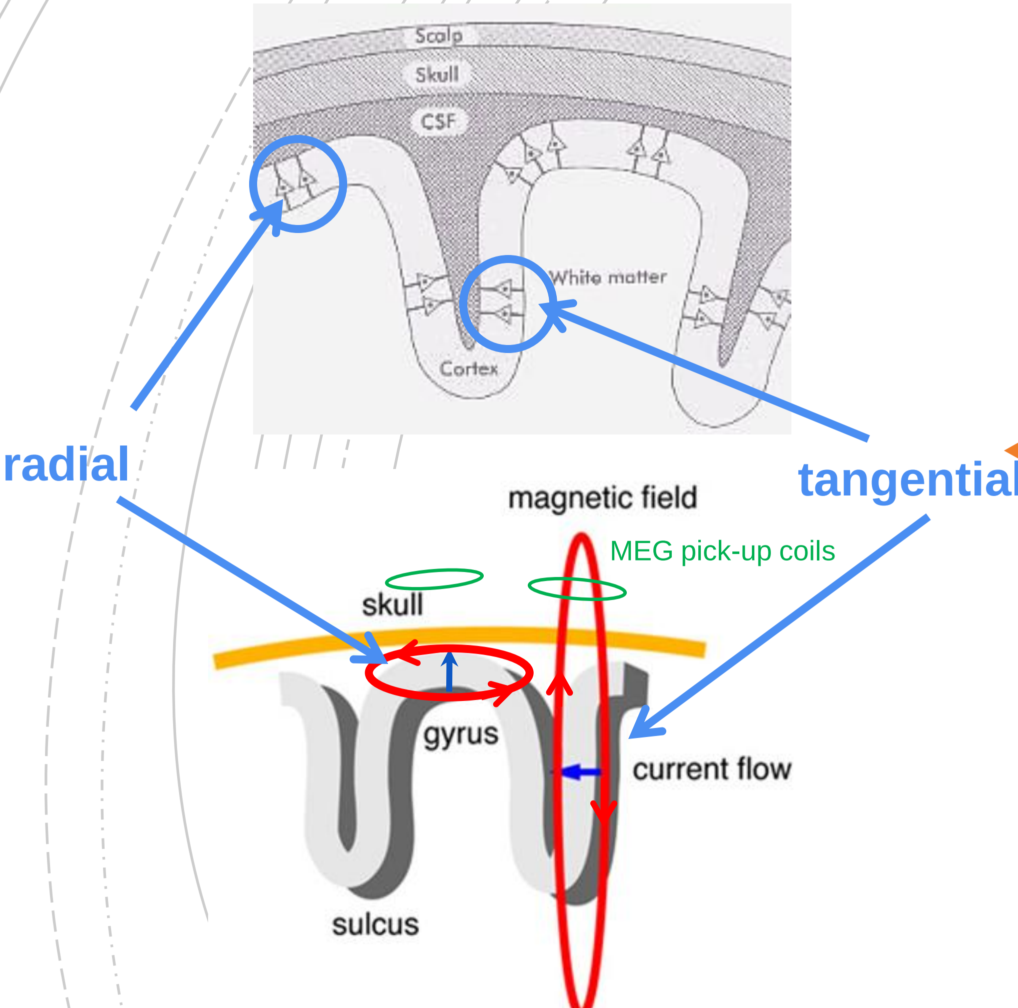
http://www.youtube.com/watch?v=CPj4jJACeIs



Ochi et al. 2011

- Recall: **large pyramidal neurons** in layer V of cortex, arranged in parallel, similarly-oriented, perpendicular to surface, fire synchronously
- Dipolar current flow generates a **magnetic field.**
  TRY IT: 'Right hand grip'!
- **10,000 to 50,000** active neurons required for detectable signal
- **Scalp topography:**
  - Influx maxima 'source'
  - Efflux maxima 'sink'

MEG: tangential vs. radial



- MEG magnetic field **not distorted** by conductive properties of scalp/head
- MEG coil not sensitive to **perfectly radial sources**
- But in practice, only a **small proportion (<1%)** of cell populations are perfectly radial – i.e. on top of gyri

Tiege and Zlobinski, 2006

MEG: scale of magnetic field

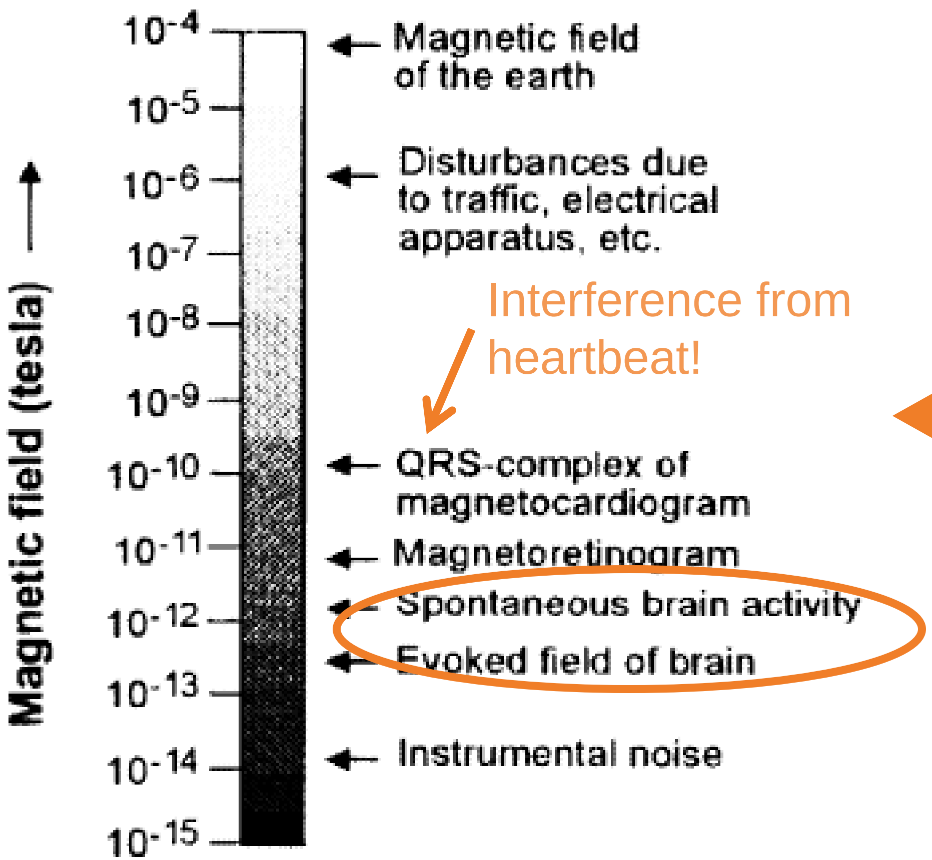


Figure I.3: *Comparison of field strengths*

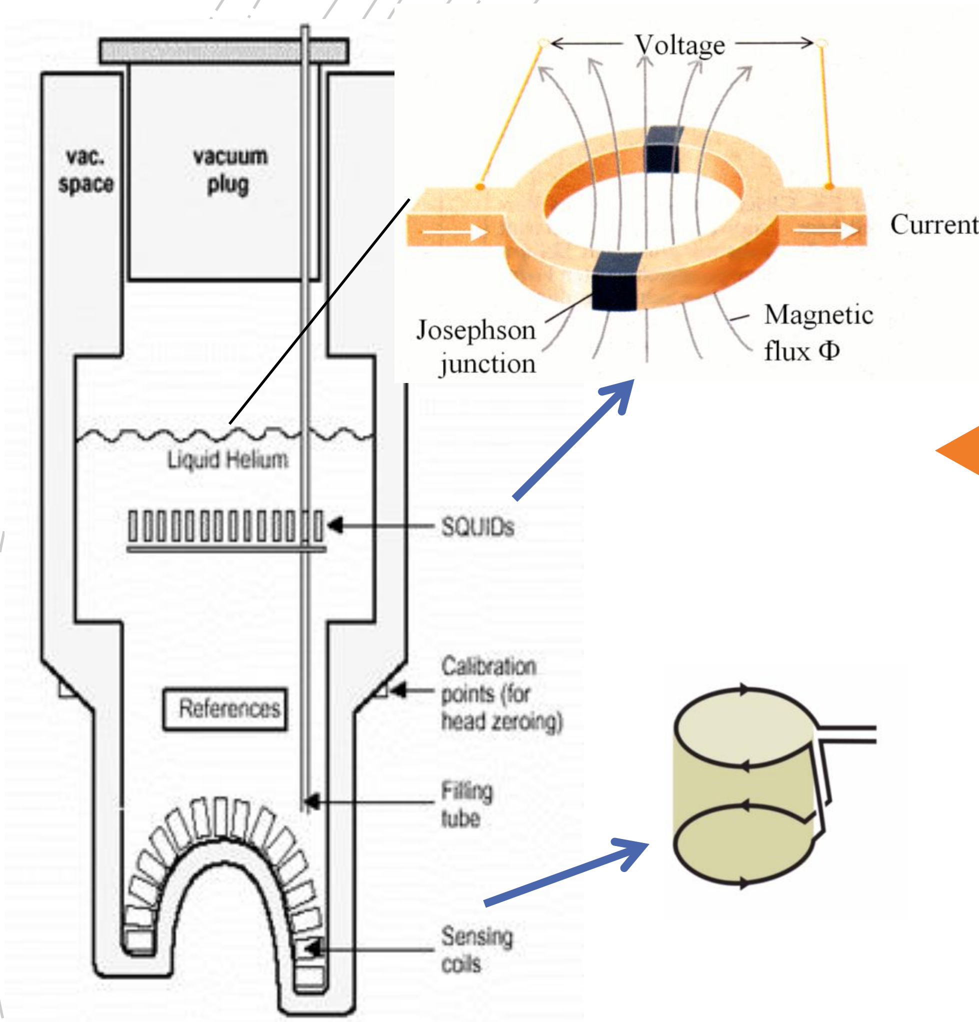
- MEG signal is **tiny!**
- **Interference** from electrical equipment, traffic, the earth, participant's heartbeat etc.
- Requires **magnetically shield rooms** and **supersensitive magnetometers**

MEG: magnetically shielded room (MSR)

Brock & Sowman (2014)

- 3, 5 or 6 layers with different magnetic properties to protect from different frequencies of magnetic interference

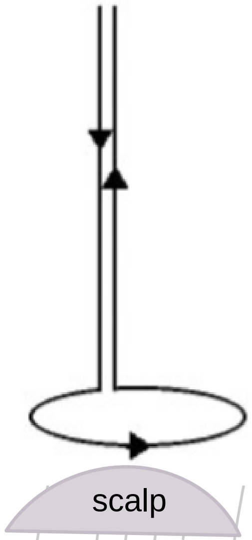
MEG is super-cool

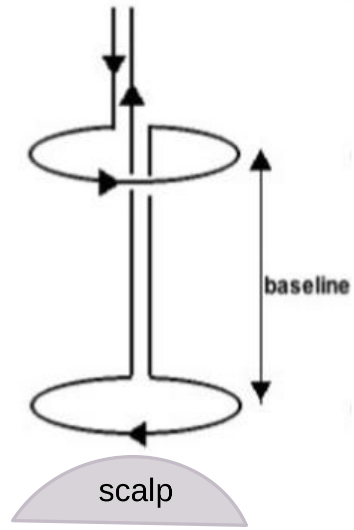


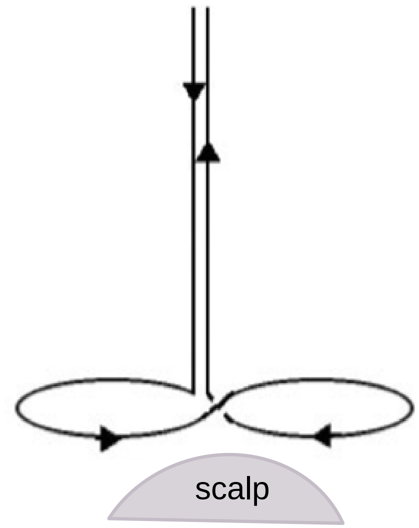
- **SQUID**
- **S**uperconducting **QU**antum **I**nterference **D**evice, immersed in super-cool liquid helium
- Sensitive to field changes in order of **femto-Tesla** (10^{-15})
- Superconductive ring with two **Josephson junctions**
- **Flux transformers** (coils)
  - Magnetometers
  - Gradiometers (planar/axial)

http://www.csiro.au/~/media/CSIROau/Images/Maps%20%20Graphs/SQUID_CESRE_ind/High_Resolution.gif

MEG: flux transformers





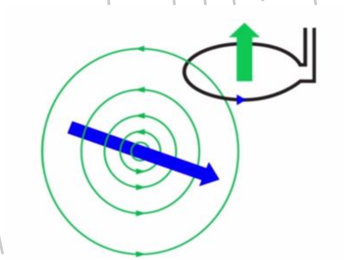


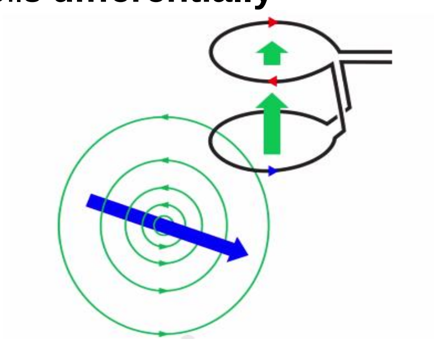
Axial magnetometer

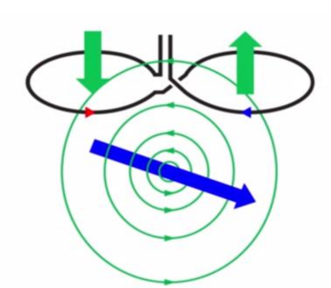
Single superconducting coil – highly sensitive but affected by environmental noise

Axial/planar gradiometers (1st order)

Two oppositely-wound coils – environmental noise affects both electrodes : **no net noise.** Sources from cortex affect coils **differentially**



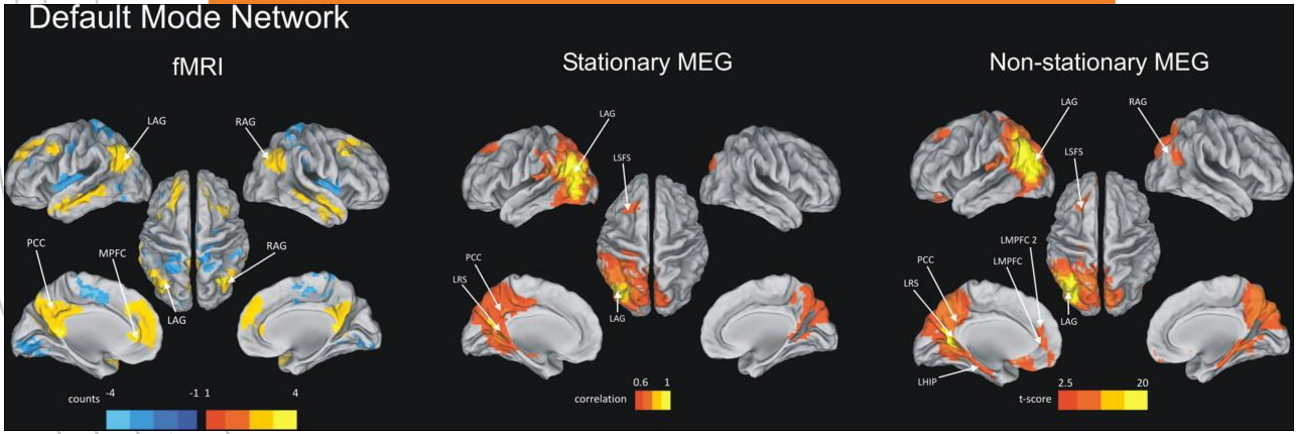




http://www.youtube.com/watch?v=CPj4jJACeIs

MEG: applications

- **Excellent spatial resolution**
  - good for functional mapping of specific cortex (M1, V1) during behavioural, cognitive, perceptive tasks
- **Surgical planning (?)** in patients with brain tumours or intractable epilepsy
- **Research** into whole-brain network connectivity
  - Millisecond temporal resolution



de Pasquale et al (2010)

EEG vs. MEG

	EEG	MEG
Signal magnitude	10 mV (easily detectable) ✓	10 fT (magnetic shielding required)
Measurement	Secondary currents	Primary currents ✓
Signal purity	Distortion by skull/scalp	Little effect by skull/scalp ✓
Temporal resolution	~1ms	~1ms
Spatial resolution	~1cm	<1cm ✓
Experimental flexibility	Moves with subject ✓	Subject must remain stationary
Dipole orientation	Tangential and radial ✓	Tangential better

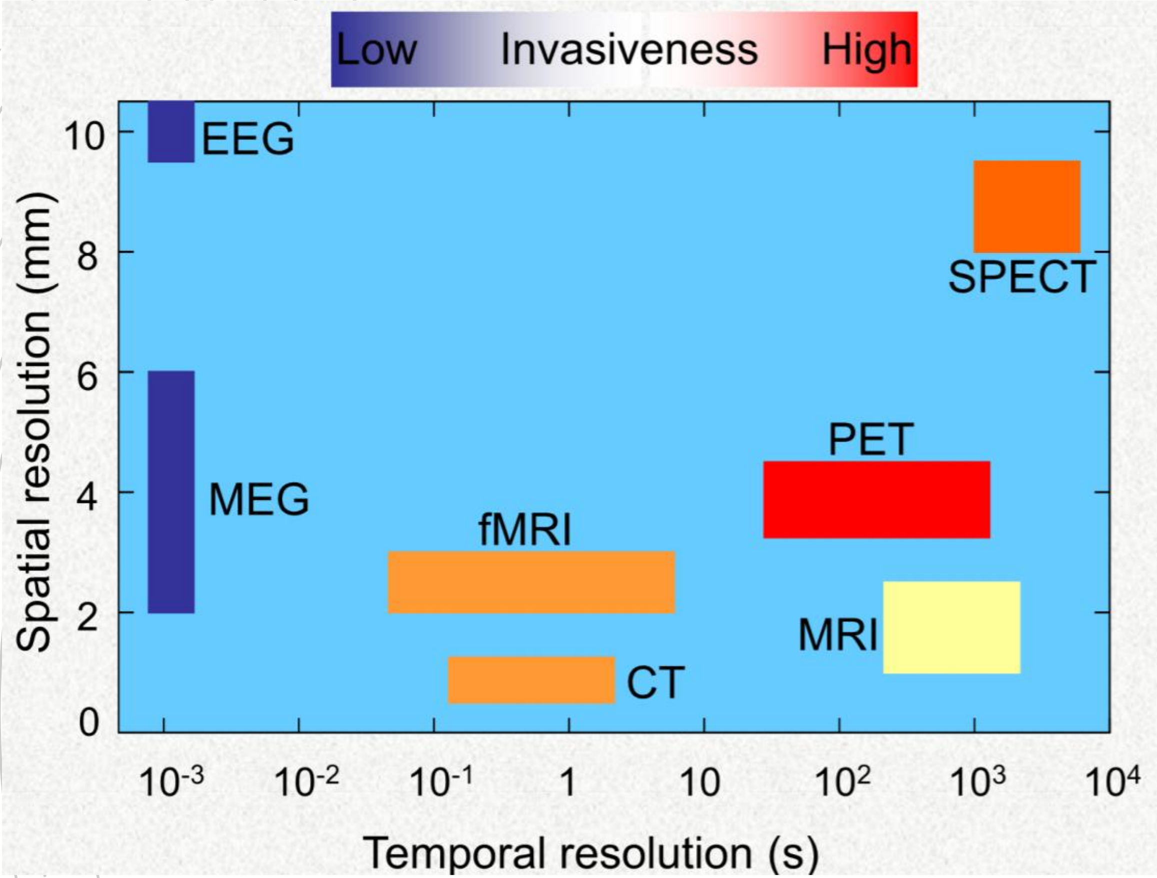
EEG/MEG advantages

- ✓ **Non-invasive**
- ✓ **Direct** measurements of neuronal function (unlike fMRI)
- ✓ High **temporal resolution** (1ms or less, 1000x better than fMRI)
- ✓ Easy to use **clinically** (adults, children)
- ✓ **Quiet!** (can study auditory processing)
- ✓ **Affordable**, EEG is portable
- ✓ Subjects can perform tasks **sitting up** (more natural than MRI scanner)

https://www.colbertnewshub.com/2013/04/05/april-4-2013-dr-francis-collins/

https://medicalxpress.com/news/2015-02-brain-imaging-links-language-chromosome.html

EEG/MEG disadvantages



- Not as good **spatial localisation** as fMRI, MRI, CT
- **Sensitivity depth** only ~4cm (c.f. whole brain sensitivity of fMRI)
  - Sensitivity loss proportional to square of distance from sensor
- 3D Source reconstruction is ill-posed? **forward** and **inverse problems**

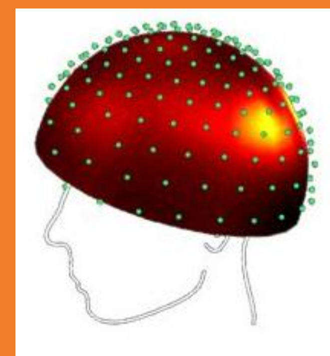
https://ngp.usc.edu/files/2013/06/Syed__EEG_MEG.pdf

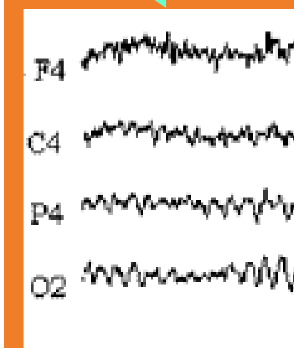
Forward & inverse problems

Forward modelling:

easy!

Neuronal activity/ Current density





EEG/MEG Sensor data

Inverse problem:
More possible solutions for sources than there are sensors: ill-posed!

https://www.youtube.com/watch?v=AogBOXtXk1s

→**SOLUTION:** Use forward models for inverse problem. Source localisation models and algorithms; iterative source reconstruction

Summary

- **Direct,** non-invasive measures of cortical electrical activity
  - **EEG**: secondary currents,
  - **MEG**: magnetic fields
- Good **spatial & temporal** resolution
- **Depth sensitivity?**
  - Add thalamus, hippocampus, amygdala to MEG source reconstruction models (!)
- **Spontaneous** or **evoked** neural activity;
- **Applications** in epilepsy, sleep, Alzheimer's disease biomarkers(?), schizophrenia(?), autism(?), whole-brain functional networks

Thank you for listening!

Any questions?

Sources

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(and Dr. Sofie Meyer)

Sources (cont)

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