Advanced Cognitive Neuroscience

Week 40: Basic physiology and Evoked responses

The course plan

Week 36:
Lesson 0: What is it all about?
Class 0: Setting up UCloud and installing MNE-Python

Week 37:
No Teaching

Week 38:
Lesson 1: Workshop paradigm: Measuring visual subjective experience + MR Recordings
Class 1: Running an MEG analysis of visual responses

Week 39:
MEG workshop: Measuring and predicting visual subjective experience

Week 40:
Lesson 2: Basic physiology and Evoked responses
Class 2: Evoked responses to different levels of subjective experience

Week 41:
Lesson 3: Multivariate statistics
Class 3: Predicting subjective experience in sensor space
Deadline for feedback: Video Explainer

Week 42:
Autumn Break

Week 43:
Lesson 4: Forward modelling and dipole estimation
Class 4: Creating a forward model

Week 44:
Lesson 5: Inverse modelling: Minimum-norm estimate
Class 5: Predicting subjective experience in source space

Week 45:
Lesson 6: Inverse modelling: Beamforming
Class 6: Predicting subjective experience in source space, continued

Week 46:
Lesson 7: What about that other cortex? - the cerebellar one
Class 7: Oral presentations (part 1)
Deadline for feedback: Lab report

Week 47:
Lesson 8: Guest lecture: Laura Bock Paulsen: Respiratory analyses
Class 8: Oral presentations (part 2)

Week 48:
Lesson 9: Sensors of the future
Class 9: Oral presentations (part 3)

Week 49:
Lesson 0 again: What was it all about?
Class 10: Oral presentations (part 4)

Guest lecture + MEG NORD

Video explainer

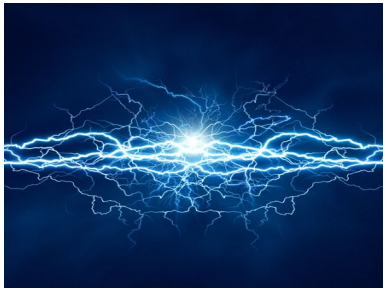
- Concepts to explain
  - post-synaptic potentials
  - current dipole,
  - open field vs closed field
  - radial and tangential sources
  - volume conduction
  - evoked responses
- Deadline Thursday next week (for feedback)

Video explainer

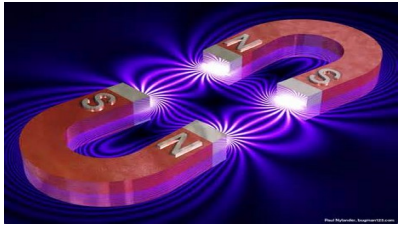
Just you talking, explaining the relevant concepts. You can gesture, but no props and no screen recordings (only I will see it)

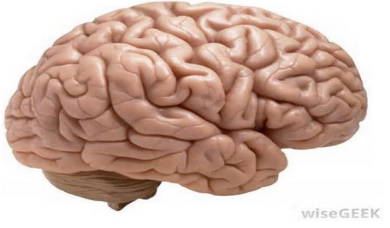
Learning goals

- Learning
  - where the electrophysiological signals mainly originate from
  - where and how are the electrophysiological signals measured
  - how the signals measurable from radial and tangential dipoles differ



Electro·encephalo·graphy (EEG)
Magneto·encephalo·graphy (MEG)





When to use MEEG:

Interested in temporal aspects (< 1 ms)

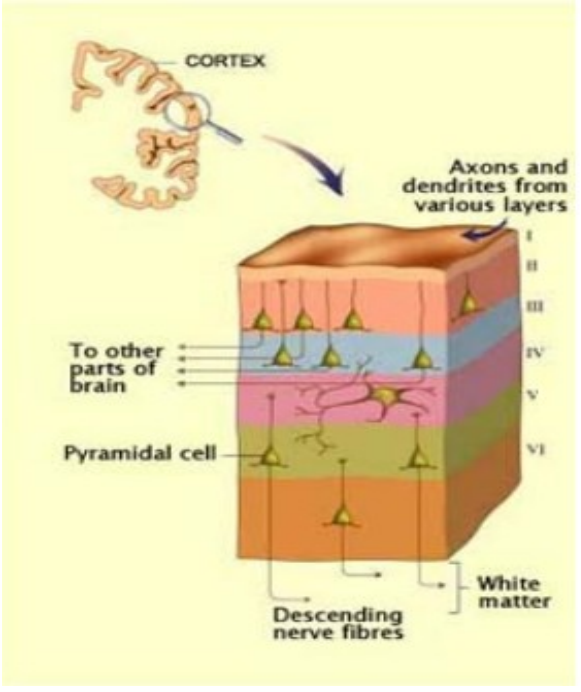
Interested in *both* temporal and spatial aspects (< 1 cm)

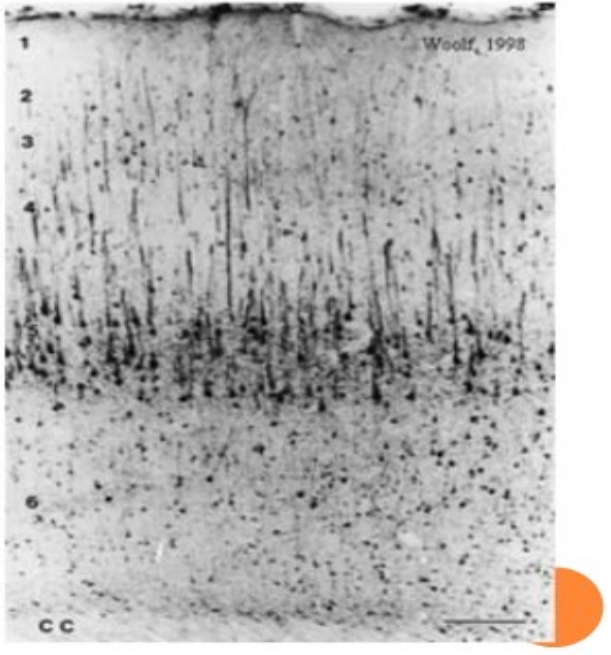
When to use fMRI:

Interested mainly in spatial aspects (<1 mm)

What generates the magnetic field and the electric potential?

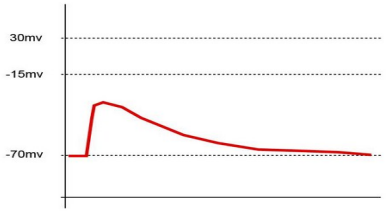
(Primarily) pyramidal cells in the neocortex





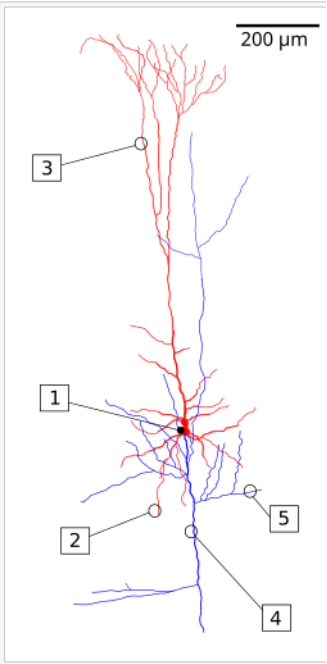
What generates the magnetic field?

(Primarily) the excitatory post-synaptic potentials in apical dendrites in pyramidal cells in the neocortex



Excitatory Post-Synaptic Potential

Action potentials are too brief to sum temporally, and the axons do not sum spatially



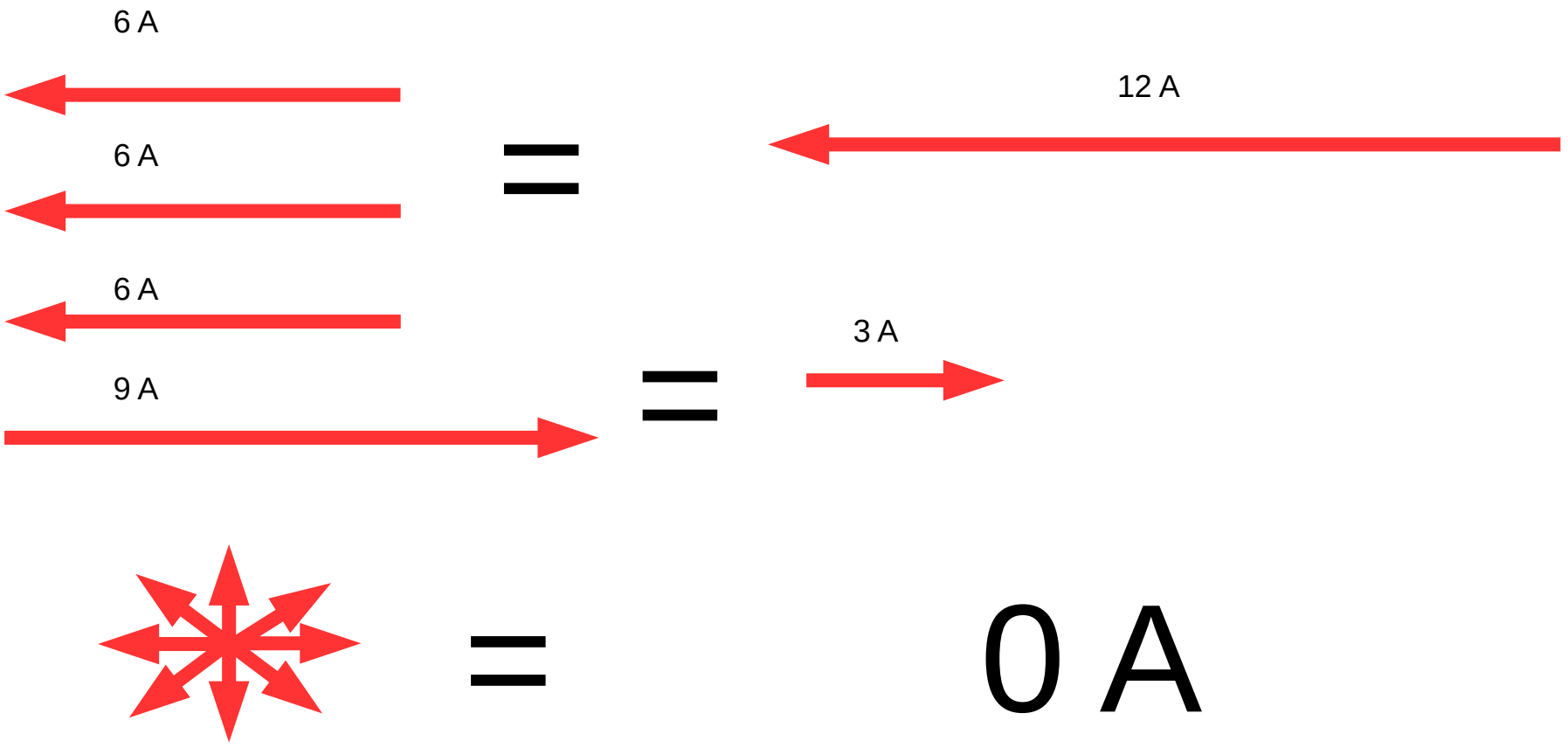
A reconstruction of a pyramidal cell. Soma and dendrites are labeled in red, axon arbor in blue. (1) Soma, (2) Basal dendrite, (3) Apical dendrite, (4) Axon, (5) Collateral axon.

By Fabuio - Own work, CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=60707501

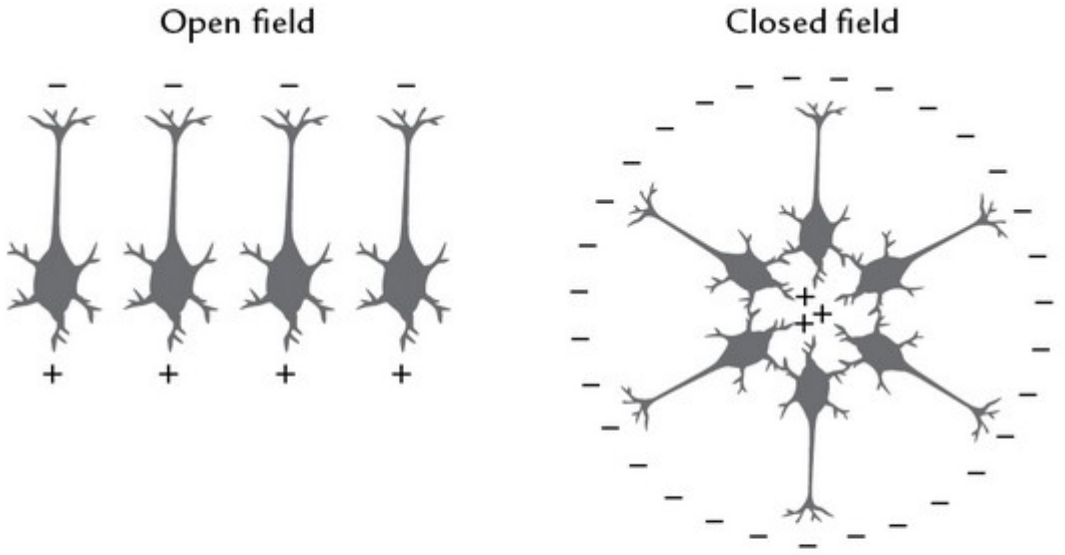
Single neurons can be seen with intracranial recordings, but generate signals many orders to weak to be seen at the scalp where we measure

Can we see the SPATIAL and TEMPORAL summations if there are “many” neurons firing at the same time?

SPATIAL Summation of currents



Open and closed fields

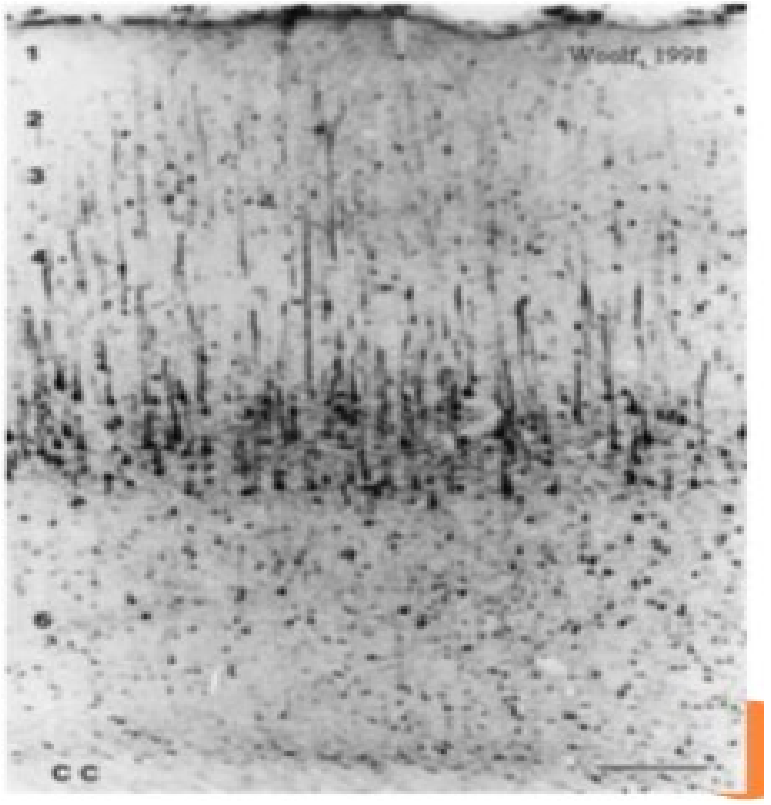


Hari and Puce, 2023

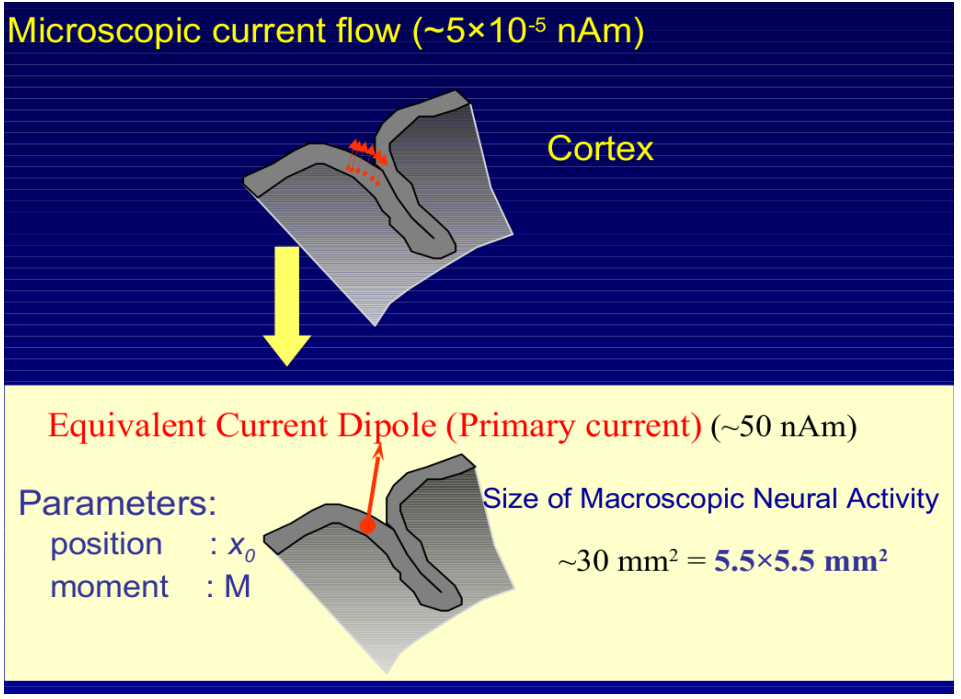
FIGURE 3.5. Open and closed fields. Polarized (activated) pyramidal cells aligned side-by-side will produce an open field whose potential and magnetic field can be seen at a distance (left panel). If the same elements are in a random order, or are radially symmetric (right panel), they will form a closed field that cannot be seen with MEG nor EEG; instead, a locally sited electrode must be inserted very close to the cluster to be able to record the potential.

SPATIAL Summation of currents

The ordering of the dendrites of pyramidal neurons creates good conditions for seeing the SPATIAL summation of post-synaptic potentials, but not the action potentials along the axons

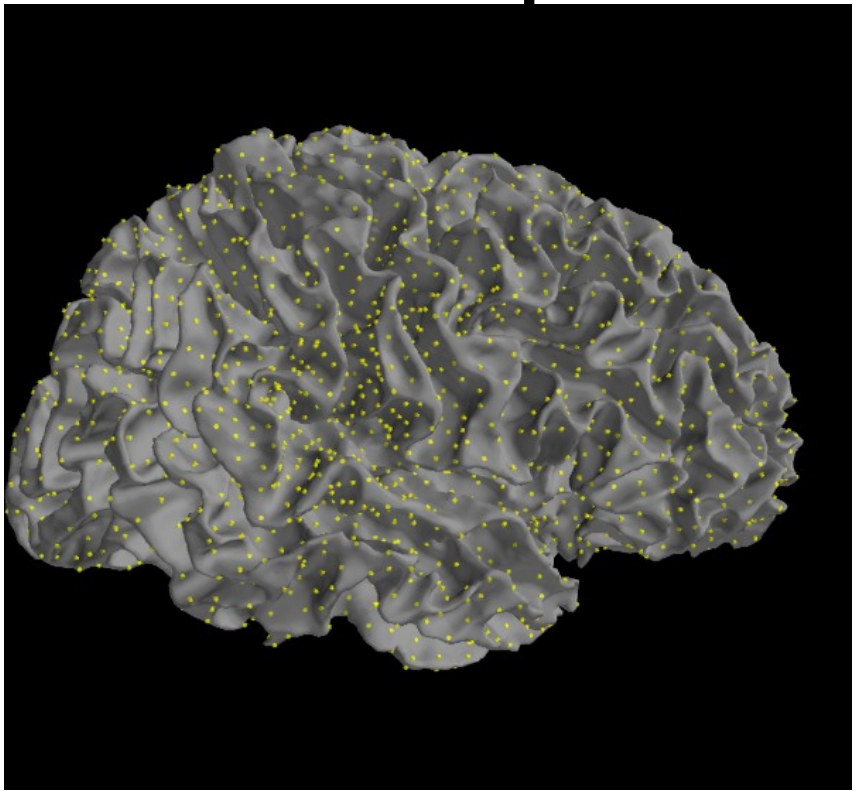


Equivalent Current Dipole



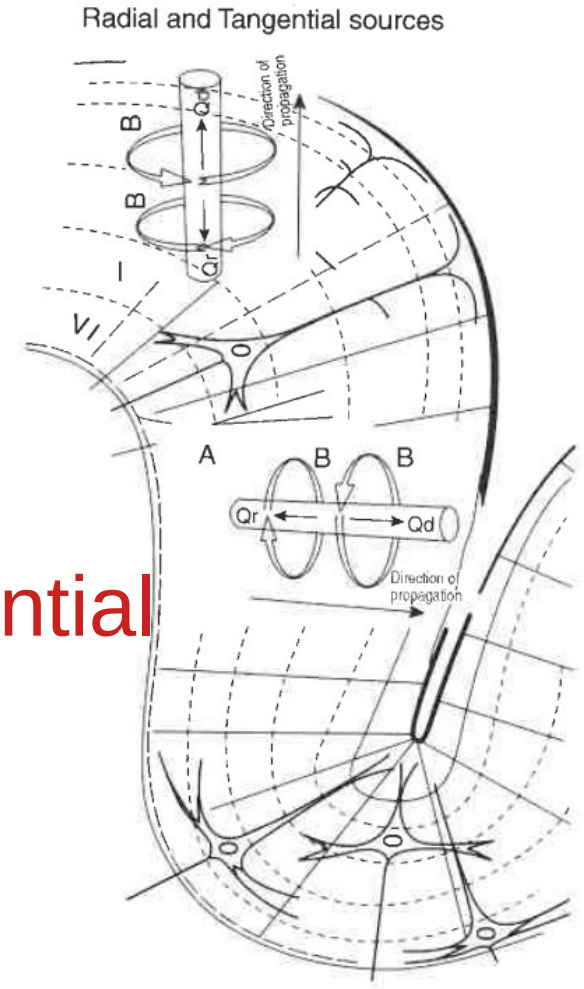
From Stephanie Sillekens

Source space with equivalent current dipoles



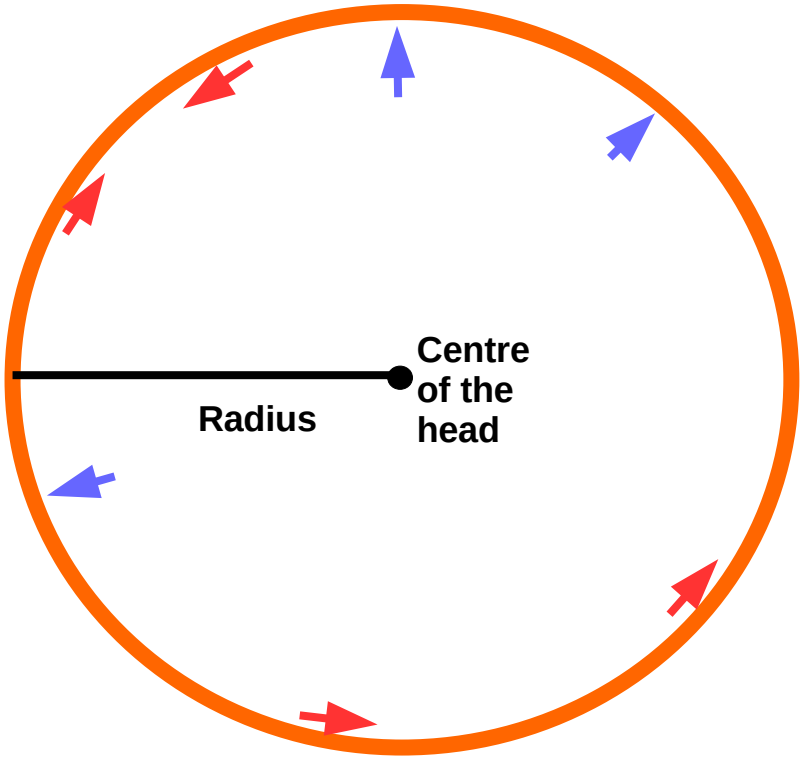
Radial

Tangential

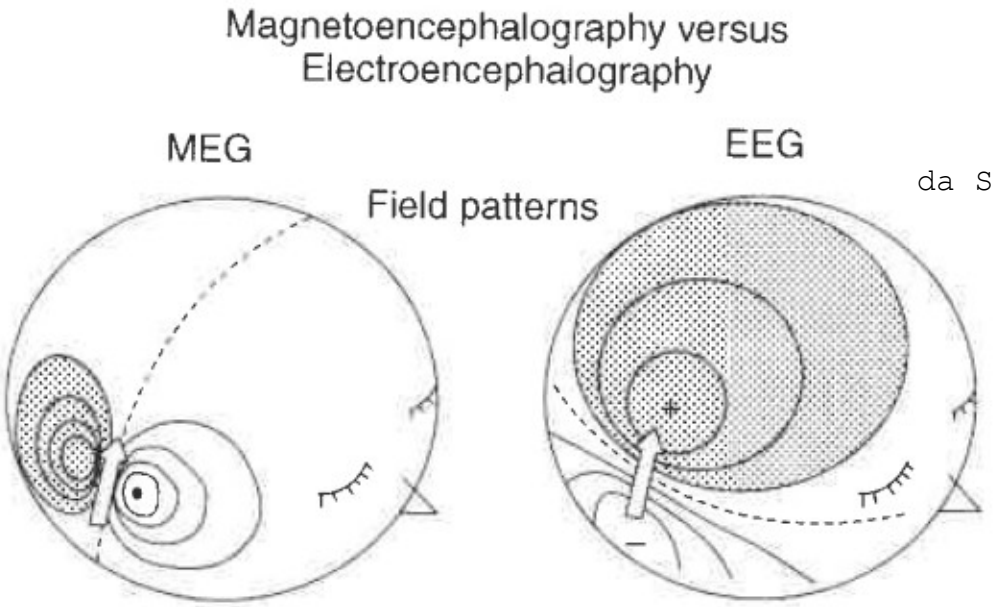


da Silva, 2010

Radial and tangential dipoles (primary current)

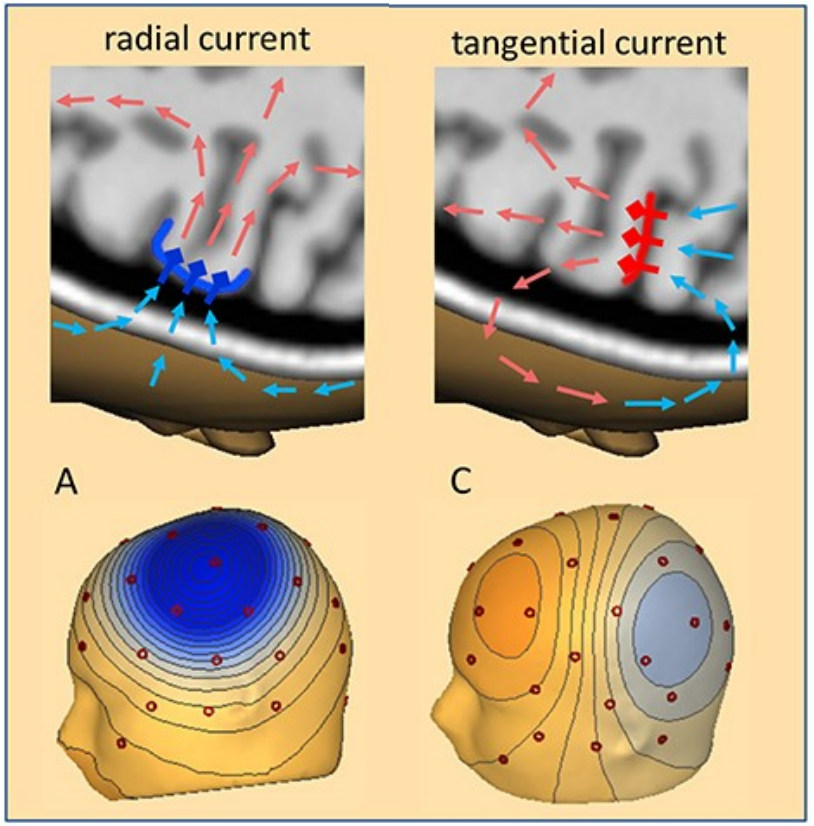


Tangential dipoles



da Silva, 2010

EEG – radial vs. tangential

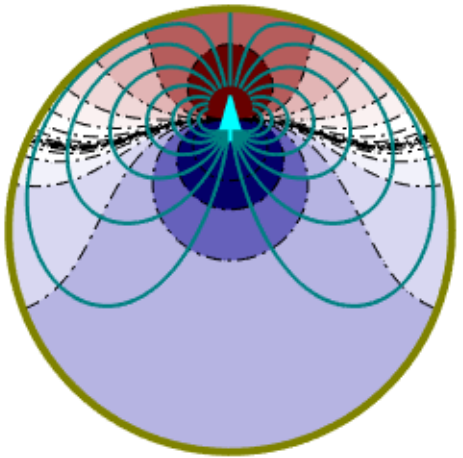


Scherg et al., 2019

MEG – what about radial sources?

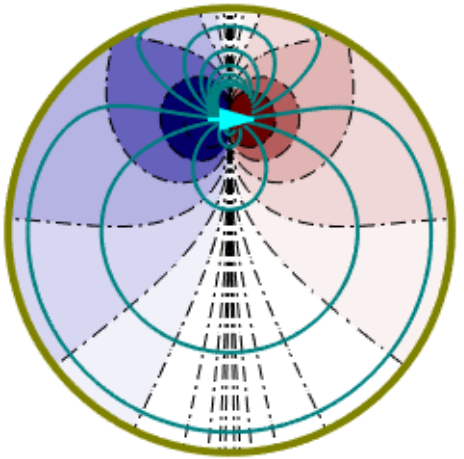
The magnetic field (*B*) is proportional to the vector sum of all electric current (Q_T). For a radial dipole, the primary current (Q_P) and the volume currents (Q_V) *cancel* one another ($Q_P + Q_V = Q_T = 0 \Rightarrow B = 0$) due to the perfect *symmetry* of the volume current in a sphere-shaped volume conductor

Radial



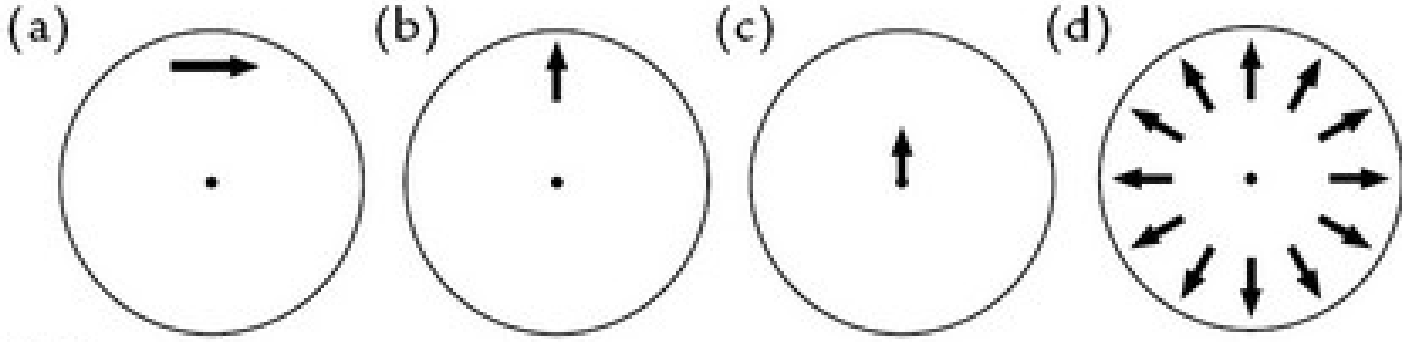
Courtesy of Christopher Bailey
https://github.com/cjaybb/meeg_training

Tangential



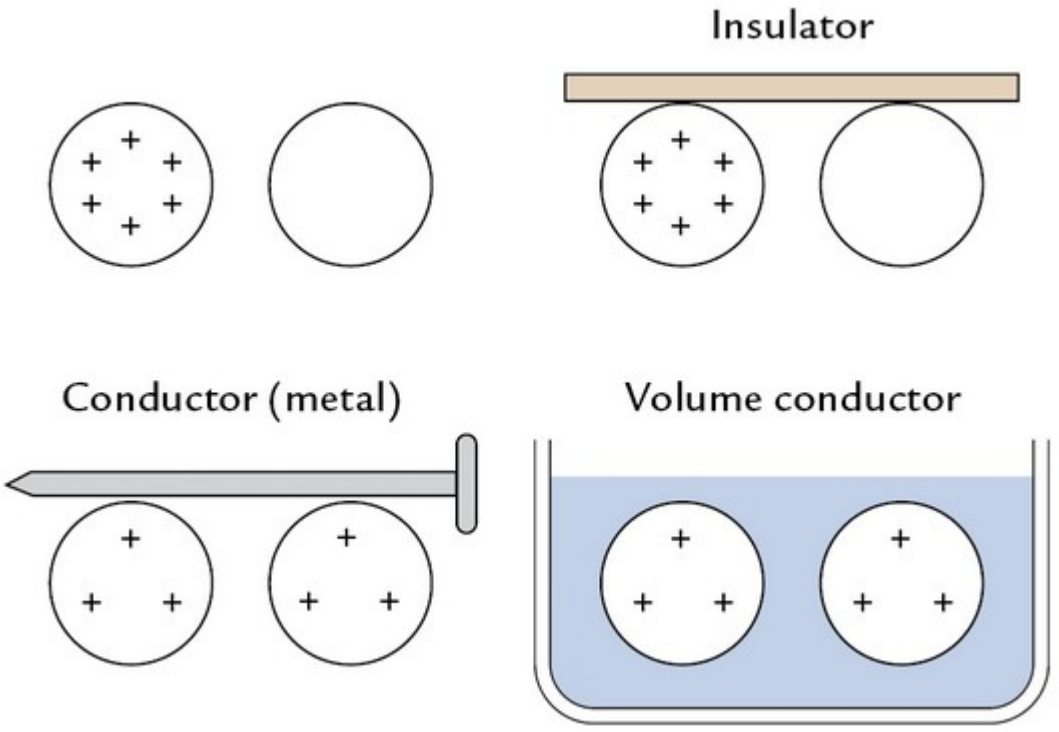
For a tangential dipole, the volume currents are *asymmetric*, thus $Q_T \neq 0 \Rightarrow B \neq 0$

Quiz



Hari and Puce, 2023

Volume conductor

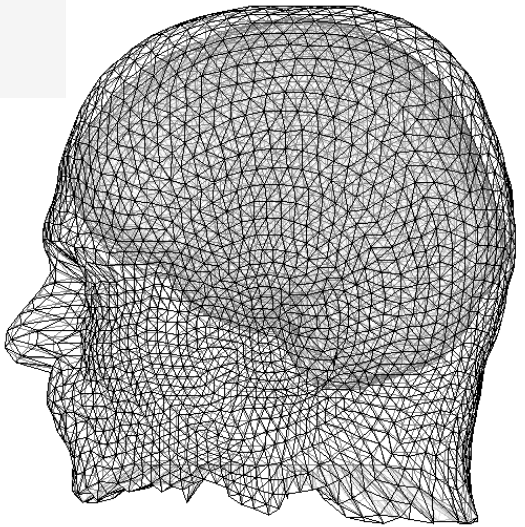


Hari and Puce, 2023

Volume conductor (head model)

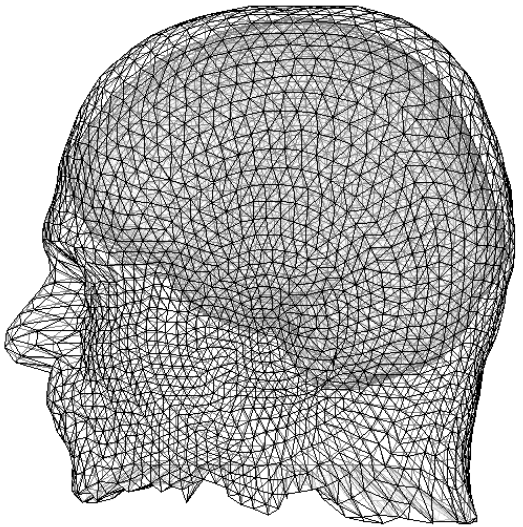
```
## BOUNDARY ELEMENT METHOD

## describe the surfaces and their conductivities
#bem_model = mne.bem.make_bem_model(subject=subject, subjects_dir=subjects_dir,
#                           conductivity=[0.3, 0.006, 0.3]) ## three layer model

## model how electrical potentials spread to the electrodes and how the
# currents of the brain are related to the magnetic field measured at the
# sensors
#bem_solution = mne.bem.make_bem_solution(bem_model)

bem_solution = mne.bem.read_bem_solution('../../subjects/sample/bem/sample-5120-5120-5120-bem-sol.fif')

print(bem_solution['solution'])
```

An anatomical model that models the conductivities of different tissues *bem*



Volume conductor (head model)

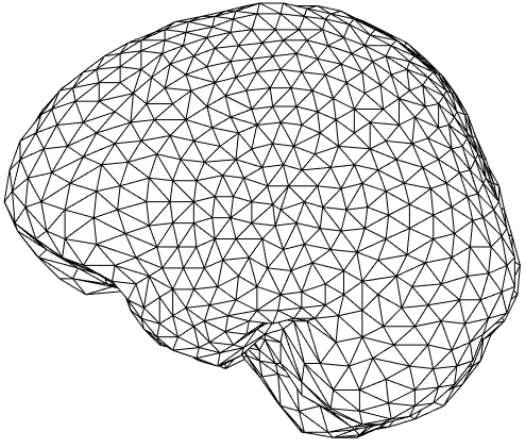
For *EEG*, we need to model the brain, skull and scalp with different conductivities (we are measuring volume currents)



Volume conductor (head model)

For MEG, the model can be much simpler since the magnetic field is roughly proportional to the magnitude of the primary current

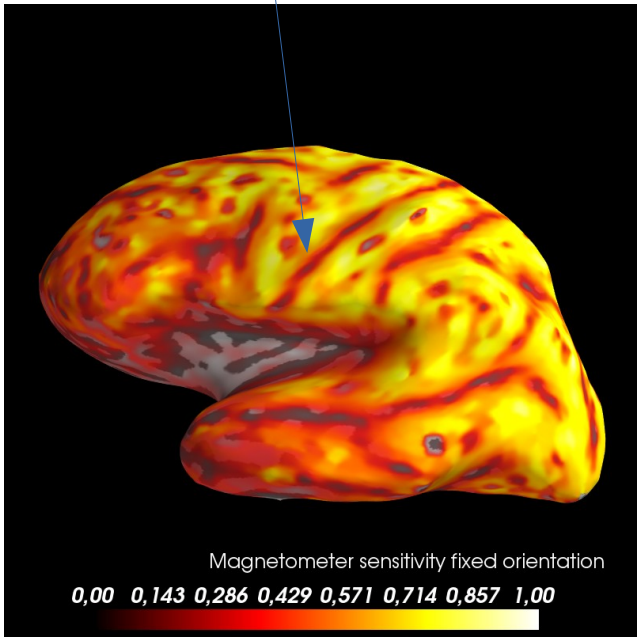
(This is why MEG has better spatial resolution than EEG)



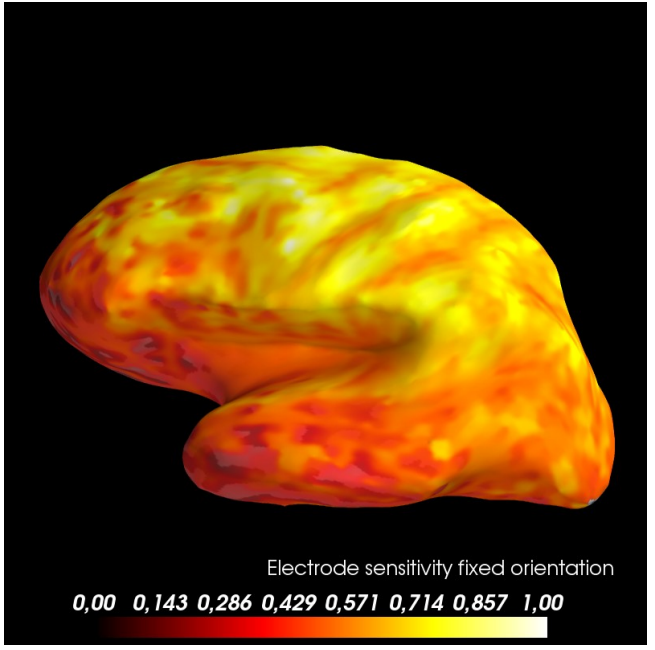
Sensitivity

Radial

MEG

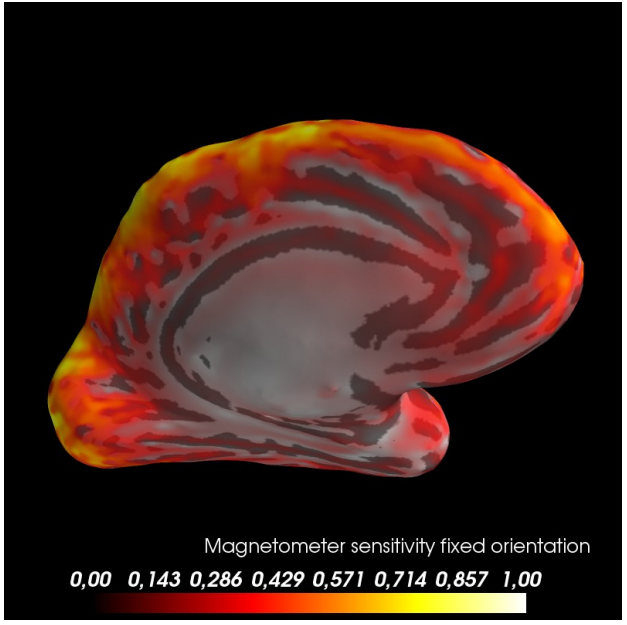


EEG

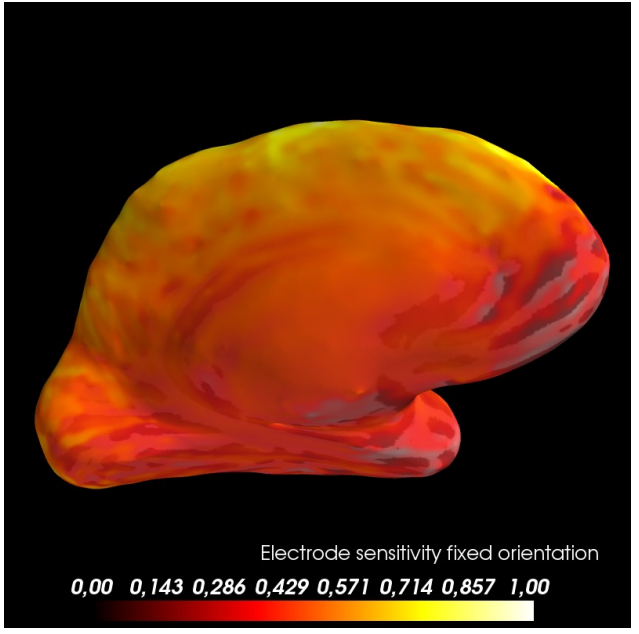


Sensitivity

MEG



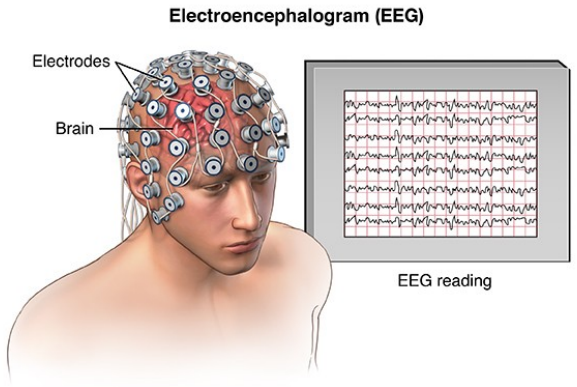
EEG



How to measure

Types of sensors

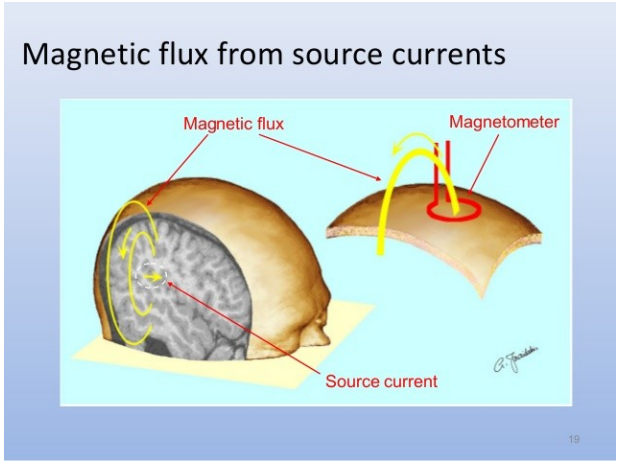
ELECTRODES



Measures electric potential [V] (the volume currents)
(relative to a reference electrode)

Don't have the details for these images

MAGNETOMETERS

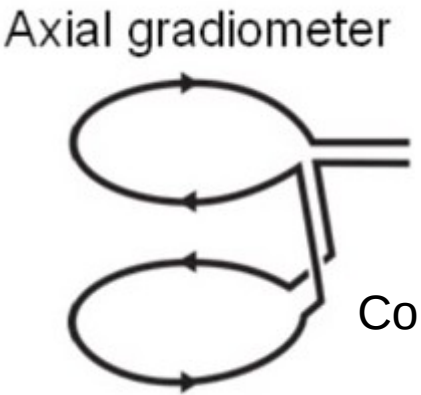


Measures magnetic flux [T]
(strength of magnetic field)

Types of sensors

AXIAL GRADIOMETERS

PLANAR GRADIOMETERS

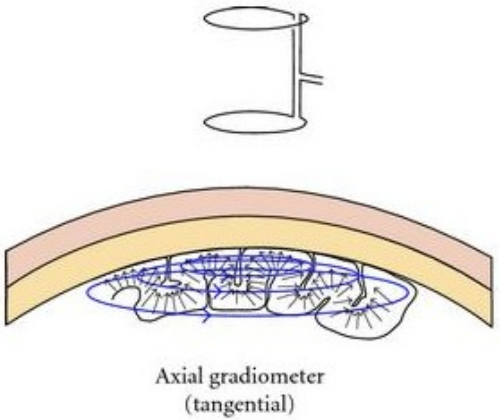


Consists of two magnetometers:

Measures magnetic gradient [T/m]
(how much strength of magnetic field changes over two locations)

Types of sensors

AXIAL GRADIOMETERS



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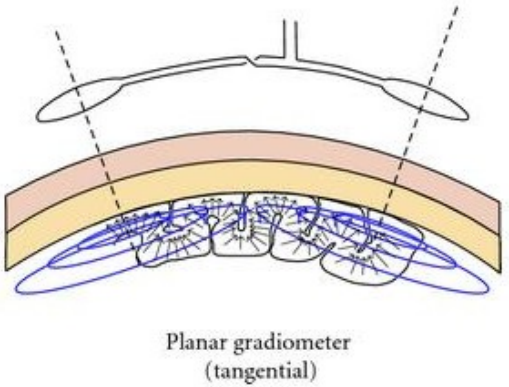
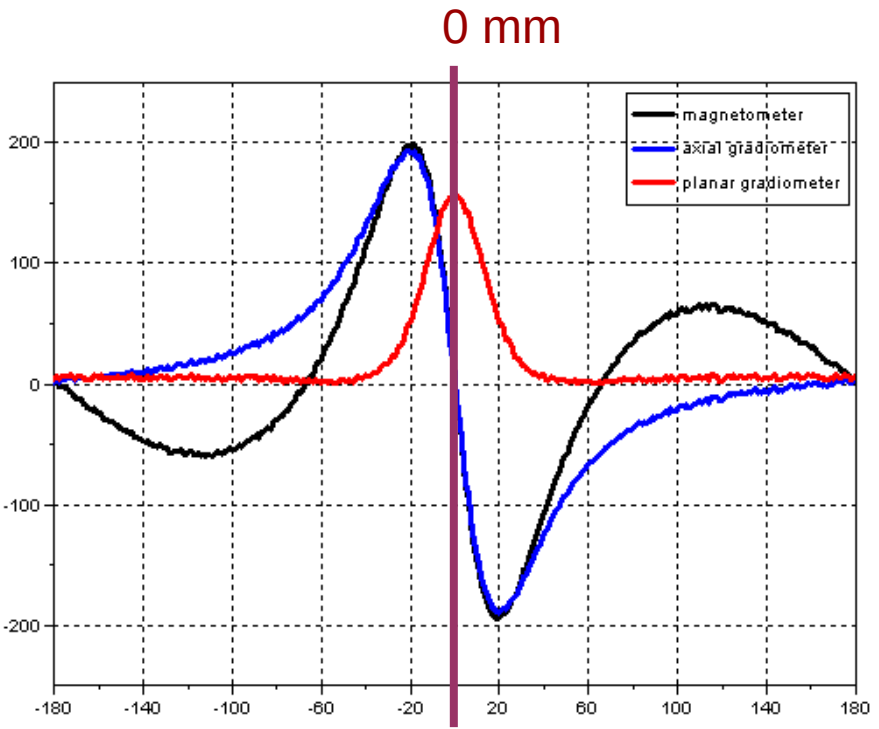
PLANAR GRADIOMETERS



Courtesy of Luzia Troebinger, University College London

Sensitivity profiles



sensitivity
to source

distance to source in x or
y direction

Courtesy of Luzia Troebinger,
University College London

MEGIN®

- 102 chips
  - each with a magnetometer
  - and two orthogonal planar gradiometers
    - thus 306 sensors total

CTF®

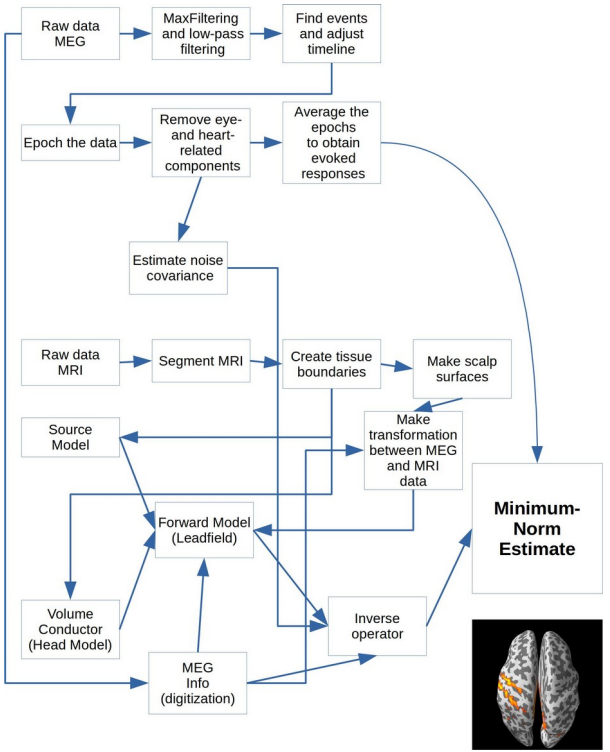
- 275 axial gradiometers
  - reference channels for noise cancellation

Interim summary

- The bulk of the MEG signal comes from post-synaptic potentials
  - In open field arrangements
- MEG is mainly sensititive to tangential sources
- We can use the equivalent current dipole to model the activity over a given patch (of cortex)
- In a volume conductor, currents will spread and the measured magnetic field will be (roughly) proportional to the primary current

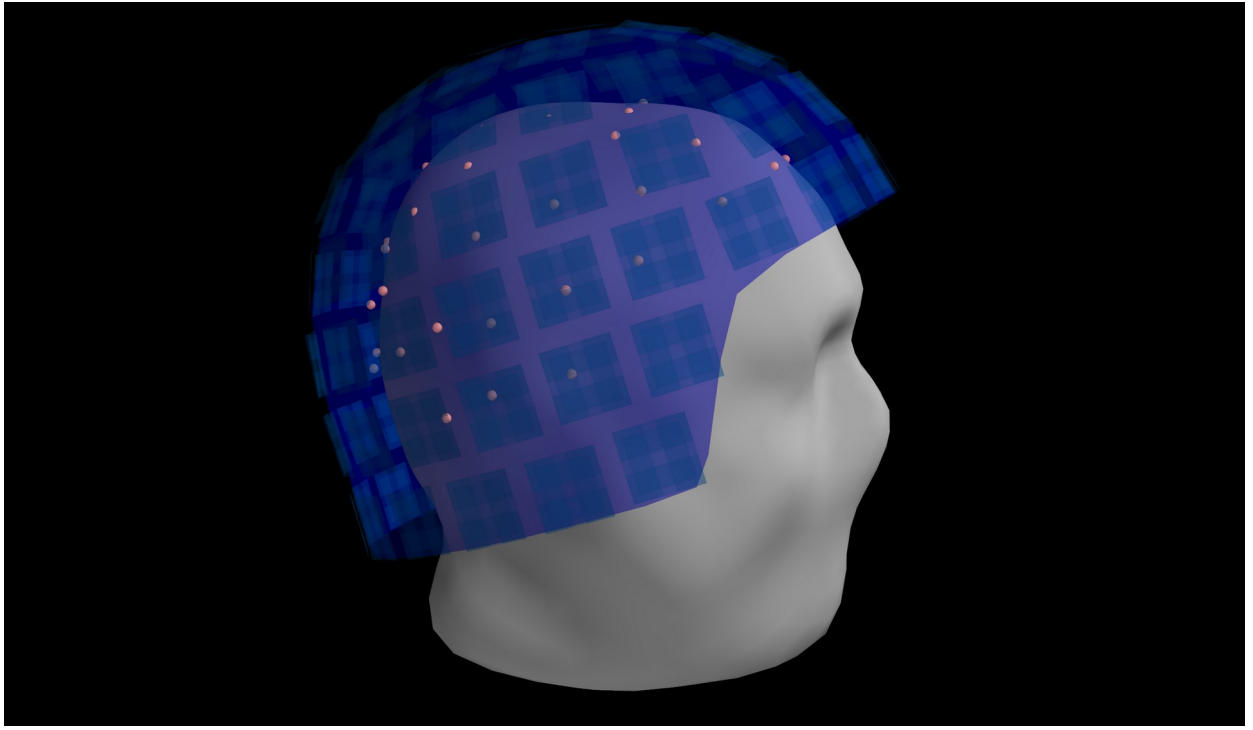
Evoked responses

An MEG pipeline



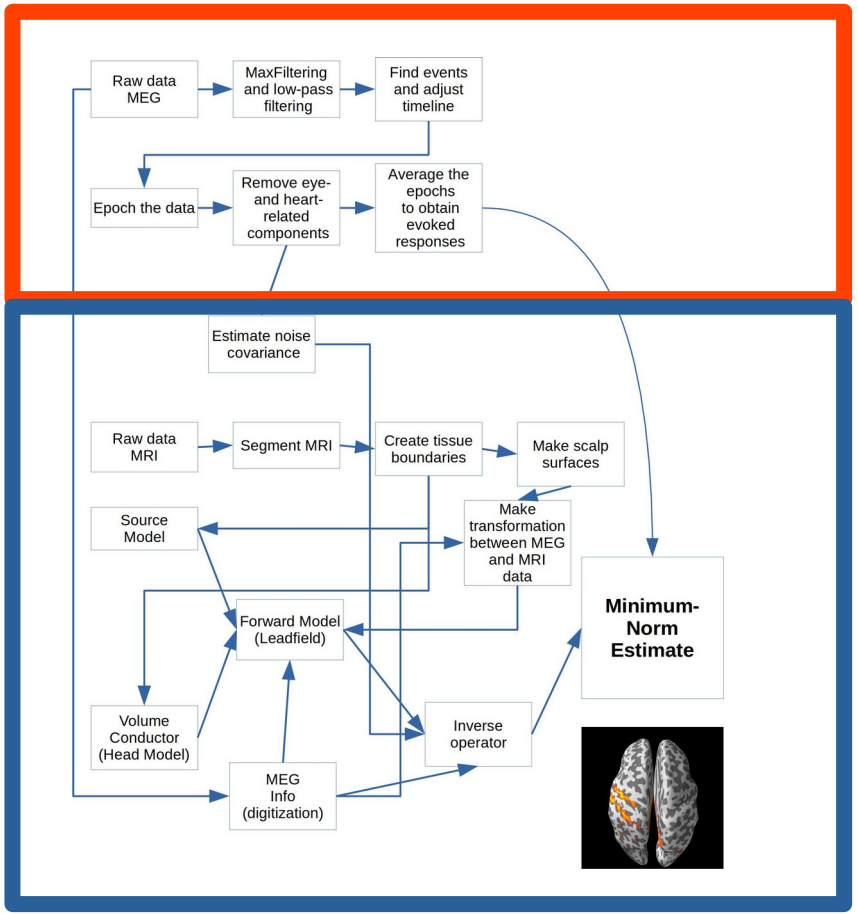
Andersen, 2018

Head and sensors



Sensor analysis

Source analysis

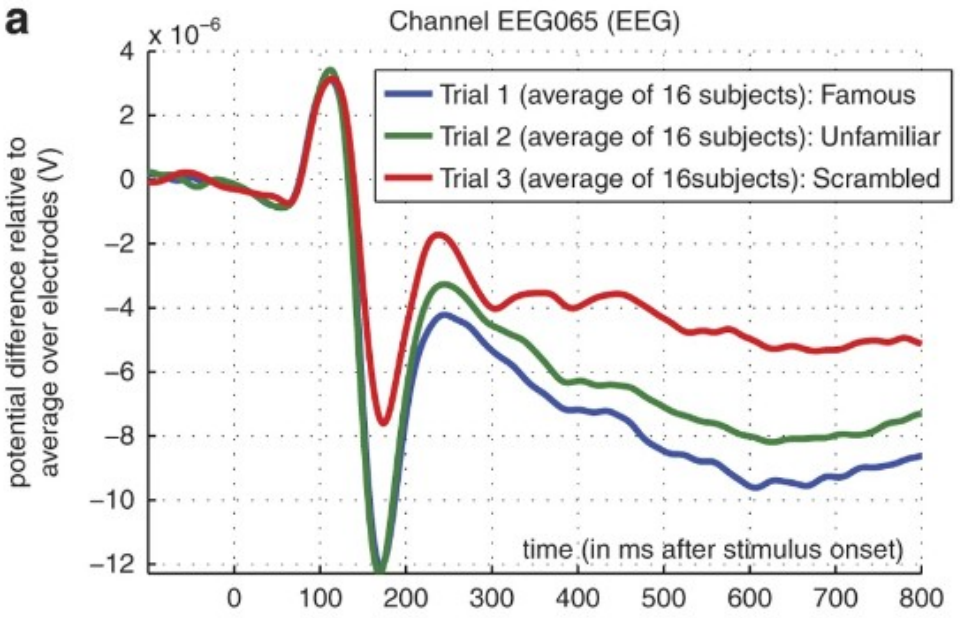


Andersen, 2018

Learning goals

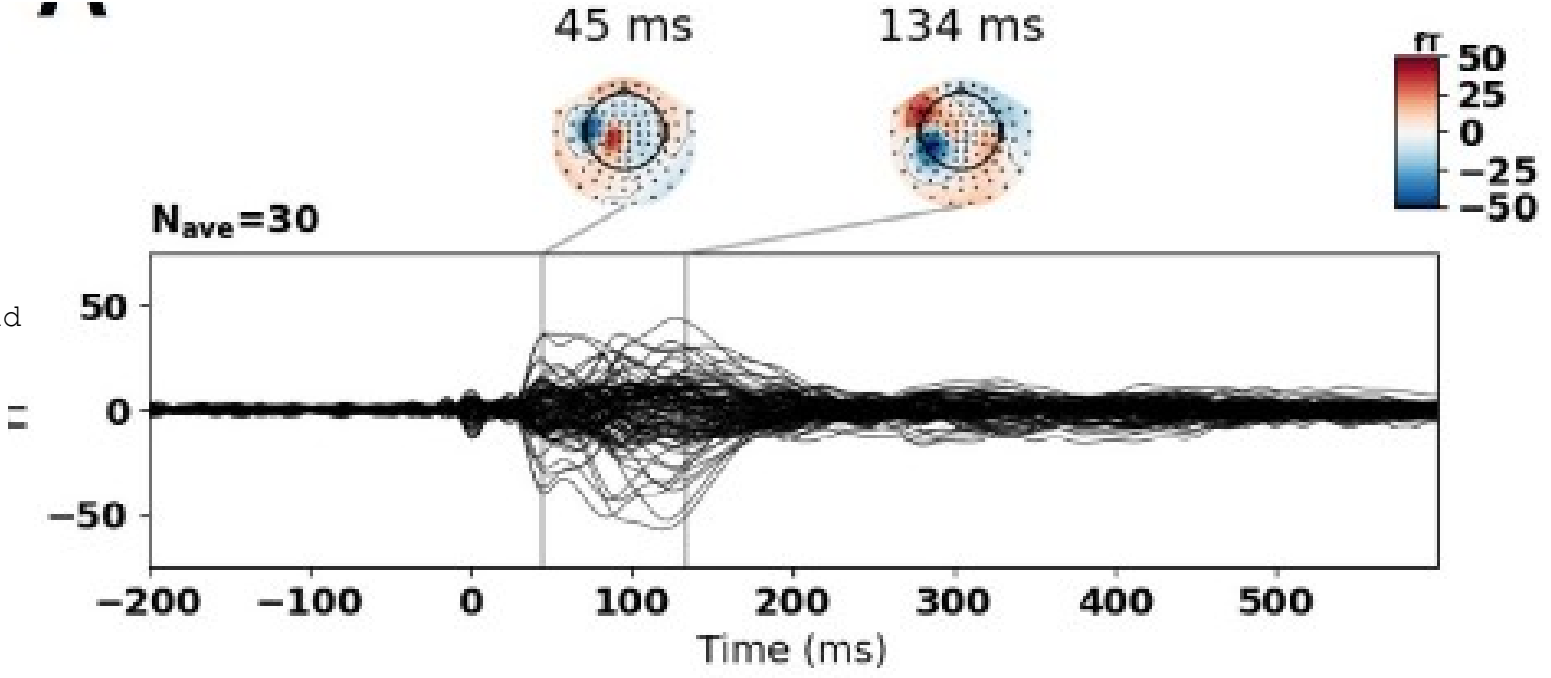
- Learning
  - the identification of physiological artefacts
  - strategies for increasing the signal-to-noise ratio
  - how to use epochs to create an evoked response
  - the importance of epochs being in-phase for an averaging strategy to be feasible
  - to do rough source localization on dipolar activations

Evoked responses – visual and face



Wakeman and Henson, 2015

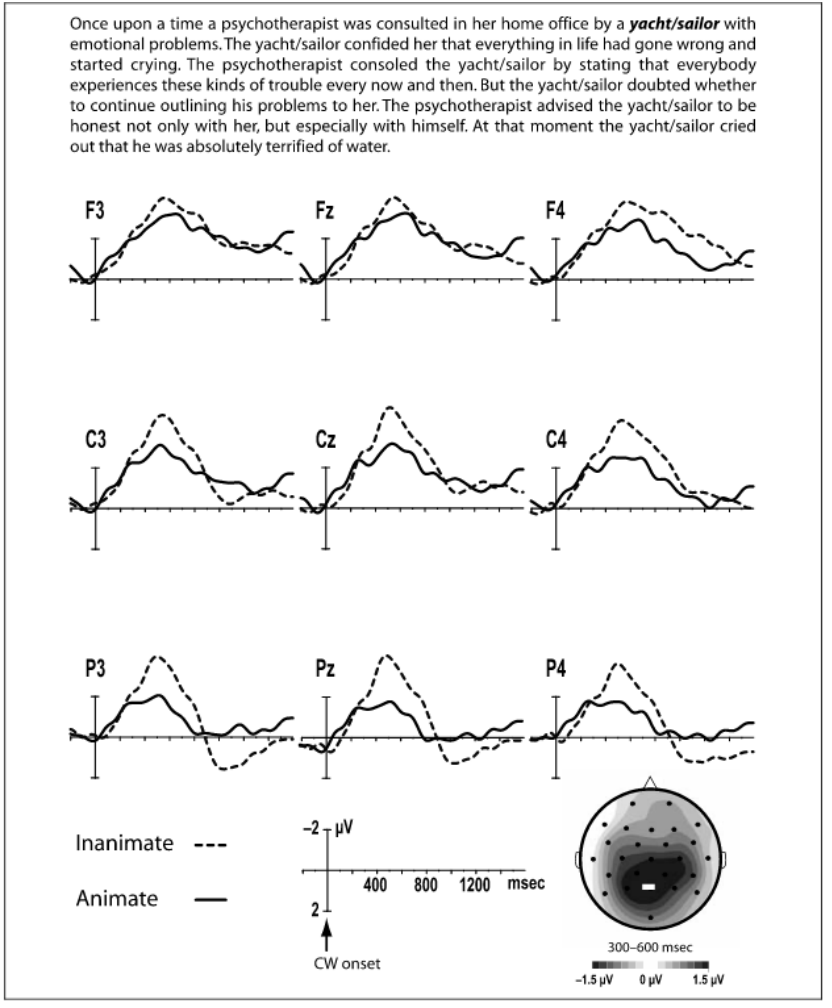
Evoked responses – tactile



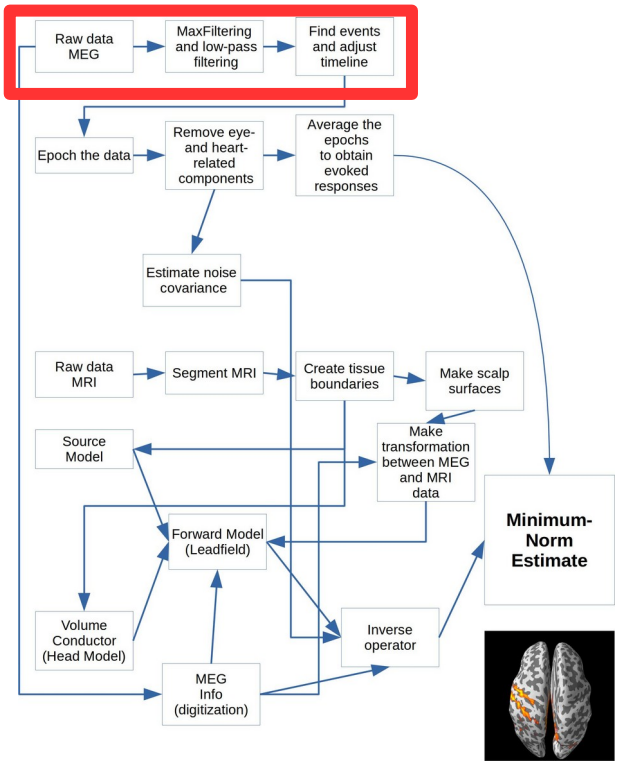
Andersen and Dalal, 2021

Evoked responses – linguistic surprise

Nieuwland and van Berkum, 2006

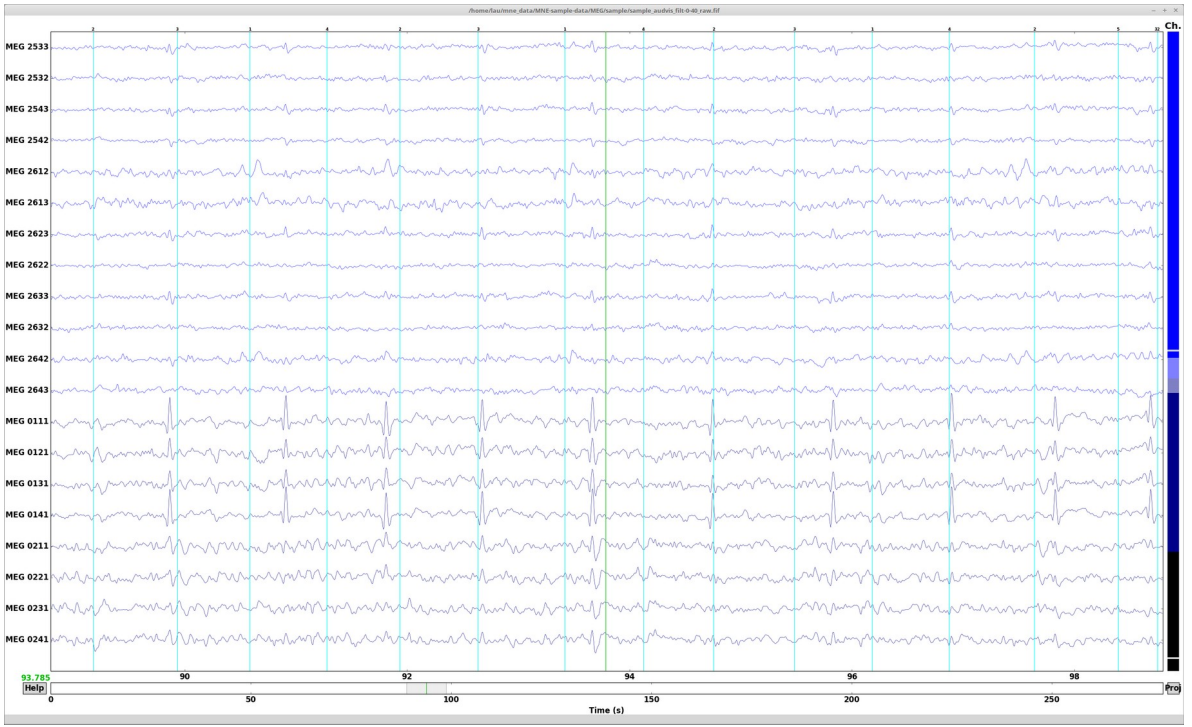


An MEG pipeline

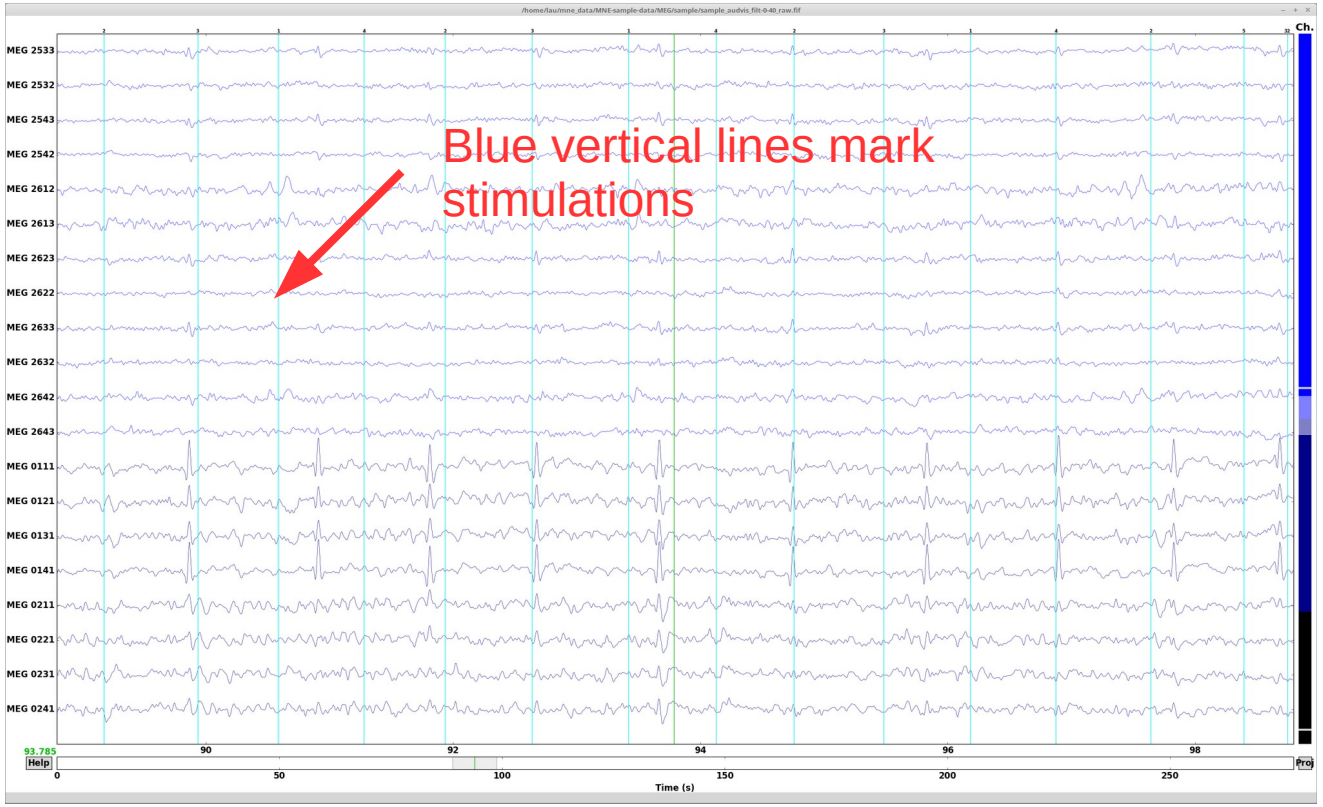


Andersen, 2018

The raw signal (MEG)



The raw signal (MEG)?

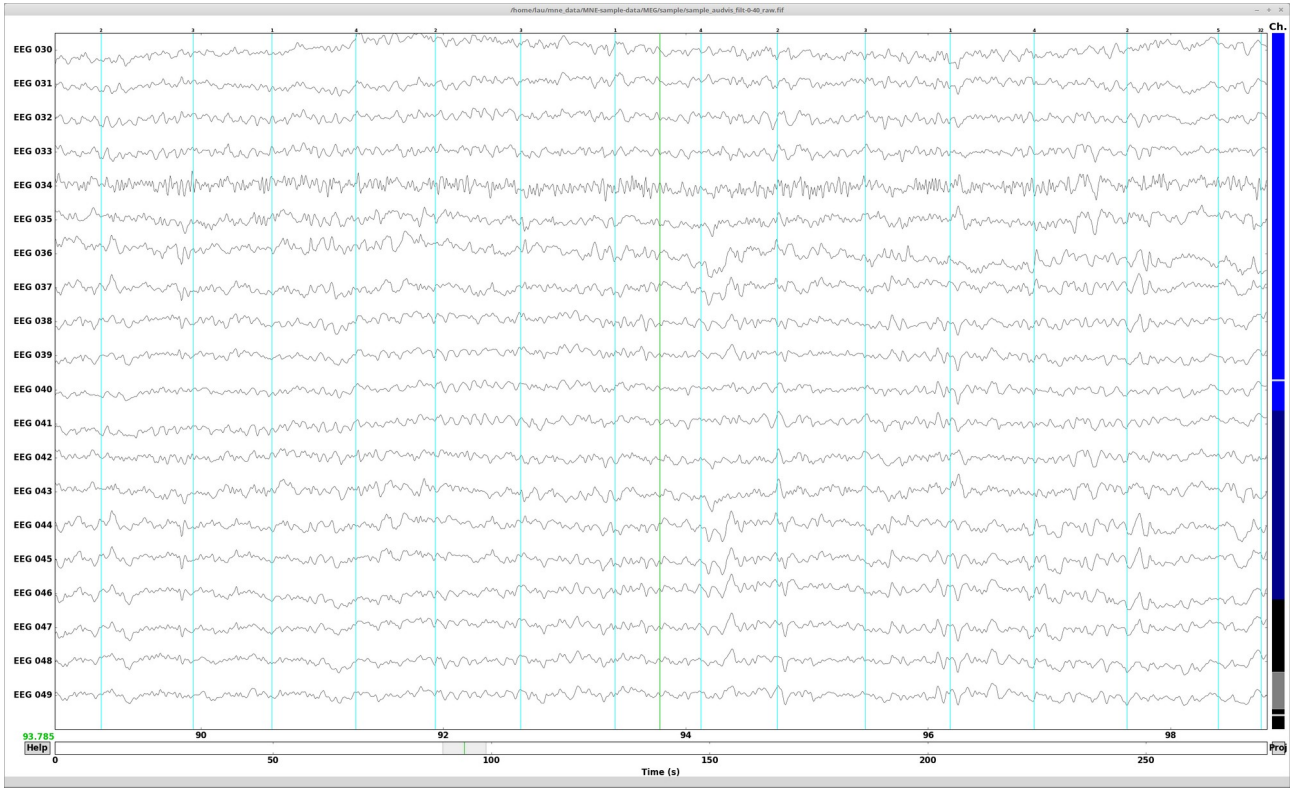


The raw signal (MEG)?

Brain Signal?

The raw signal (MEG)?

The raw signal (EEG)



Signal-to-Noise Ratio is not sufficiently high to see the brain responses to the auditory stimulation in the raw signal

(This actually holds for most brain responses)

Signal-to-noise ratio (SNR)

Crude definition:

Signal: activity of interest

Noise: activity *not* of interest

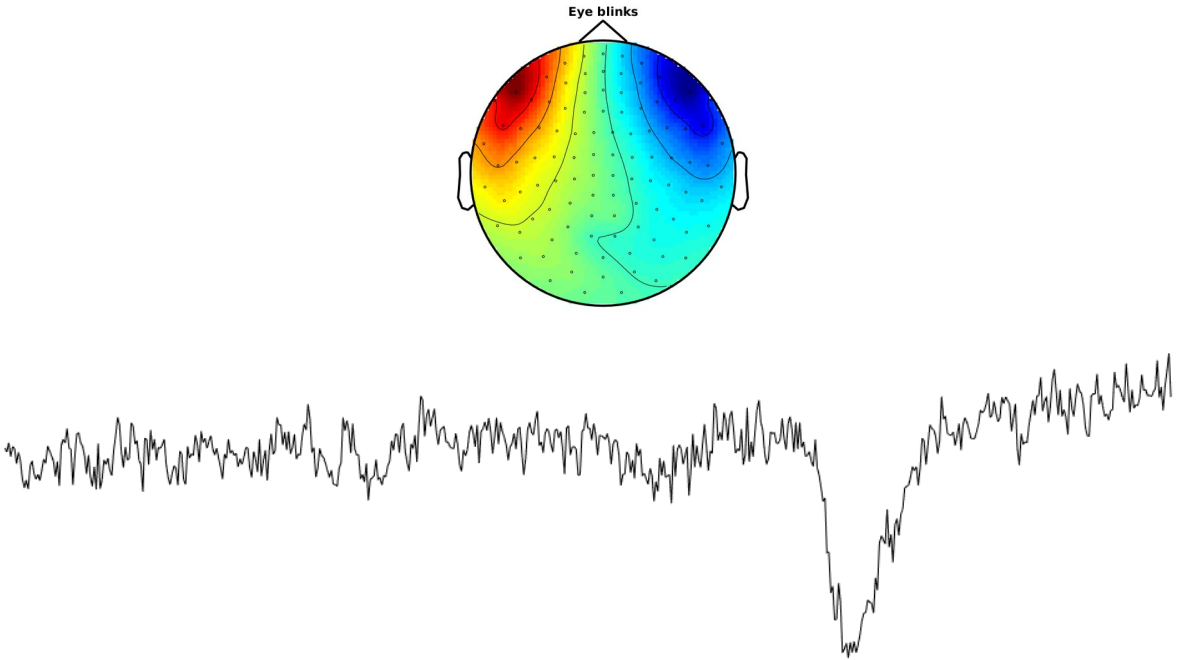
Formal Definition:

$$SNR = \frac{Magnitude\ of\ signal}{Variance\ of\ noise}$$

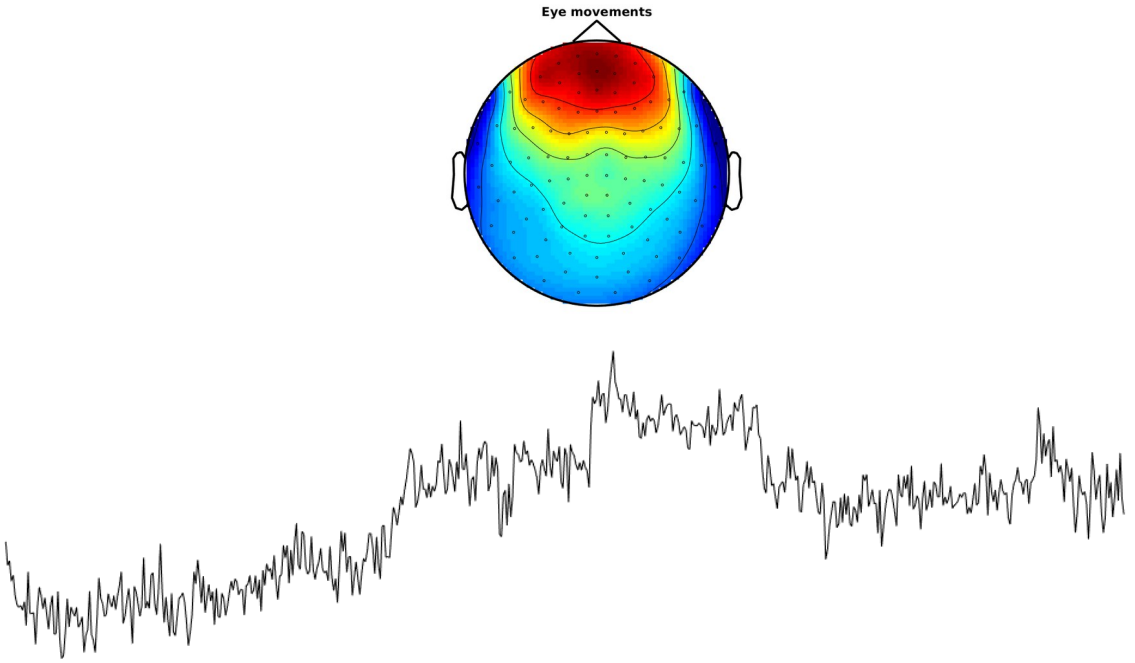
Examples of noise

- Eye blinks
- Eye movements
- Heart beats
- System noise
- External noise

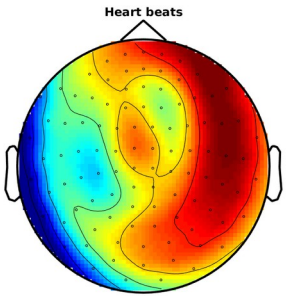
Eye blinks

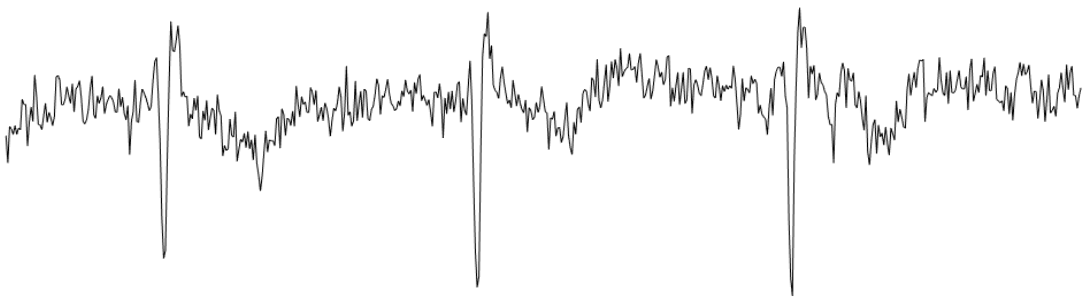


Eye movements



Heart beats



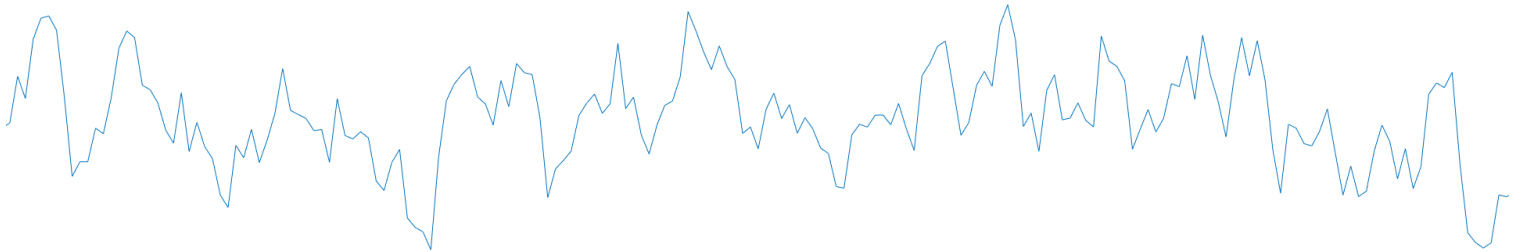


How do we increase the signal amidst all the noise?

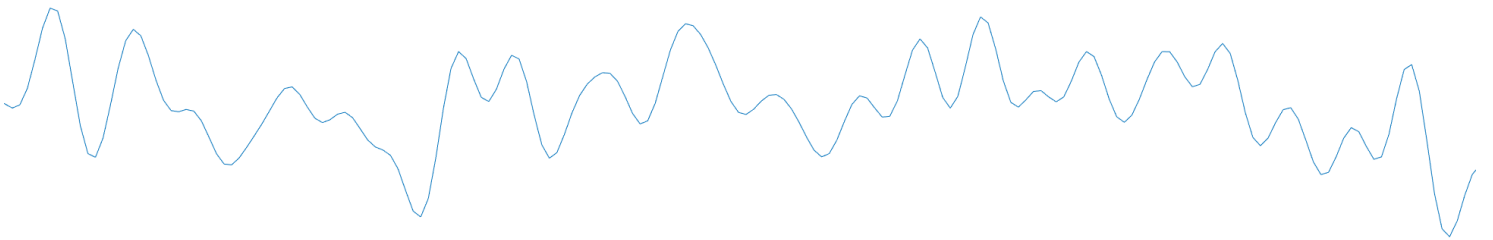
Increasing SNR

1) Filtering
   - Remove contributions from frequencies not of interest
2) Clean data
   - Reject trials with noise in them
   - Remove activity associated with physiological noise
3) Average trials
   - SNR increases
     - NB! The averaging strategy only works if responses are phase-locked

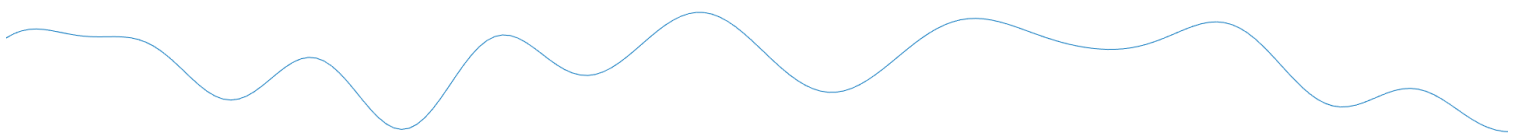
NO FILTERING



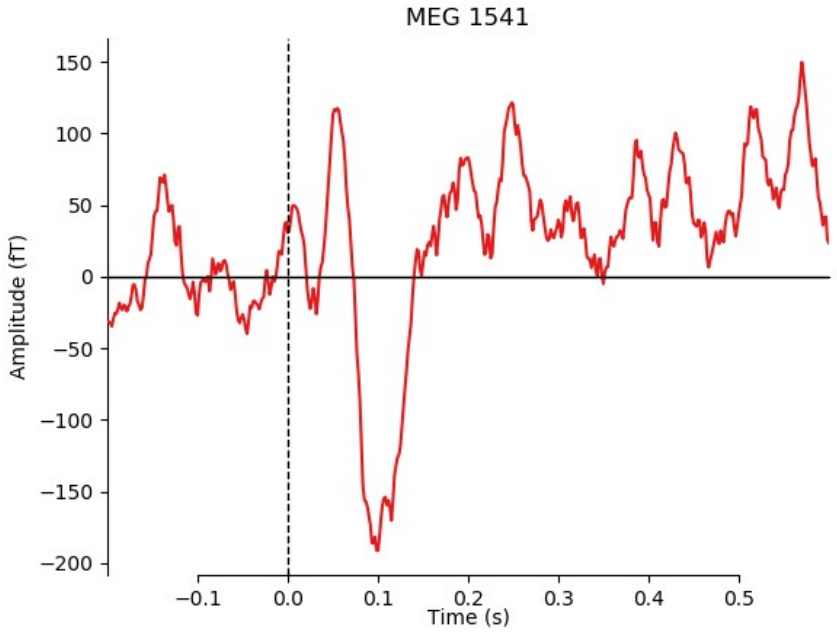
LOW-PASS 30 Hz (remove > 30 Hz)

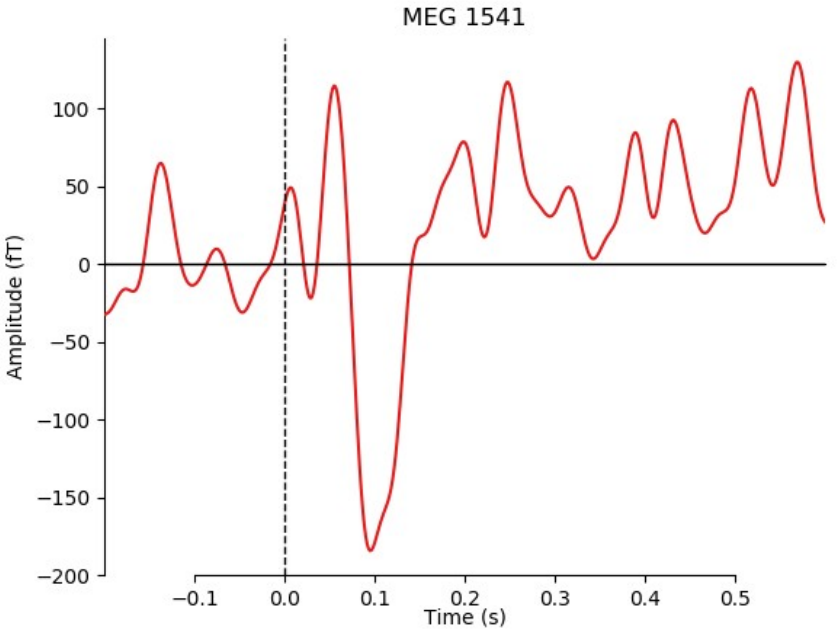


LOW-PASS 10 Hz (probably also removing brain signal)

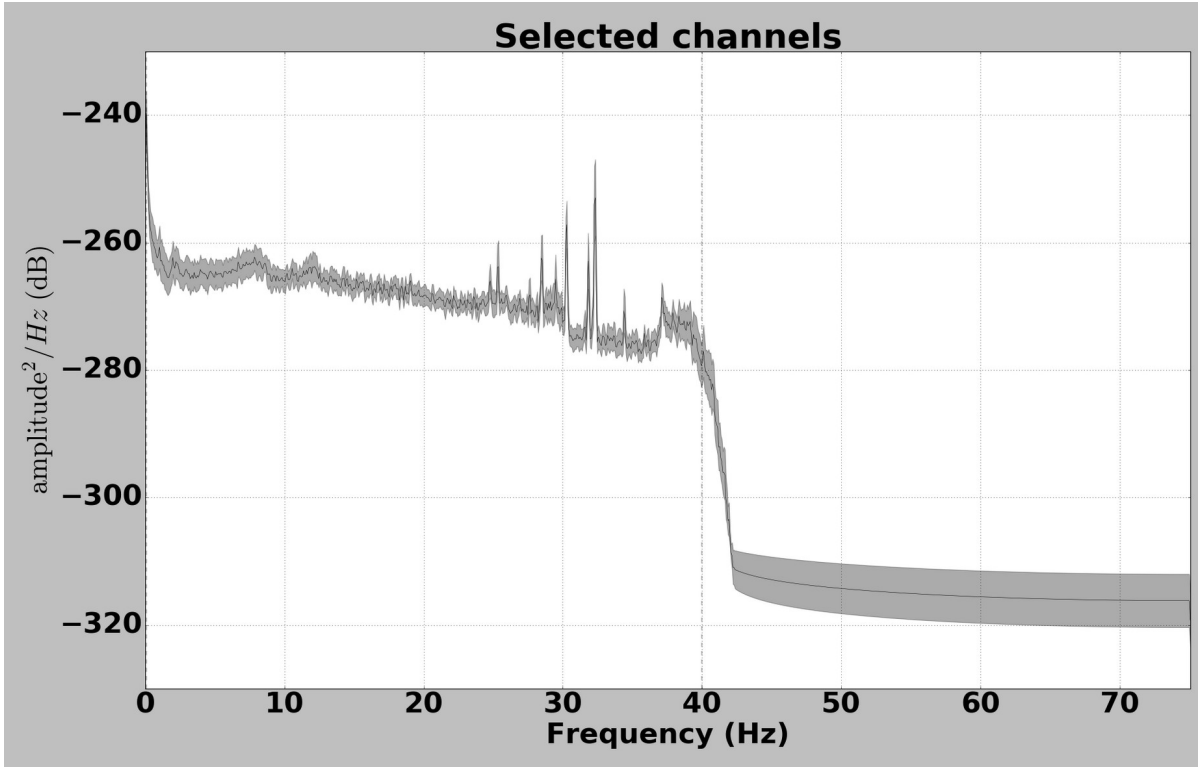


With or without 30 Hz lowpass filter

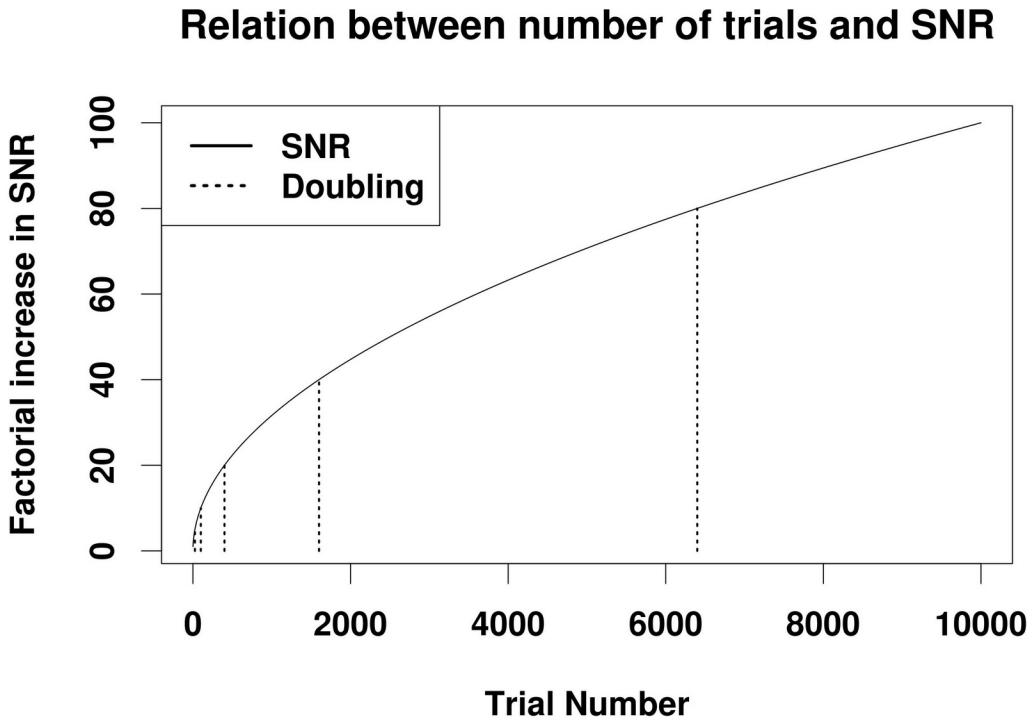




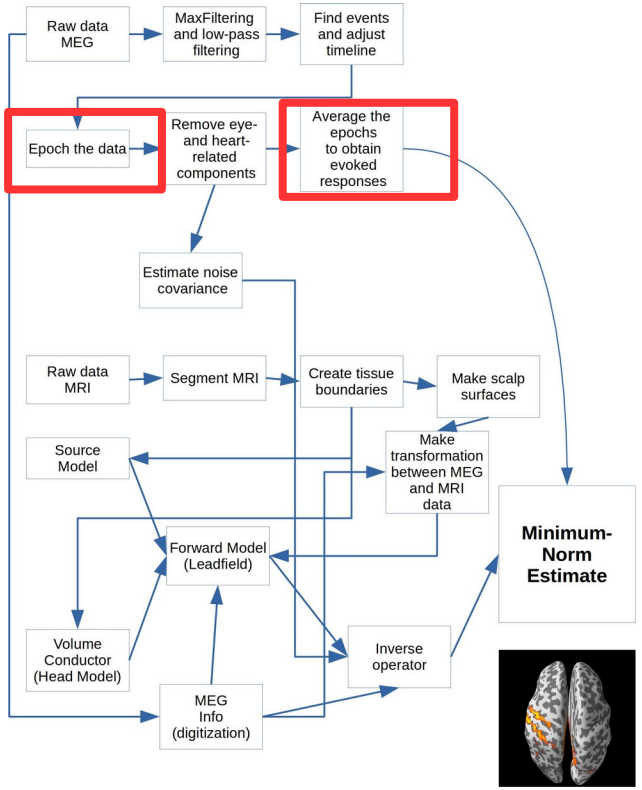
Another look at filtering



Averaging
DIMINISHING RETURNS

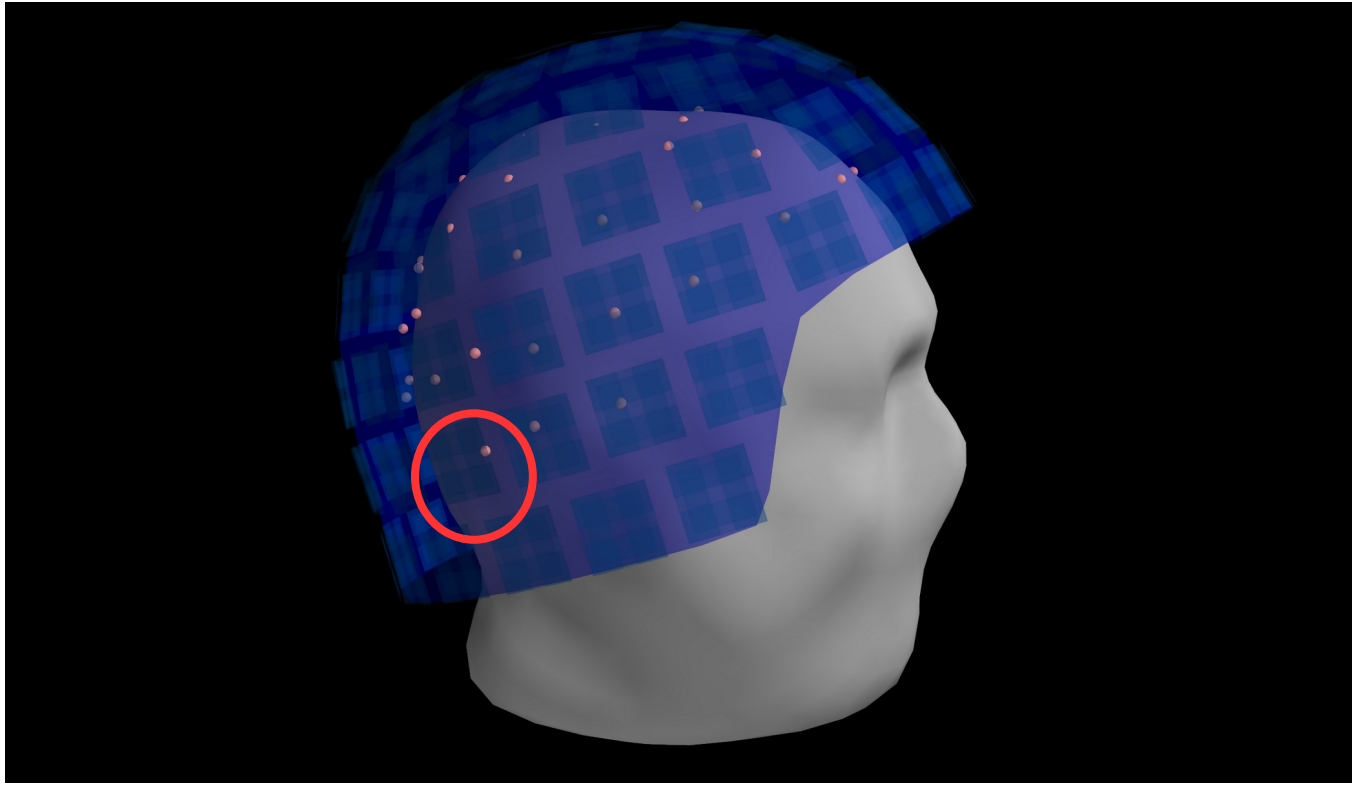


An MEG pipeline

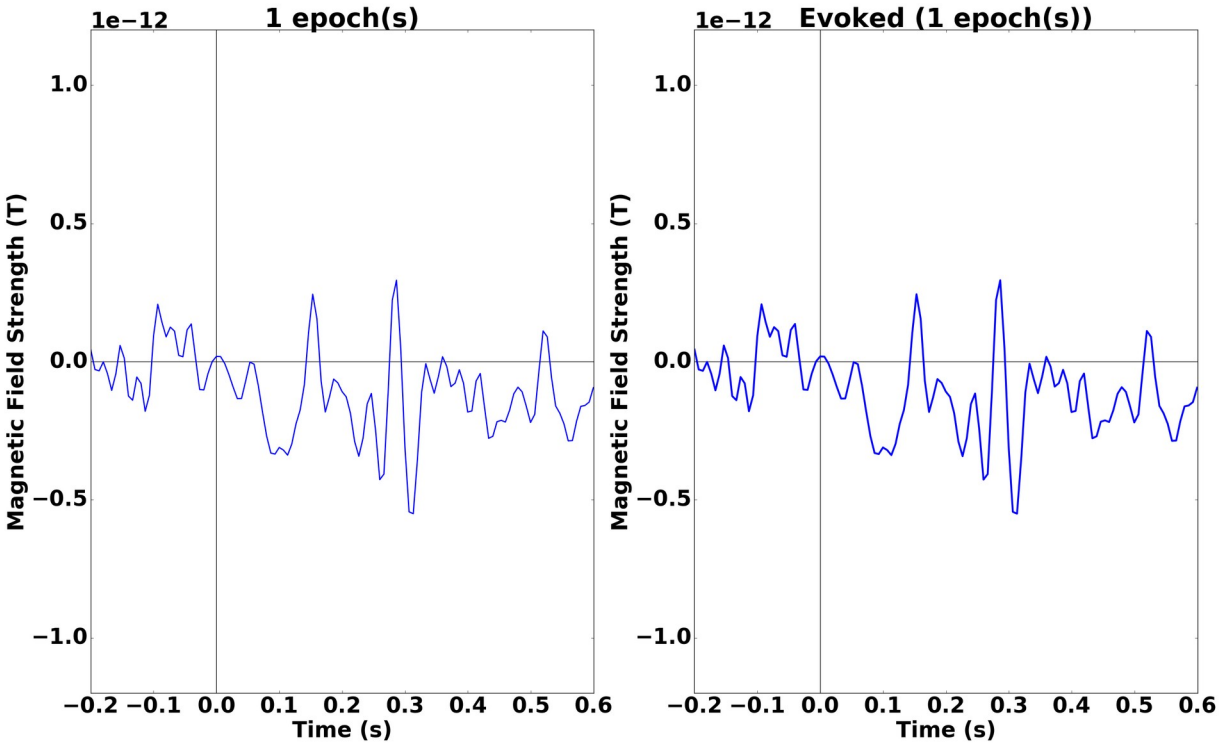


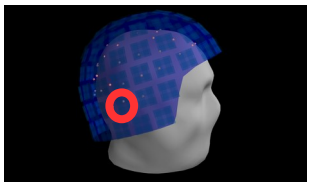
Andersen, 2018

Head and sensors

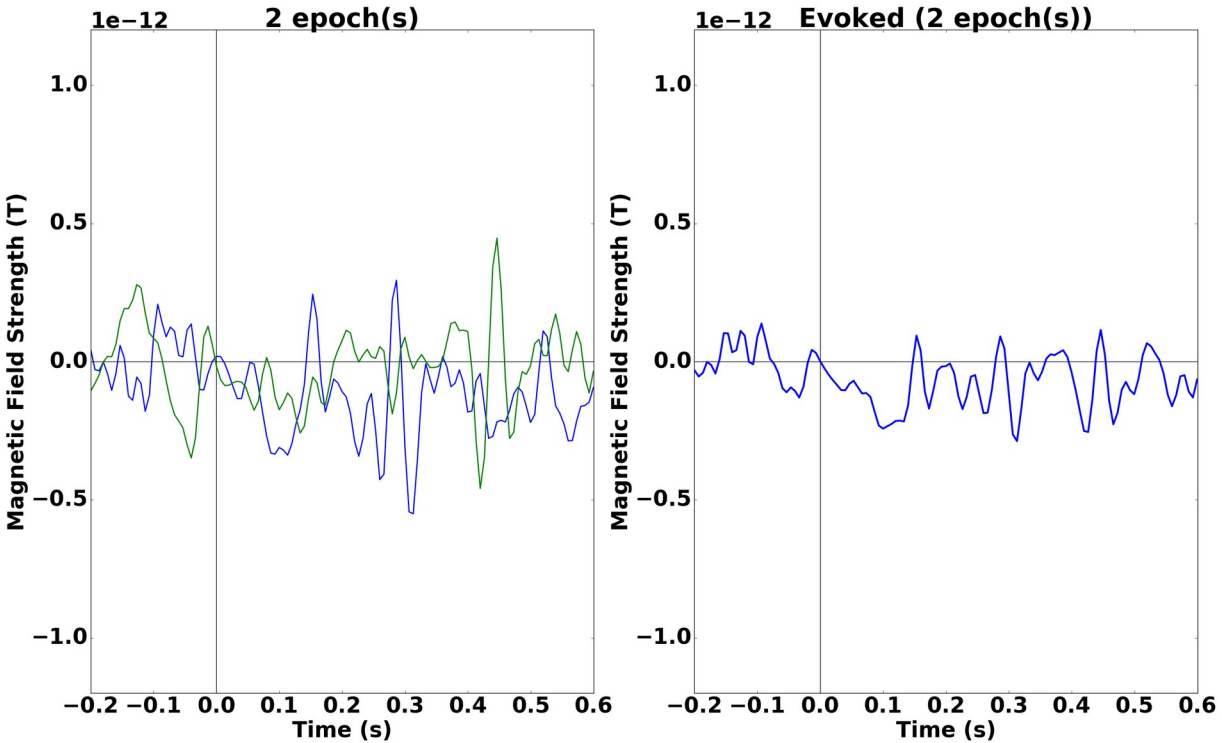


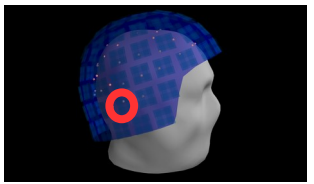
Epochs and Evoked



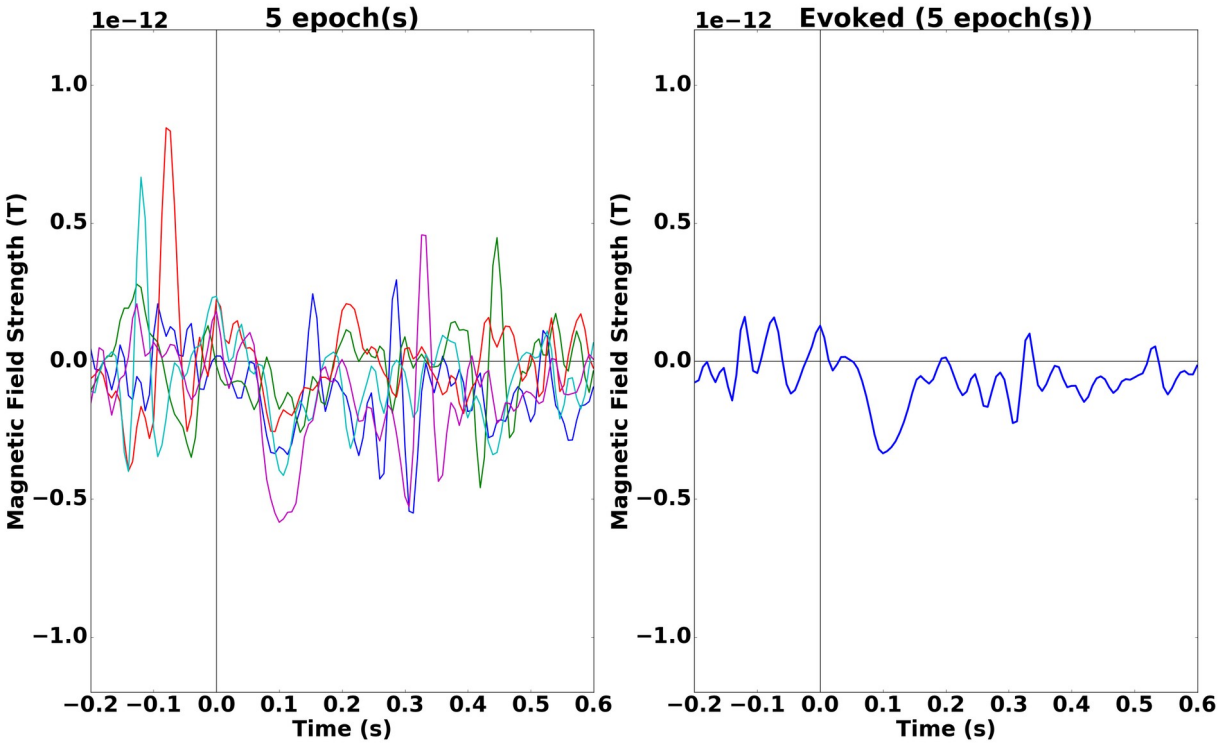


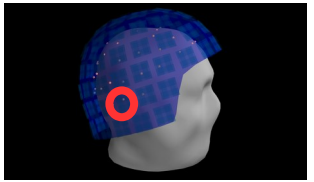
Epochs and Evoked



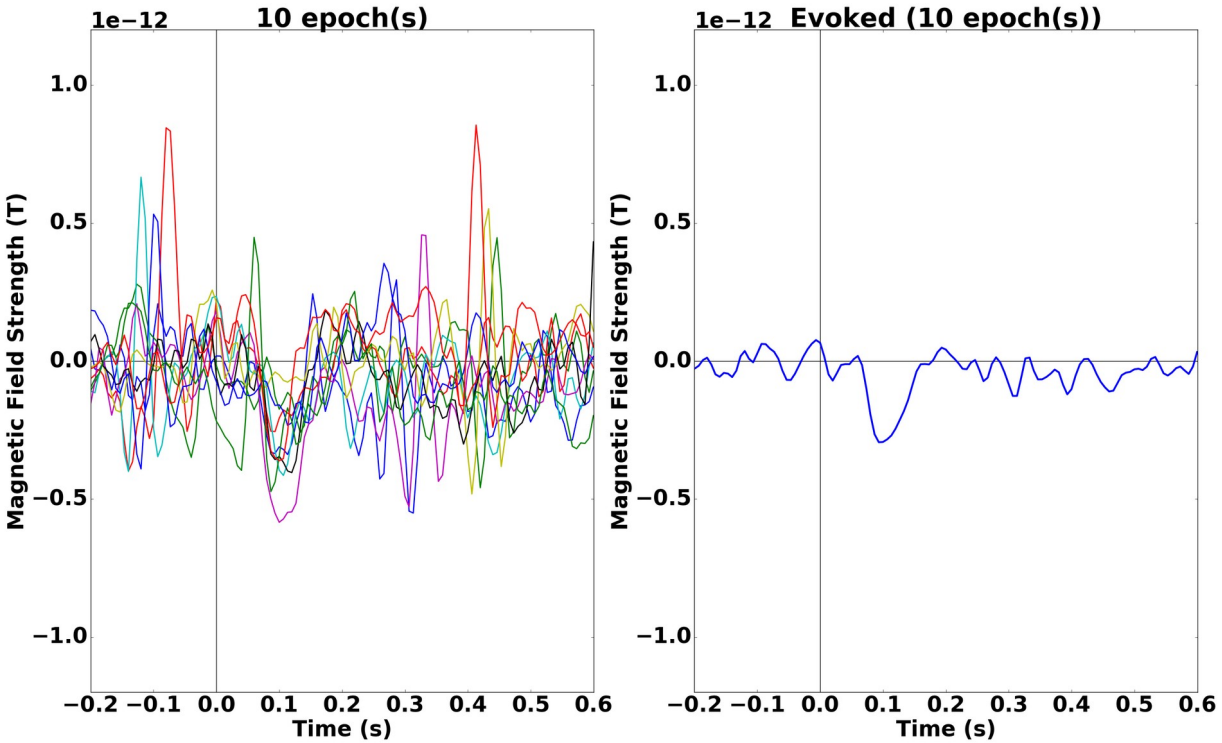


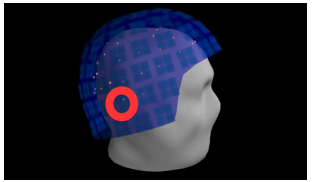
Epochs and Evoked



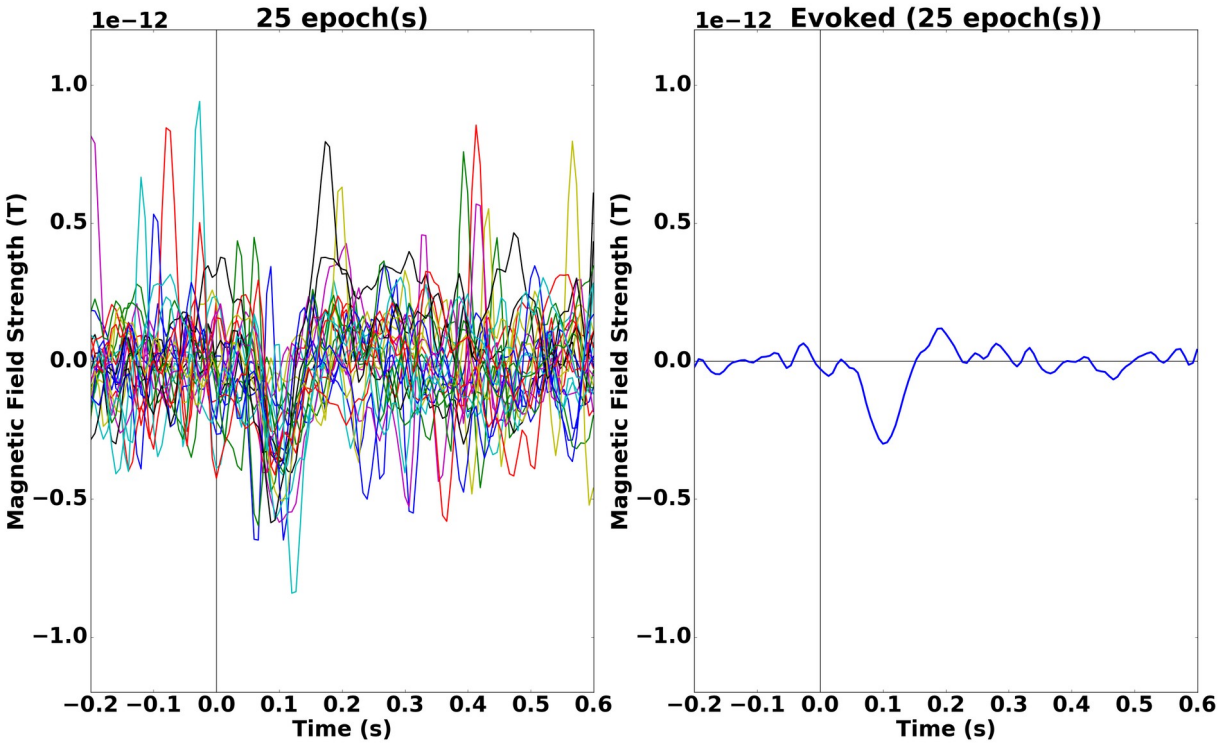


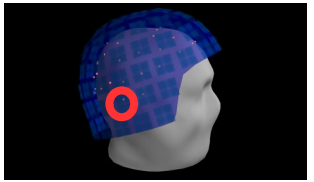
Epochs and Evoked



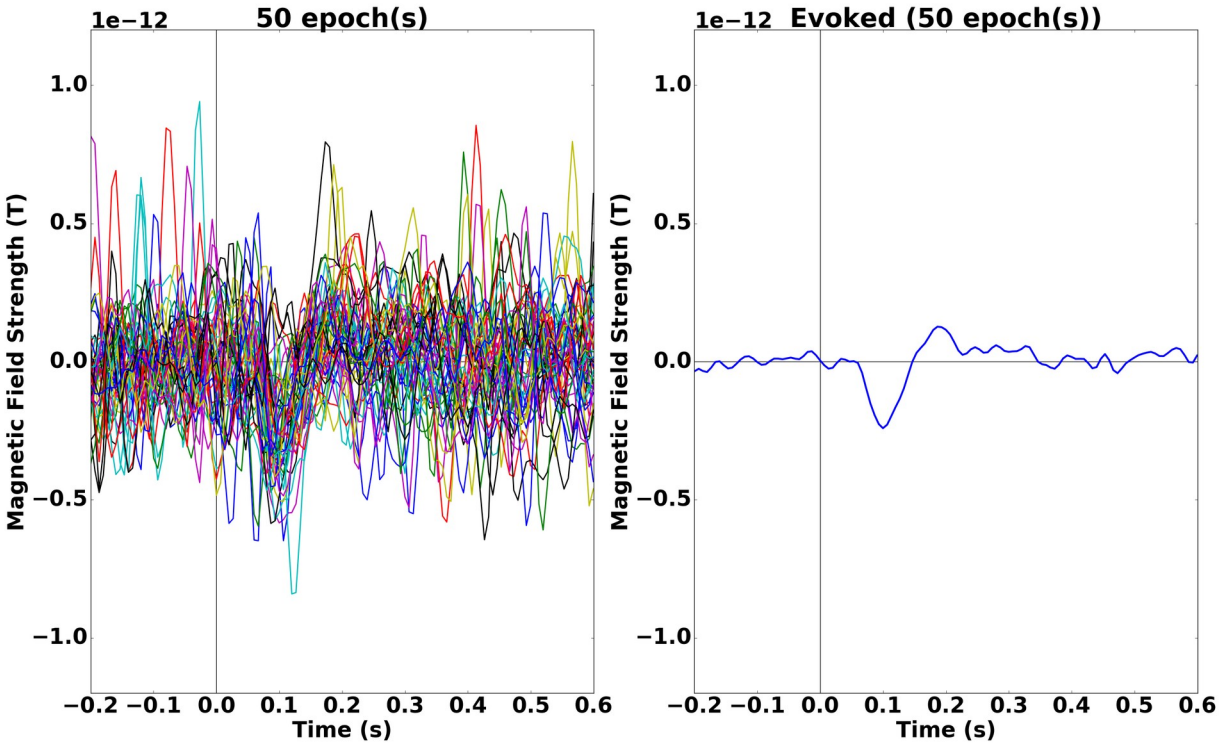


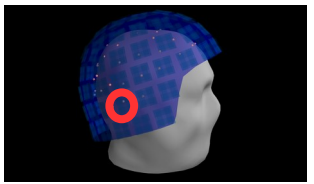
Epochs and Evoked



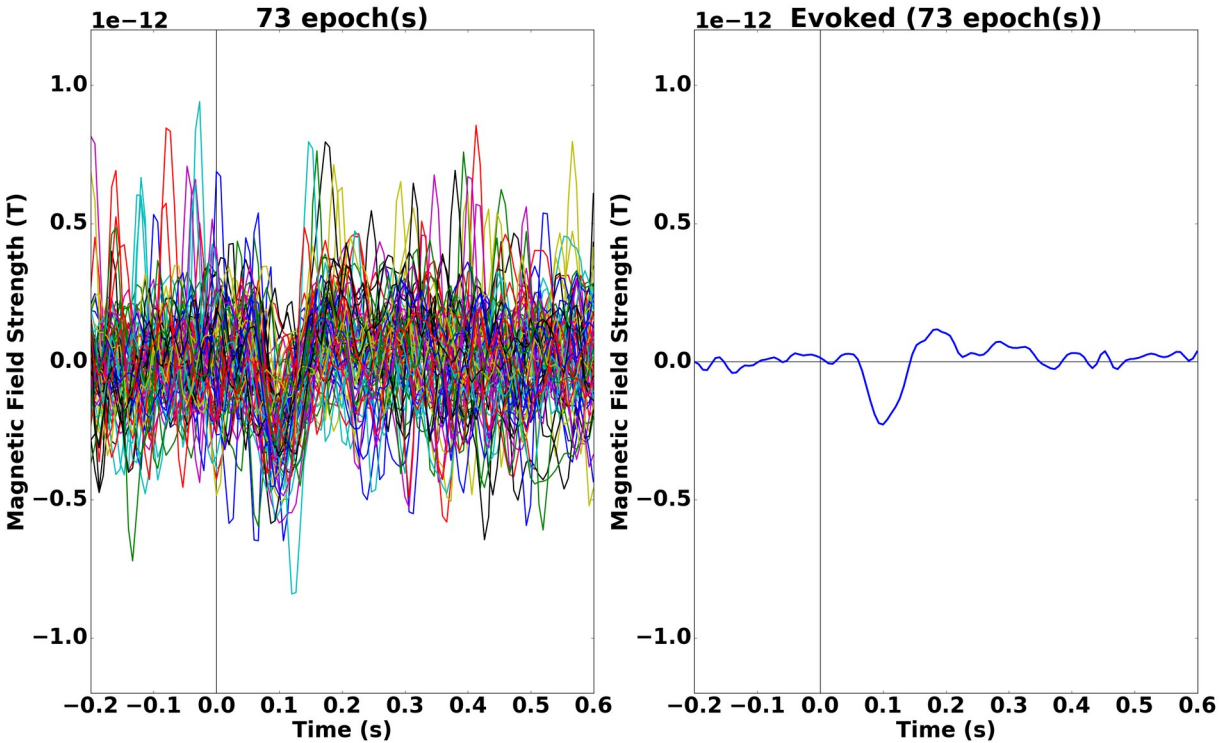


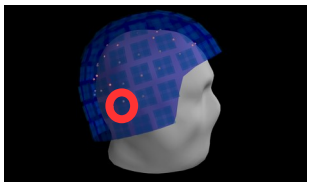
Epochs and Evoked



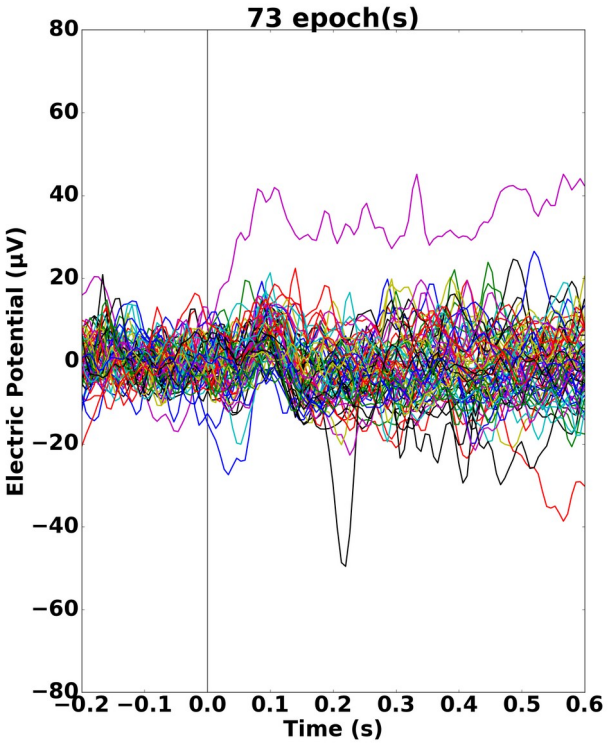


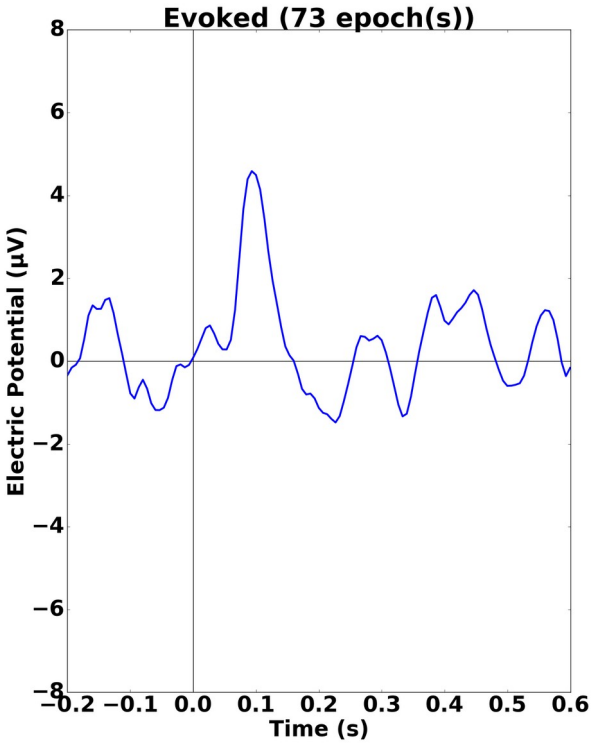
Epochs and Evoked

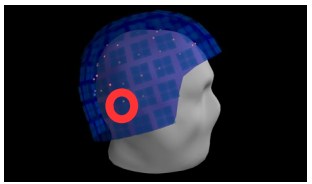




The same with EEG



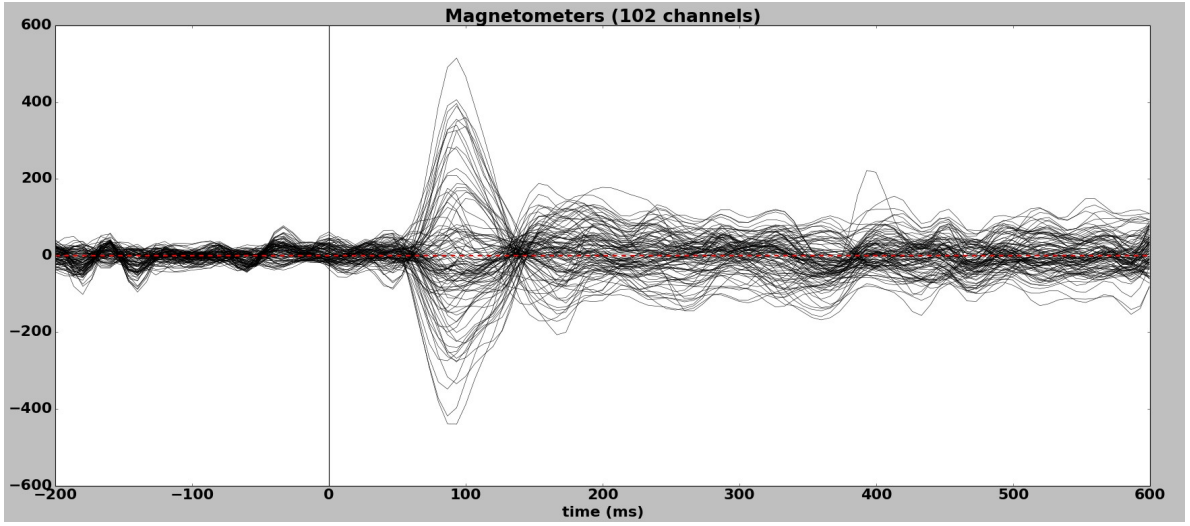


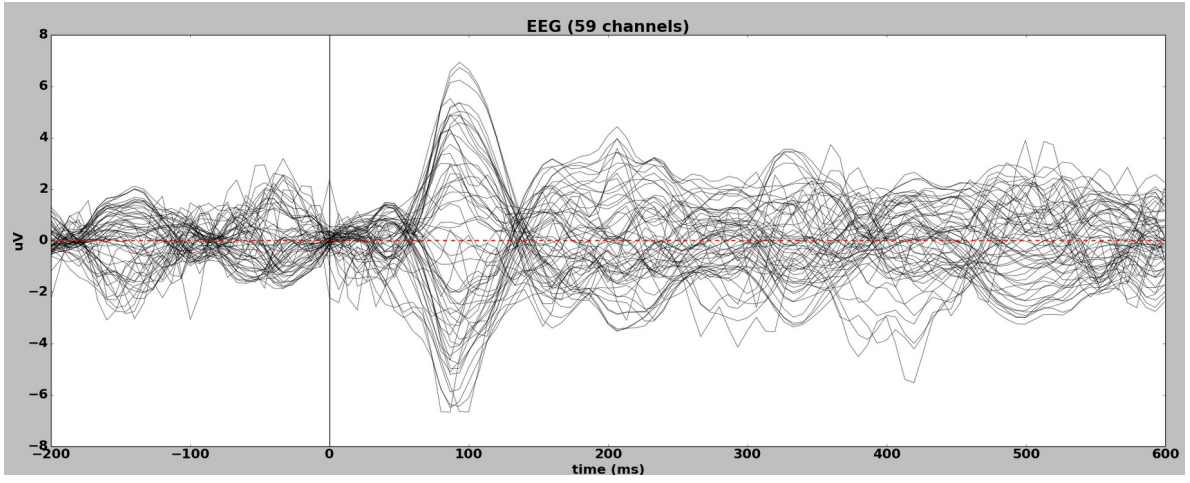


```
#%% FIND EVENTS

events_sample = mne.find_events(raw_sample)
mne.viz.plot_events(events_sample, sfreq=raw_sample.info['sfreq']);
```

```
#%% EPOCH THE DATA
event_id = dict(LA=1) ## we'll just look at this one event
tmin = -0.200 # s
tmax =  0.600 # s
baseline = (None, 0) # s (from beginning to 0); for demeaning

## segment the data
epochs_sample = mne.Epochs(raw_sample, events_sample,
                           event_id, tmin, tmax, baseline, preload=True)
```

```
#%% AVERAGE (EVOKED)
evoked_sample = epochs_sample.average()
```

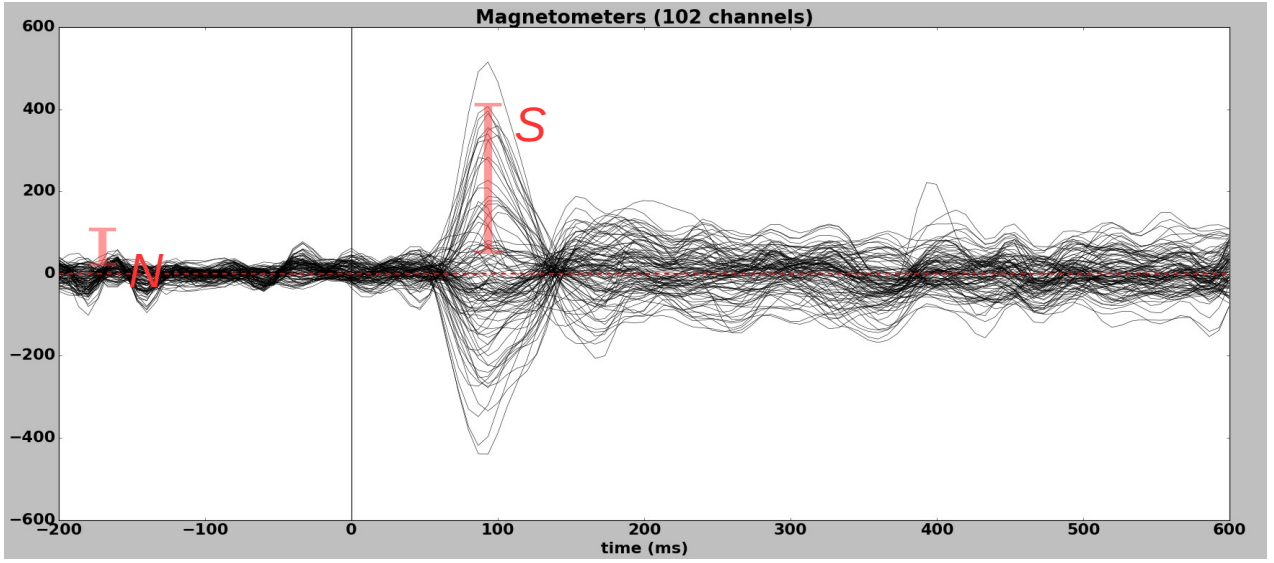


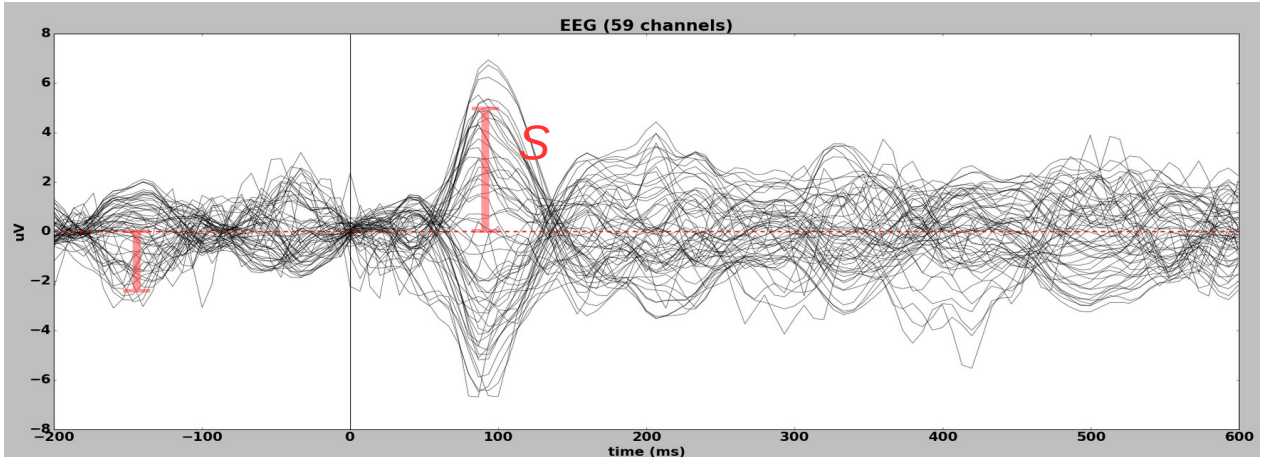


The traces look very similar, but the signal-to-noise ratio is higher in the MEG than in the EEG

$$\mathbf{SNR_{MEG}} \quad \frac{S}{N} = \frac{\text{I}}{\text{I}} \approx 4$$

$$\mathbf{SNR_{EEG}} \quad \frac{S}{N} = \frac{\text{I}}{\text{I}} \approx 2$$

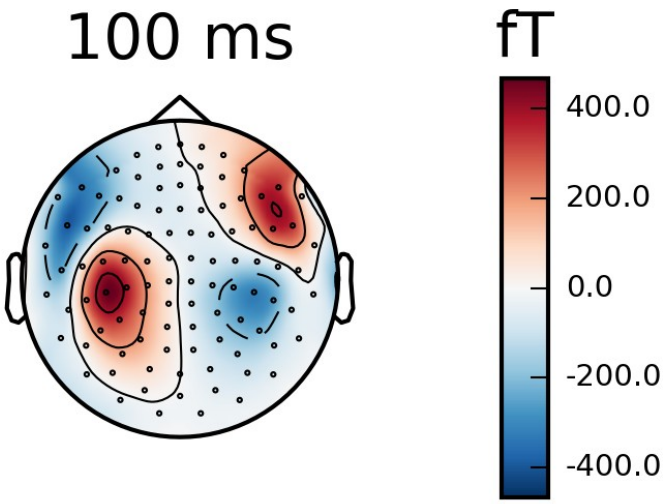




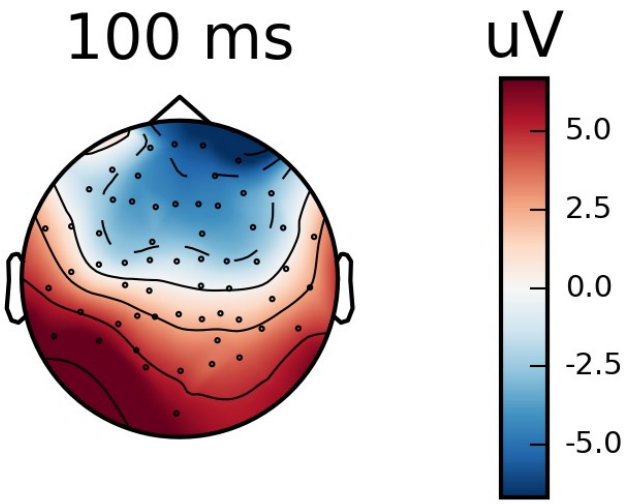
NOTE: These SNR estimates are for this particular experiment only. They are not necessarily generalizable

Topographies look very different

auditory_right mag



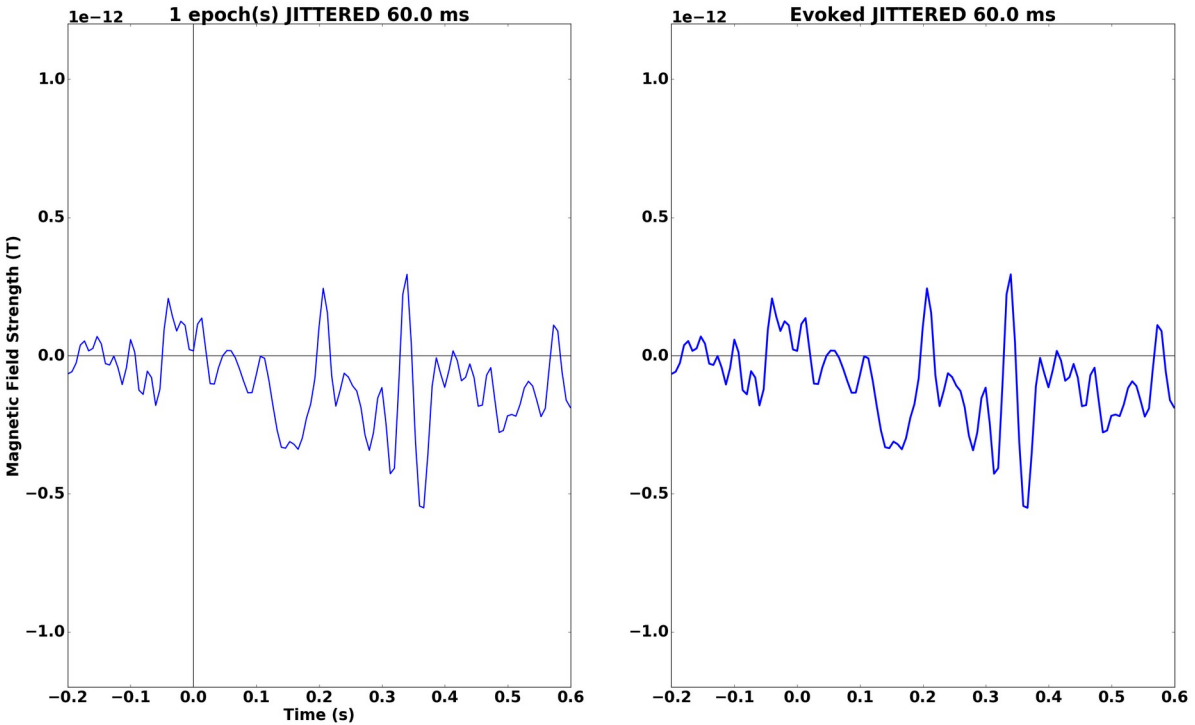
auditory_right eeg

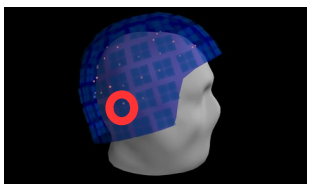


73 trials

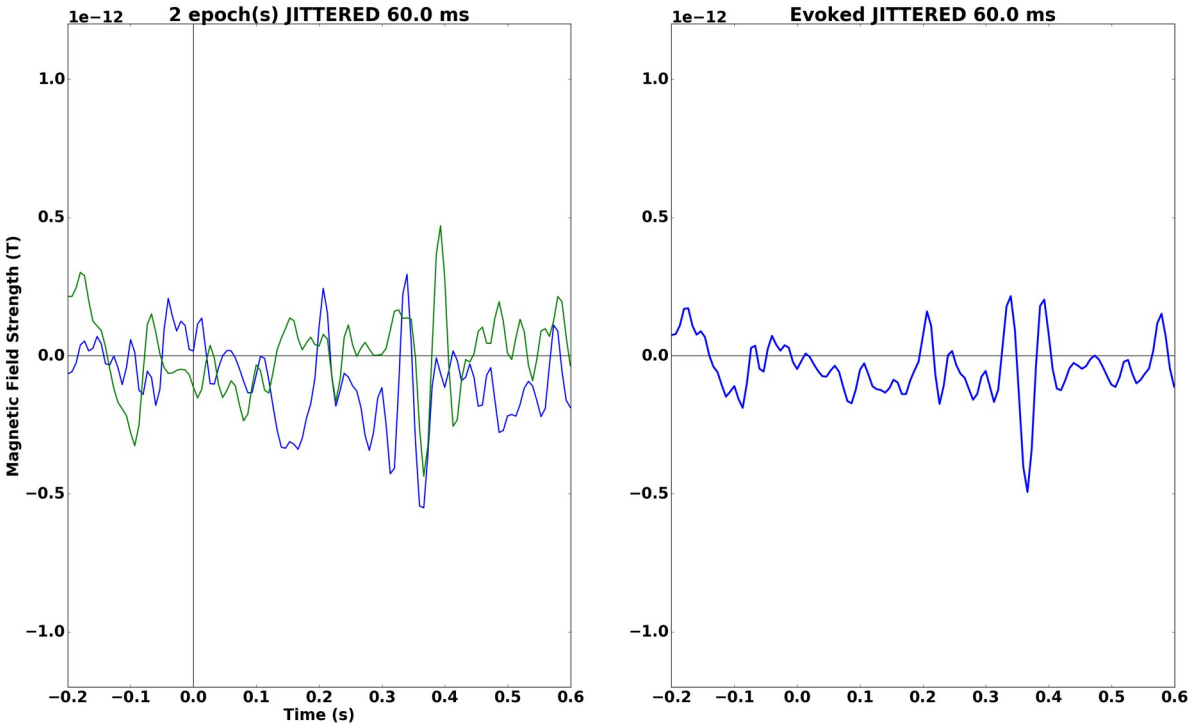
FURTHER NOTE: Averaging only works as a strategy for optimizing SNR if responses are “phase-locked”, i.e. the time course is evolving in the same manner on all (most) trials

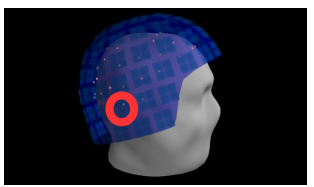
Epochs and Evoked JITTERED 60 ms



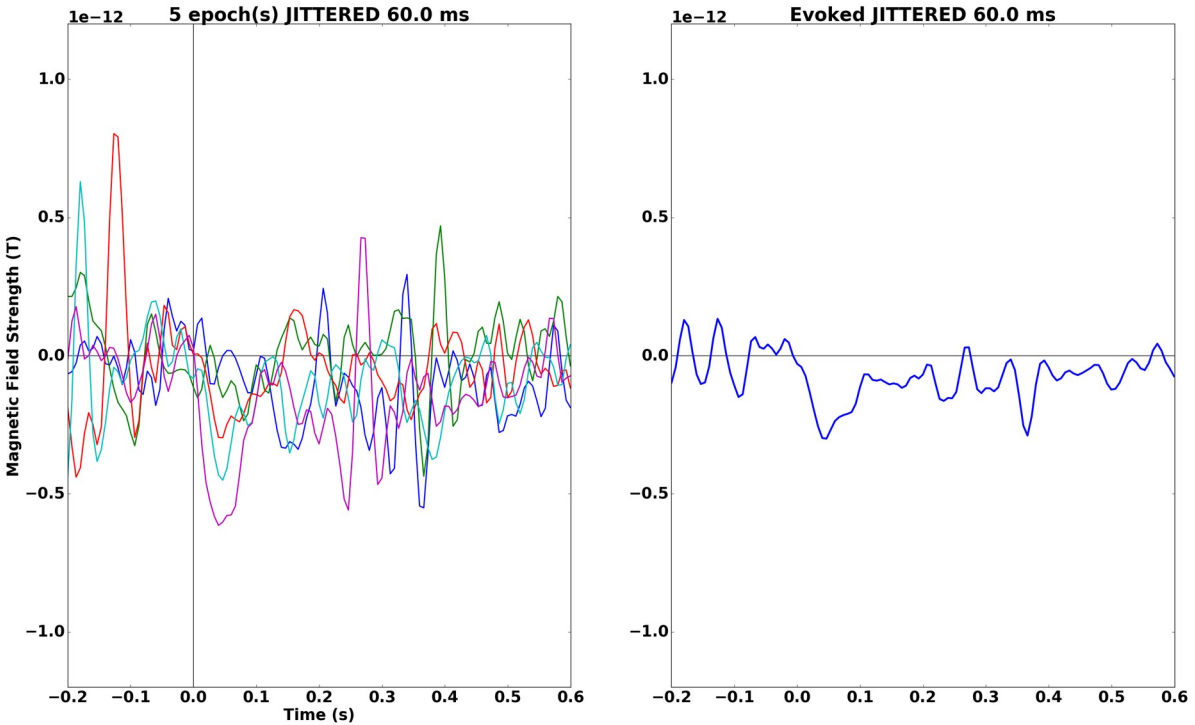


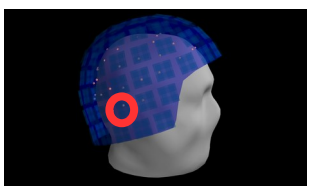
Epochs and Evoked JITTERED 60 ms



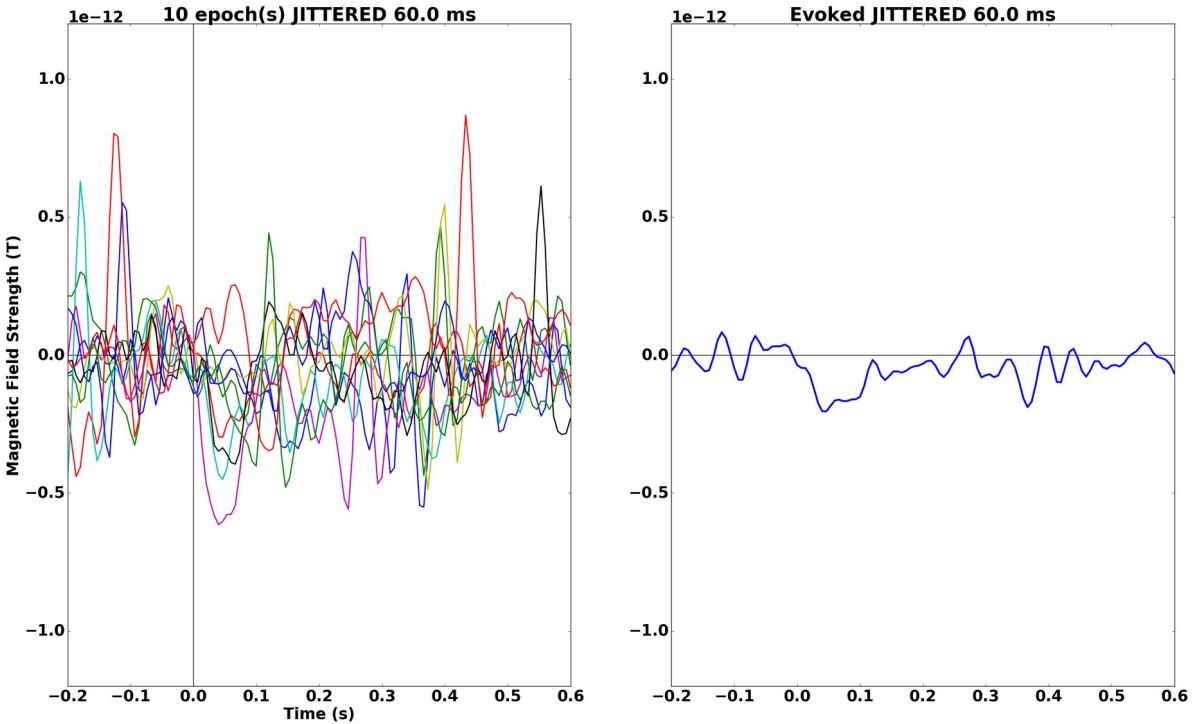


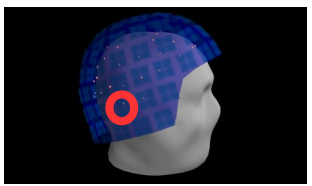
Epochs and Evoked JITTERED 60 ms



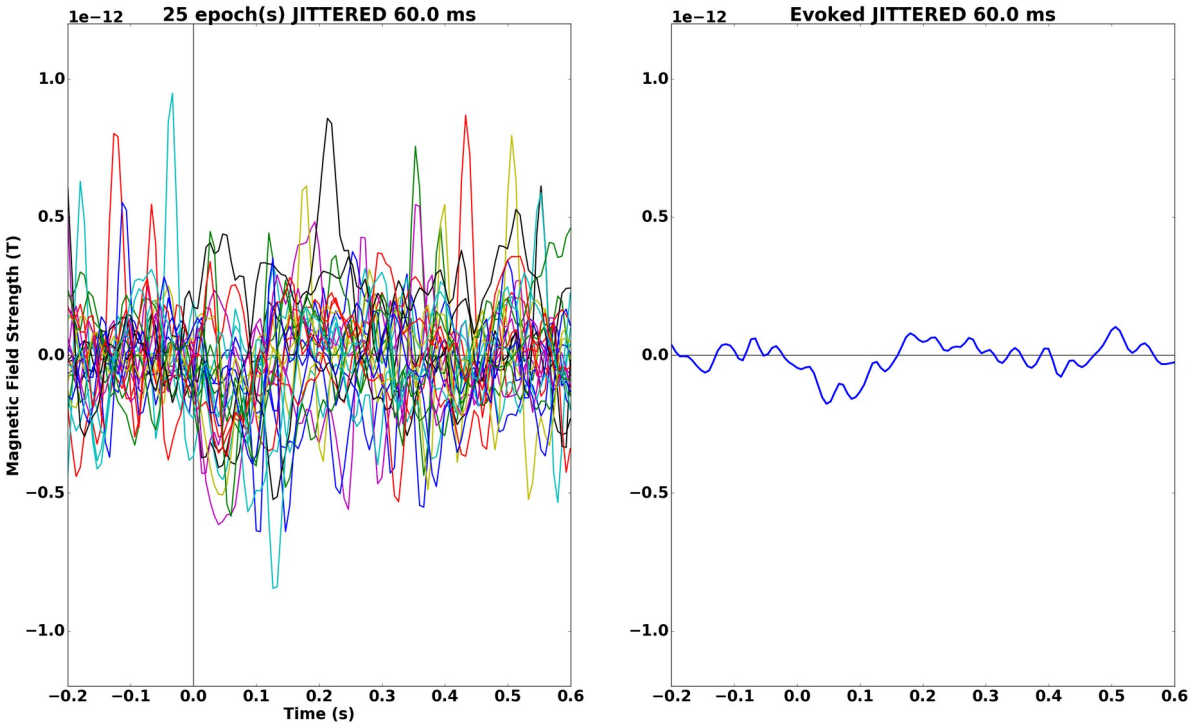


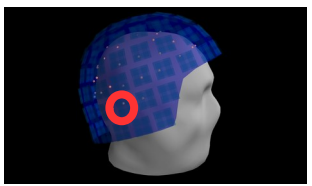
Epochs and Evoked JITTERED 60 ms



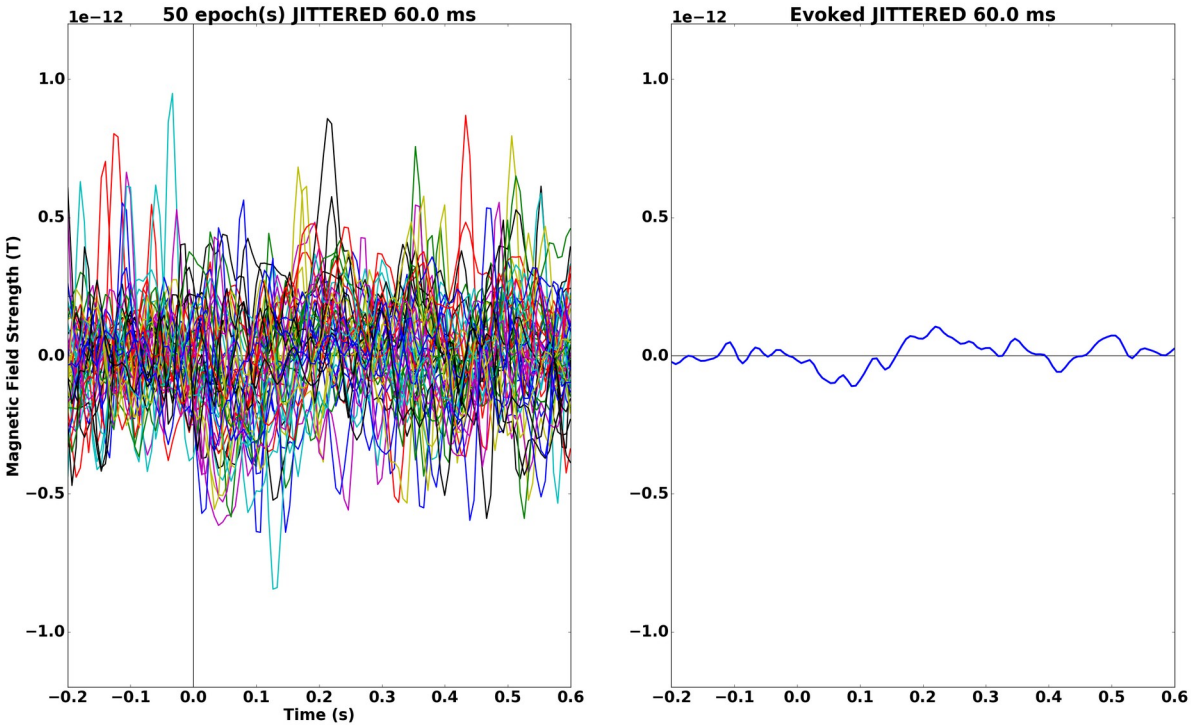


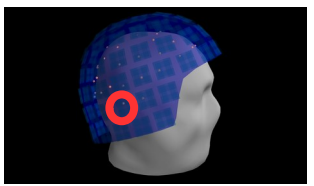
Epochs and Evoked JITTERED 60 ms



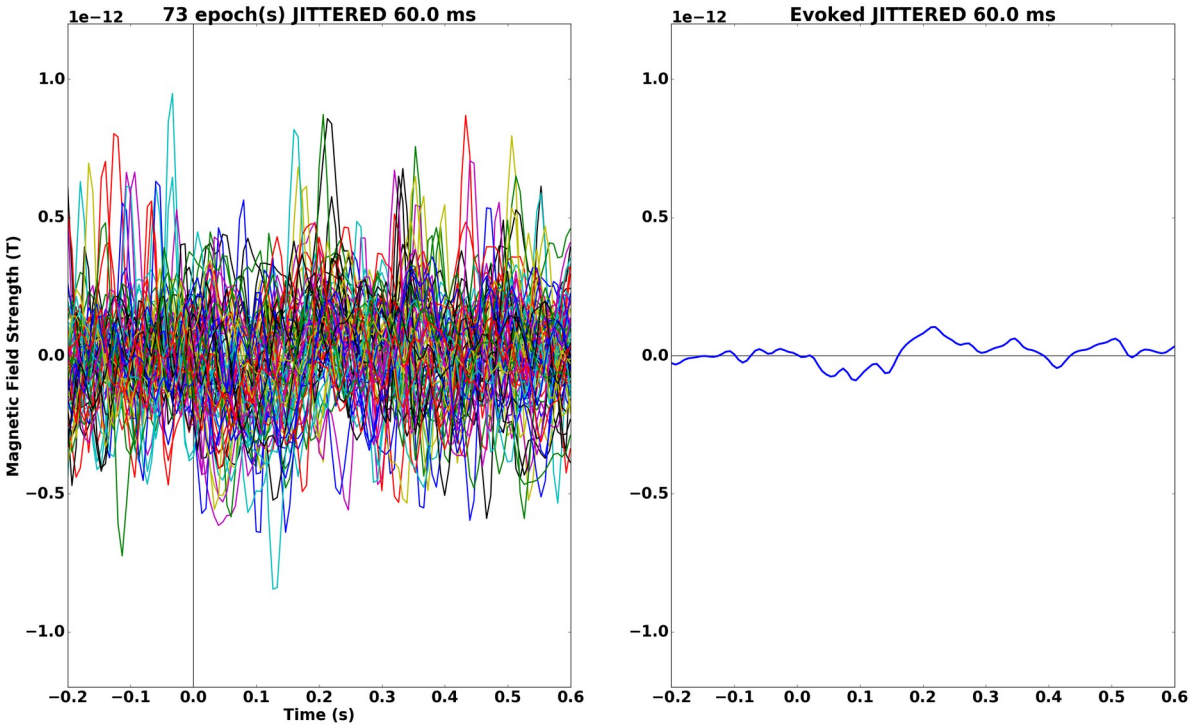


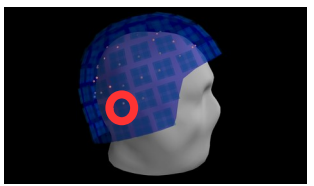
Epochs and Evoked JITTERED 60 ms



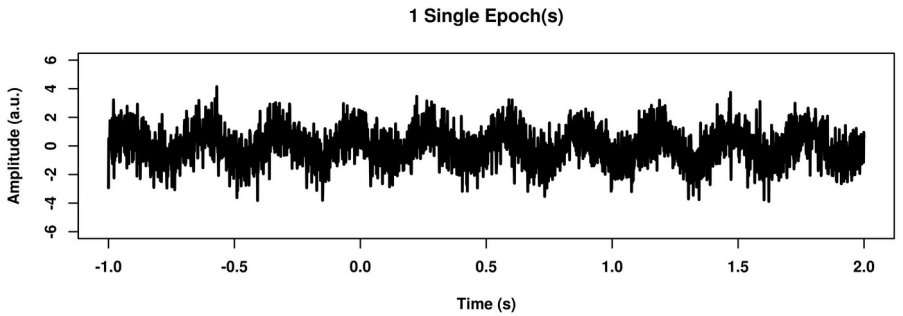


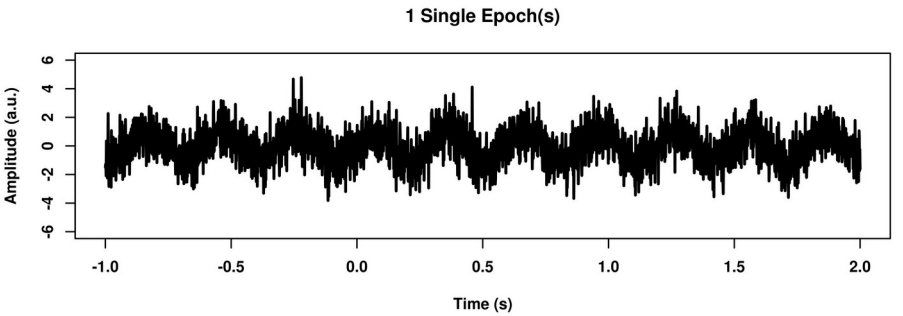
Epochs and Evoked JITTERED 60 ms

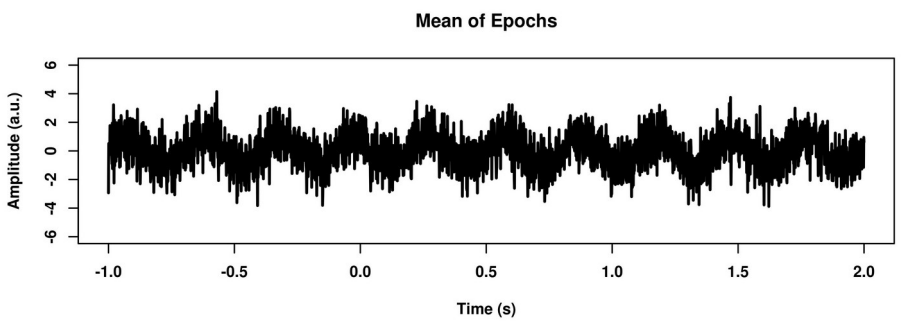


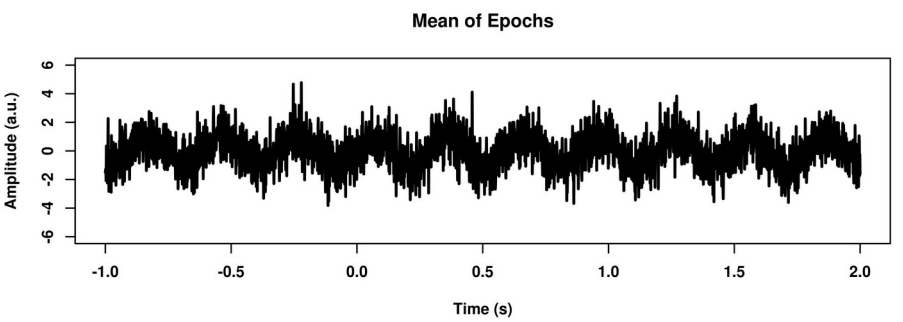


In-phase or out-of-phase with noise





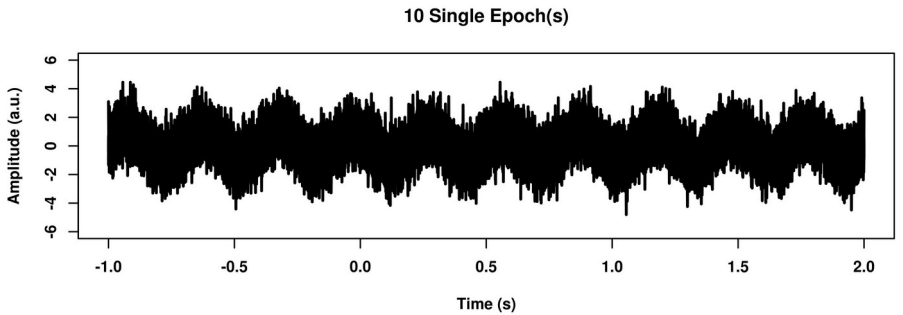


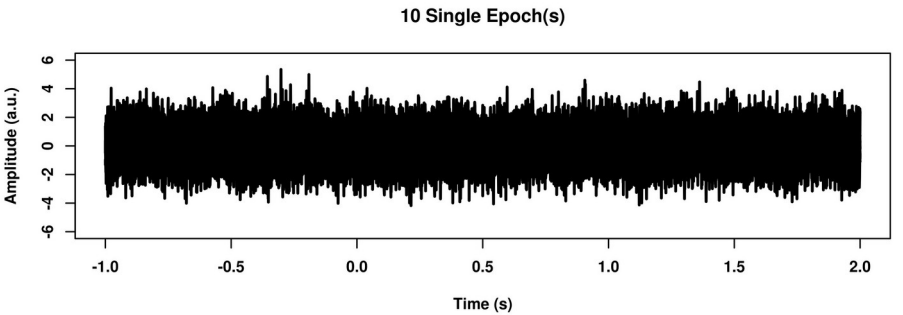


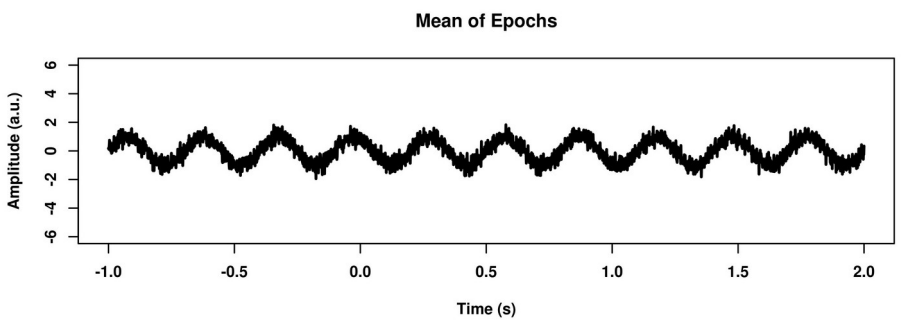
IN PHASE

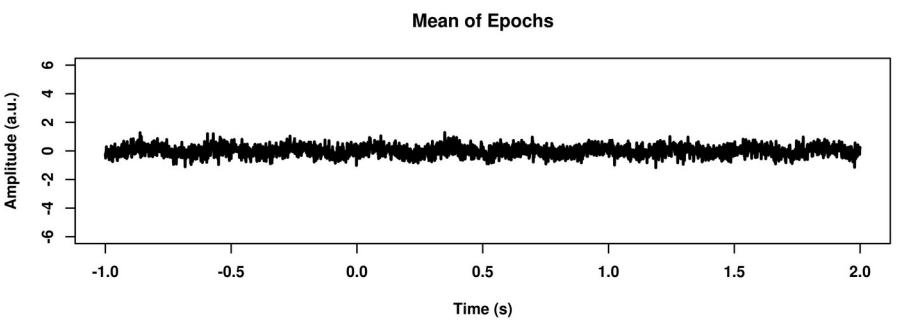
OUT OF PHASE

In-phase or out-of-phase with noise





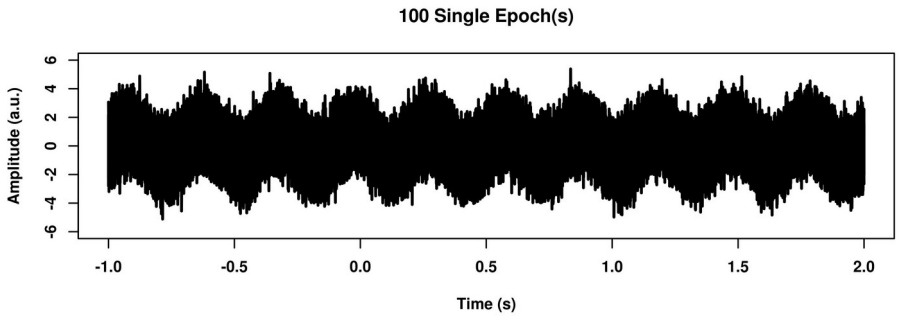


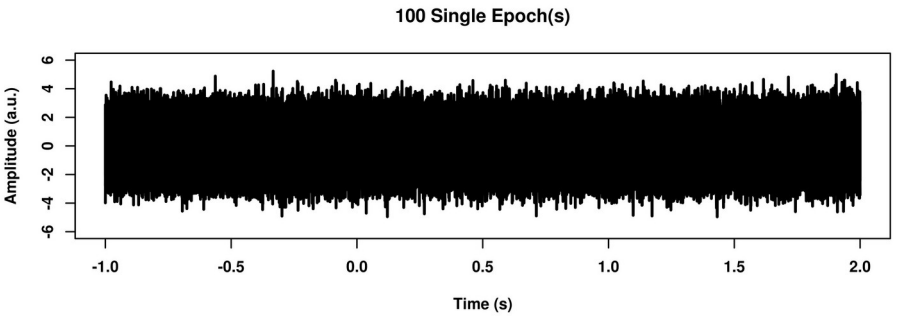


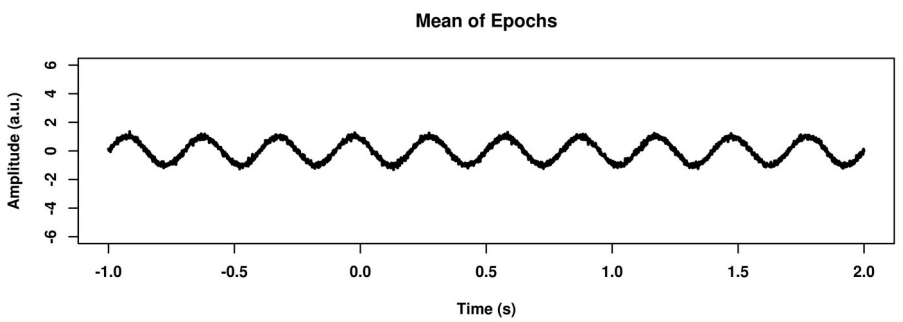
IN PHASE

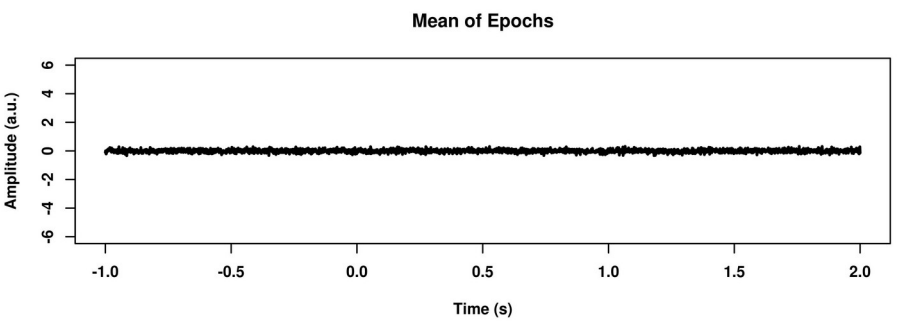
OUT OF PHASE

In-phase or out-of-phase with noise









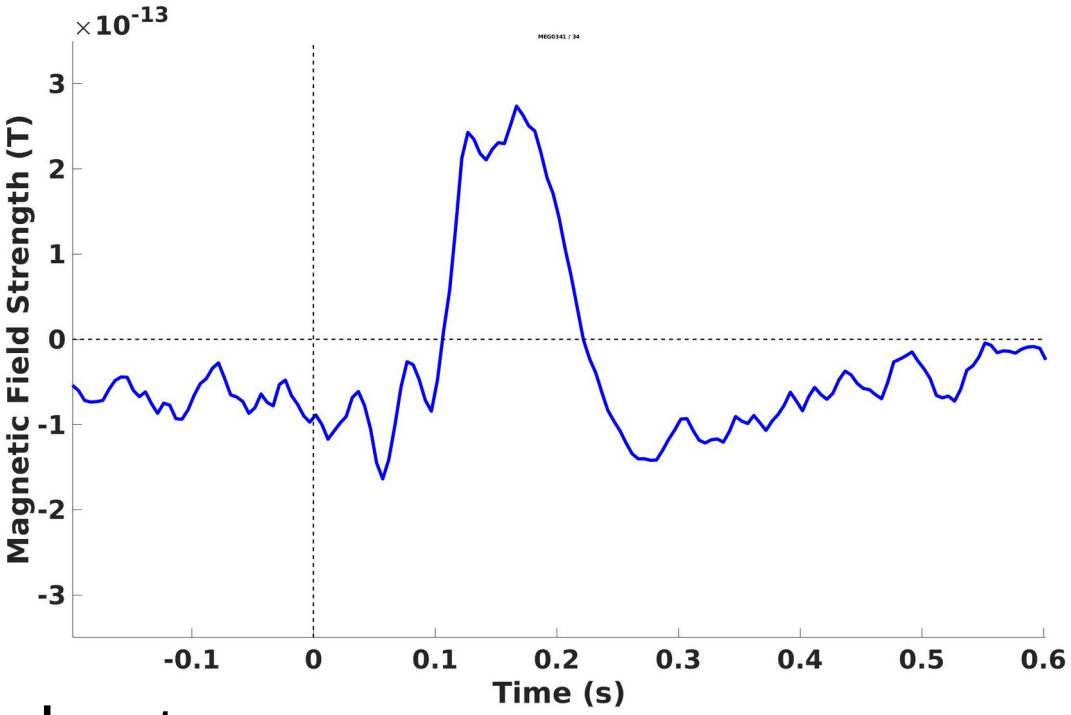
IN PHASE

OUT OF PHASE

Demeaning (baselining)

Note that all evoked responses and epochs shown thus far have been demeaned

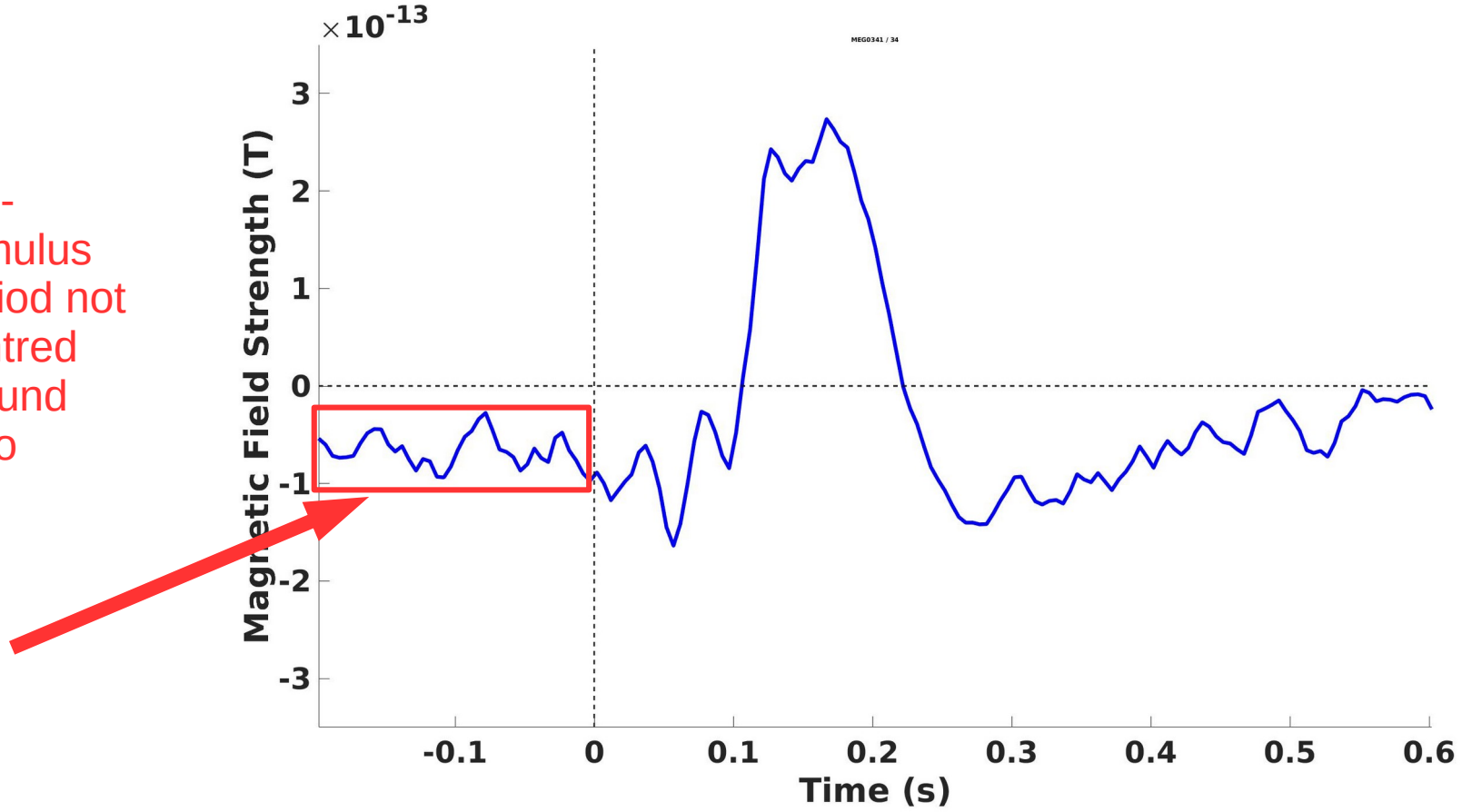
Demeaning (baselining)

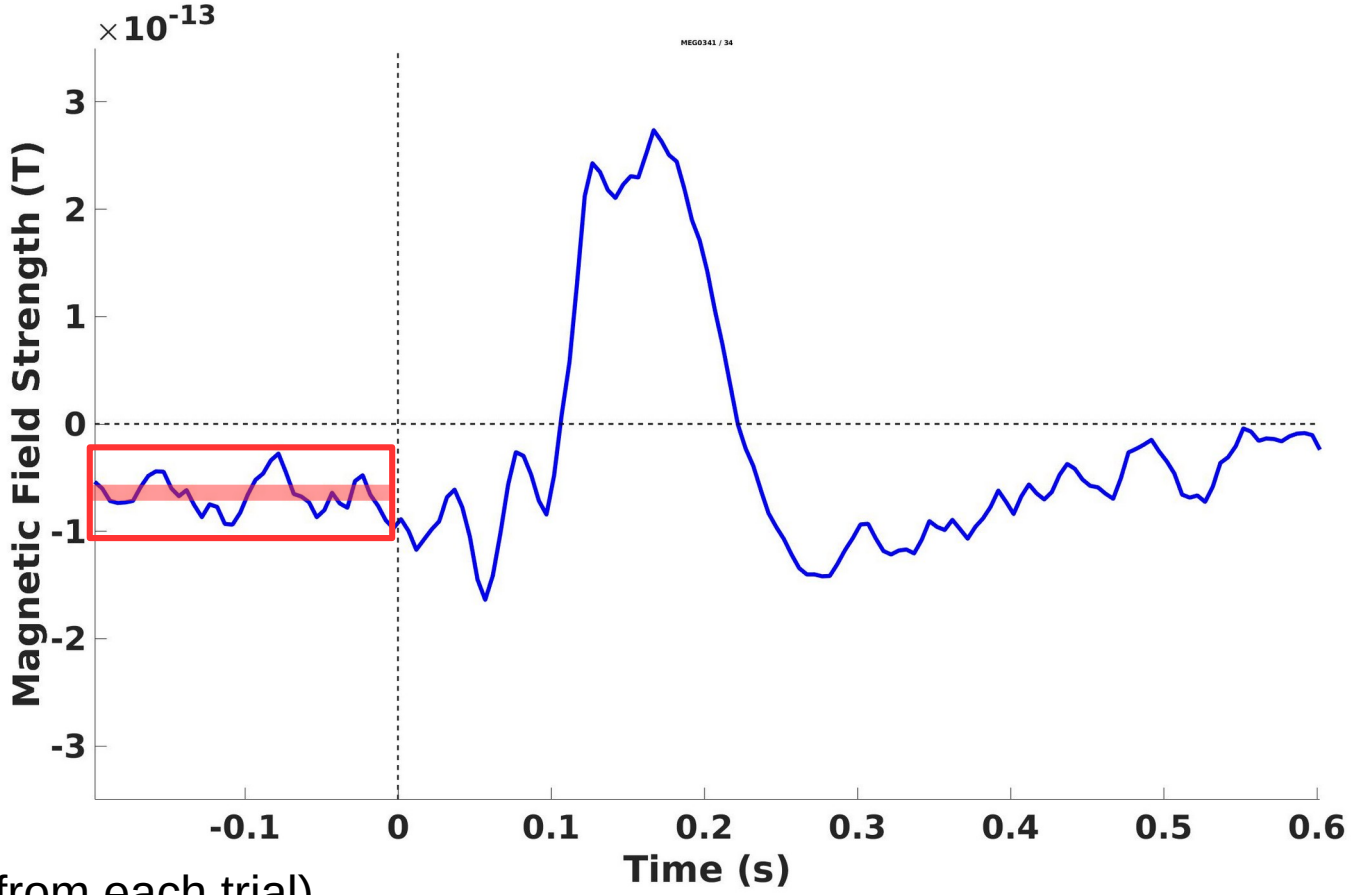


Not demeaned yet – how can we tell?

Demeaning (baselining)

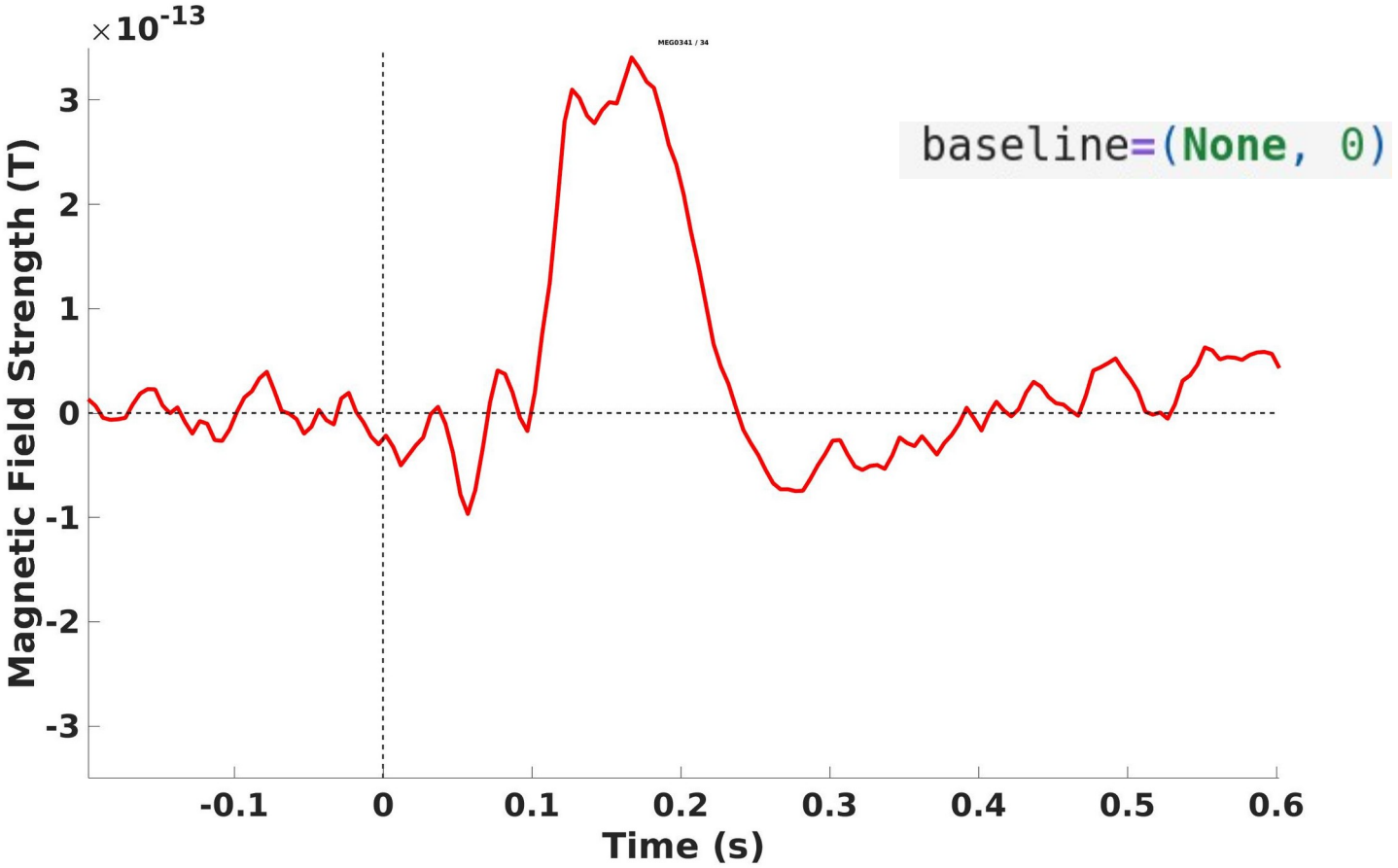
Pre-stimulus period not centred around zero



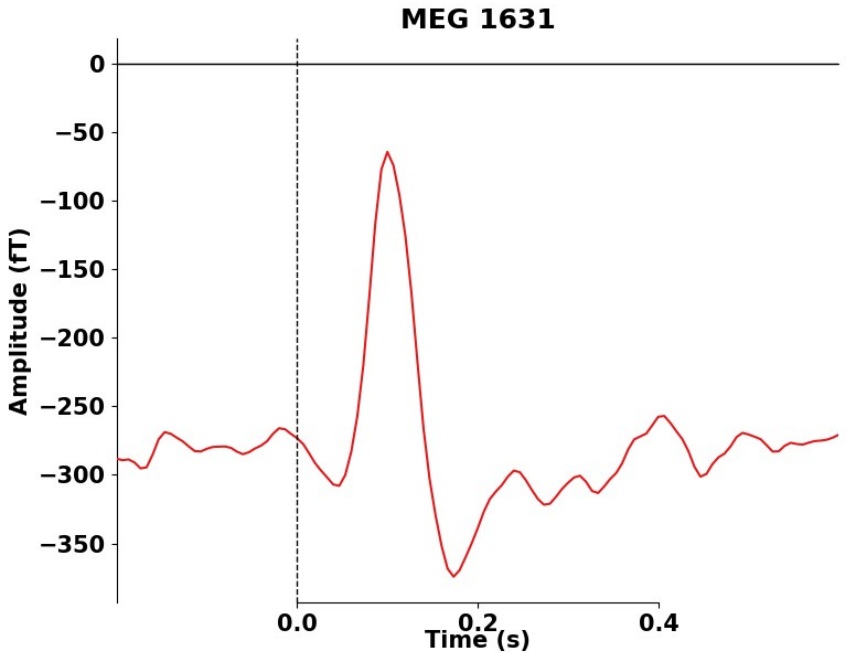


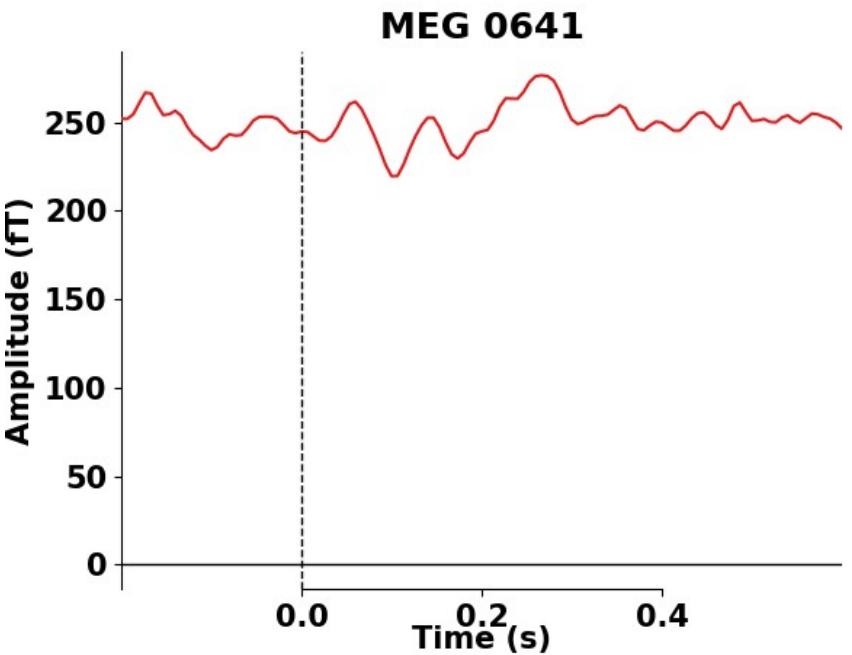
1. Find mean (from each trial)
2. Subtract the mean from each sample (time point)

Demeaning (baselining)

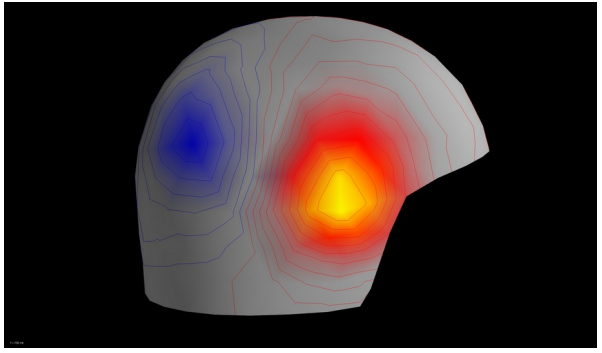


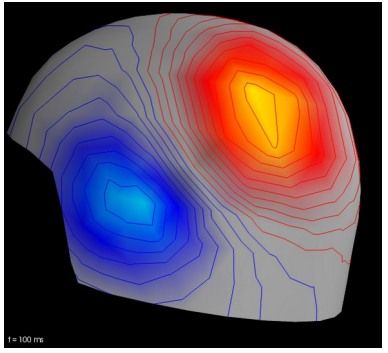
Offsets may differ a lot

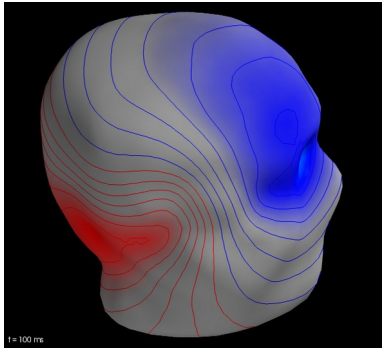


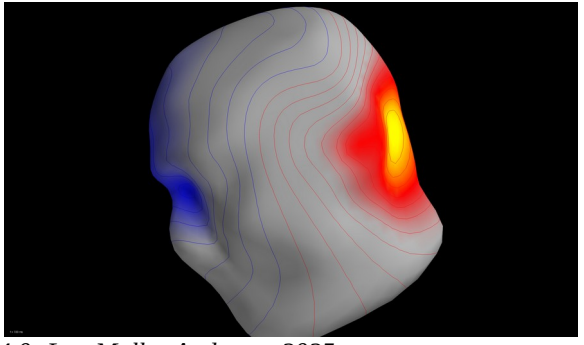


Field and potential plots; and localizing the source



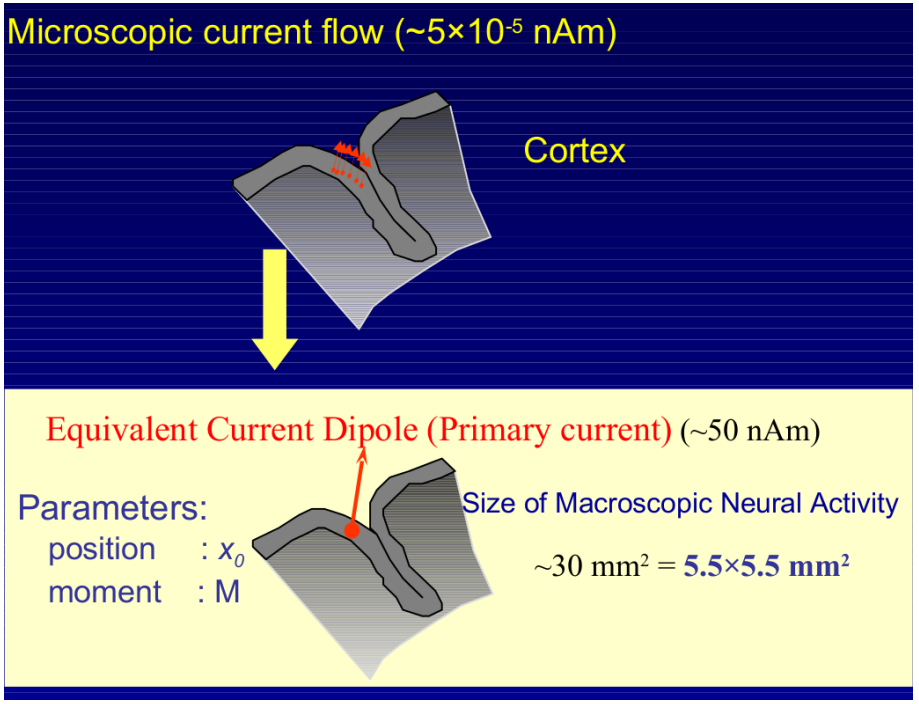






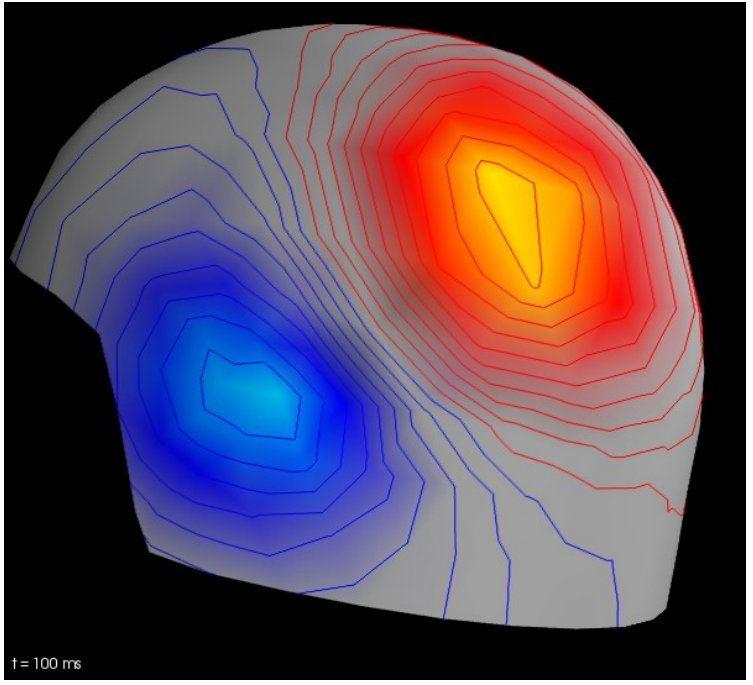
100 ms

Equivalent Current Dipole



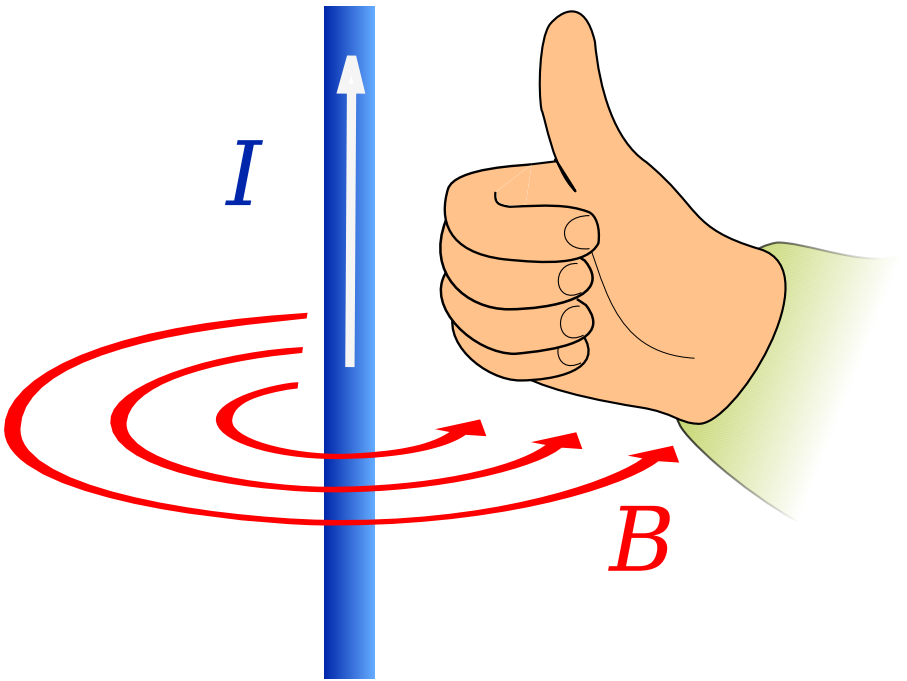
Stephanie Sillekens

Field plot

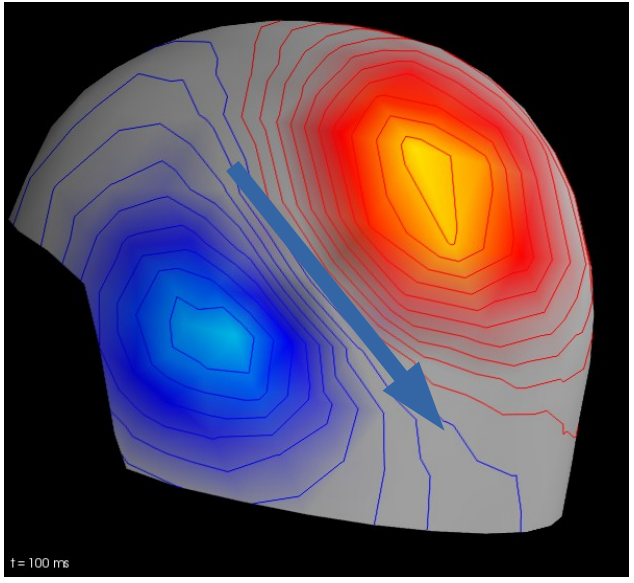


Which way does current flow in the underlying dipole?

Right-hand rule



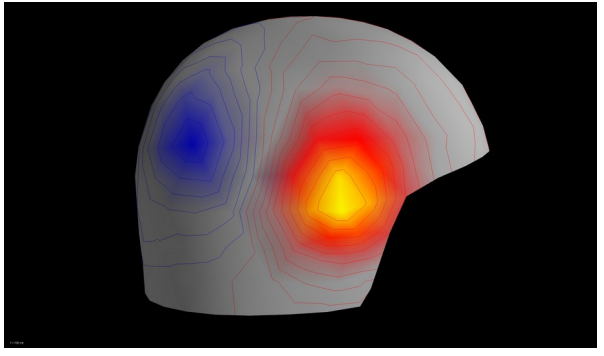
Field plot with very rough source localization

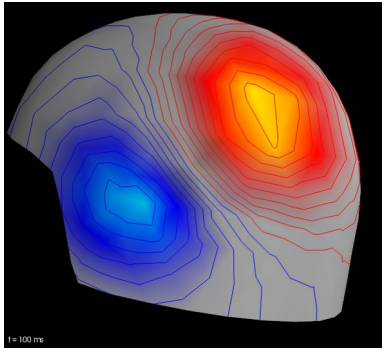


Evoked representations

Evoked representations 3d-topography

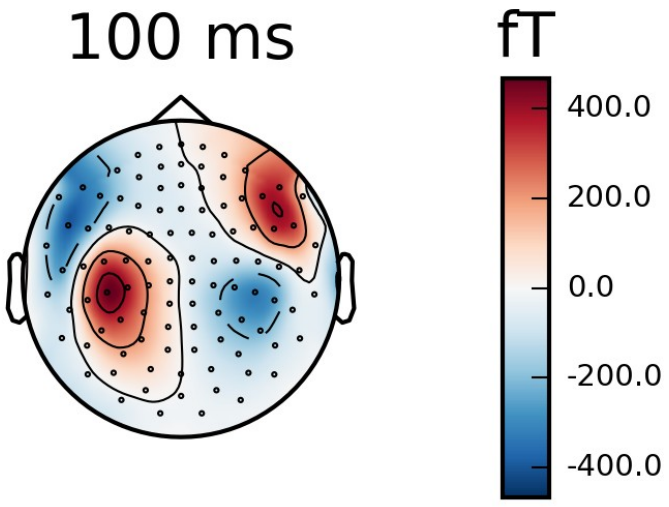
100 ms

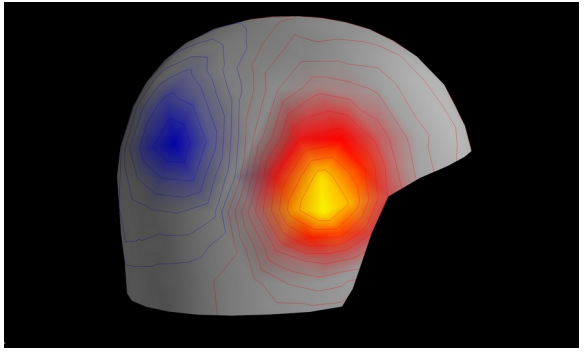


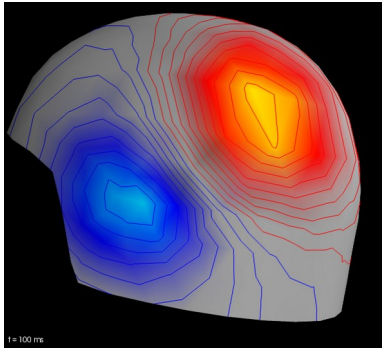


Evoked representations
2d-topography

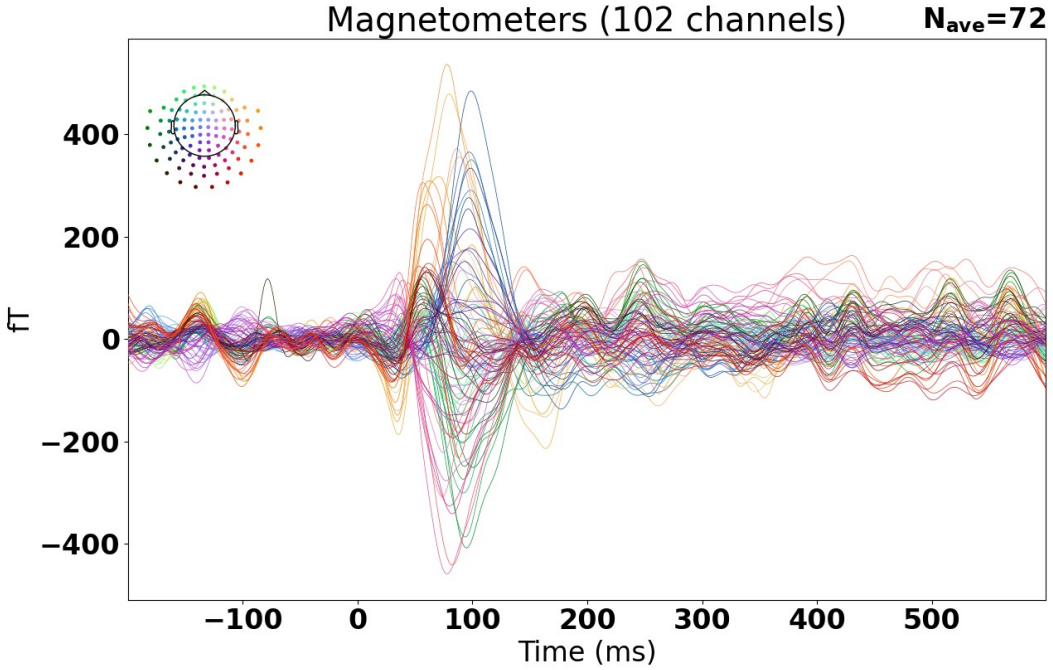
auditory_right mag

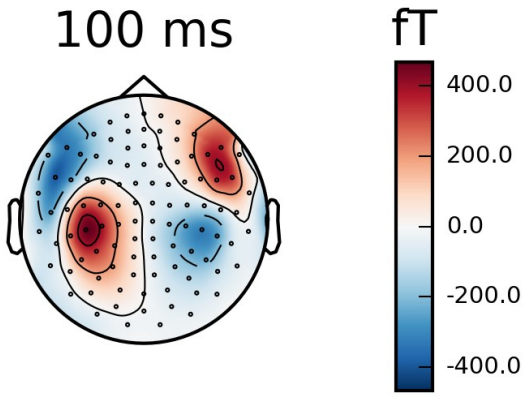




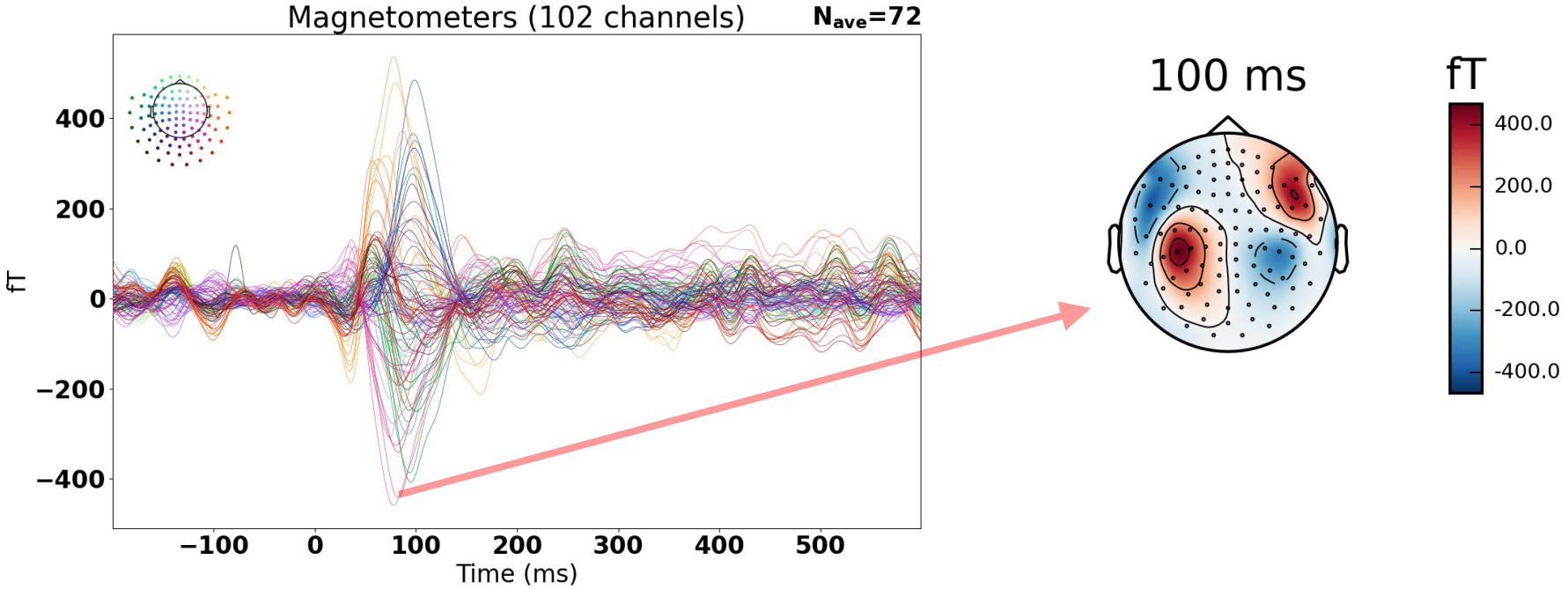


Evoked representations
Butterfly plot

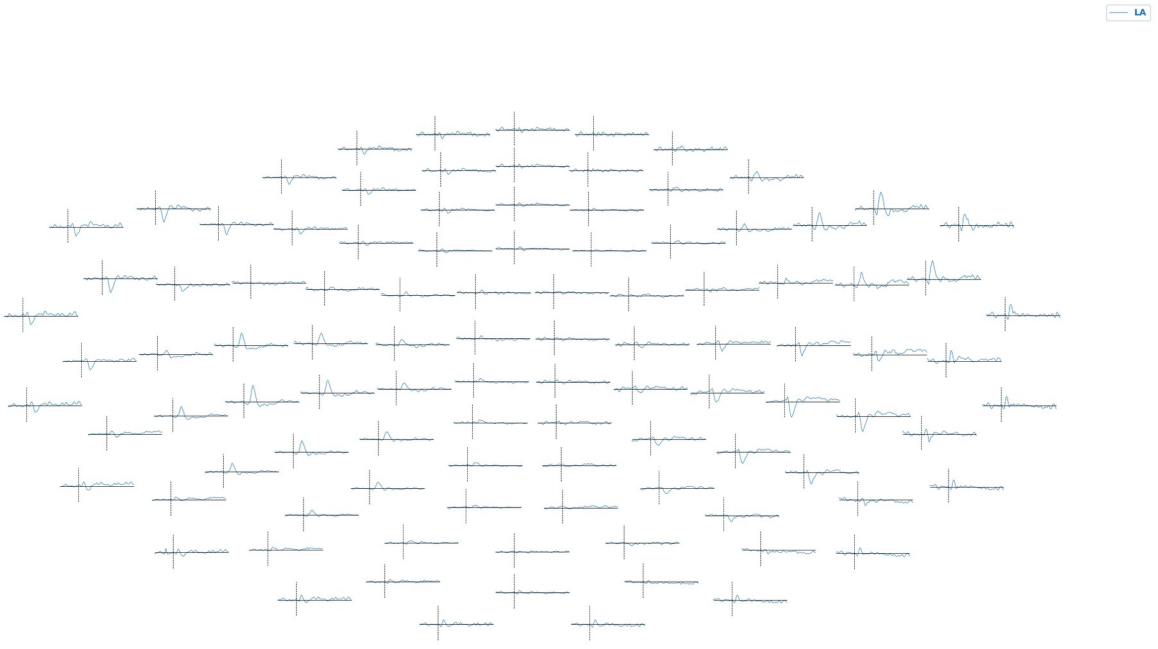




Evoked representations
Butterfly plot



Evoked representations
Channel topography



Learning goals

- Did you learn?
  - the identification of physiological artefacts
  - strategies for increasing the signal-to-noise ratio
  - how to use epochs to create an evoked response
  - the importance of epochs being in-phase for an averaging strategy to be feasible
  - to do rough source localization on dipolar activations

The course plan

Week 36:
Lesson 0: What is it all about?
Class 0: Setting up UCloud and installing MNE-Python

Week 37:
No Teaching

Week 38:
Lesson 1: Workshop paradigm: Measuring visual subjective experience + MR Recordings
Class 1: Running an MEG analysis of visual responses

Week 39:
MEG workshop: Measuring and predicting visual subjective experience

Week 40:
Lesson 2: Basic physiology and Evoked responses
Class 2: Evoked responses to different levels of subjective experience

Week 41:
Lesson 3: Multivariate statistics
Class 3: Predicting subjective experience in sensor space
Deadline for feedback: Video Explainer

Week 42:
Autumn Break

Week 43:
Lesson 4: Forward modelling and dipole estimation
Class 4: Creating a forward model

Week 44:
Lesson 5: Inverse modelling: Minimum-norm estimate
Class 5: Predicting subjective experience in source space

Week 45:
Lesson 6: Inverse modelling: Beamforming
Class 6: Predicting subjective experience in source space, continued

Week 46:
Lesson 7: What about that other cortex? - the cerebellar one
Class 7: Oral presentations (part 1)
Deadline for feedback: Lab report

Week 47:
Lesson 8: Guest lecture: Laura Bock Paulsen: Respiratory analyses
Class 8: Oral presentations (part 2)

Week 48:
Lesson 9: Sensors of the future
Class 9: Oral presentations (part 3)

Week 49:
Lesson 0 again: What was it all about?
Class 10: Oral presentations (part 4)

Reading questions

- King J-R, Dehaene S (2014) Characterizing the dynamics of mental representations: the temporal generalization method.
  - Make sure you understand Figure 1
  - Which of the patterns in Figure 2 do you think are likely in the brain?
- Sandberg K, Andersen LM, Overgaard M (2014) Using multivariate decoding to go beyond contrastive analyses in consciousness research.
  - Why would multivariate statistics favour reliable over large responses on the epoch level (Figure 2)

Next class – Getting started with your own data