CS463/516

Lecture 6

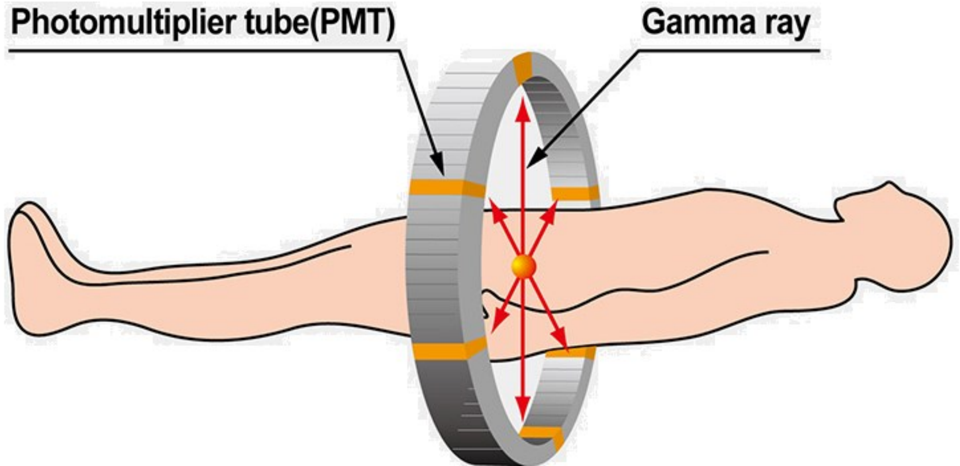
More medical imaging modalities

- We have seen a brief overview of CT and some common MRI modalities:
  - T1, T2, SWI, BOLD fMRI, TOF, Diffusion (all based on MRI)
    - Will look at some of these in more detail later
- For this (and next) lecture, will focus on some non-MRI modalities:
  - Electroencephalography (EEG) (a) and its close relatives (MEG, ECoG)
  - Ultrasound (b)
  - Positron emission tomography (PET) (c)

a)

b)

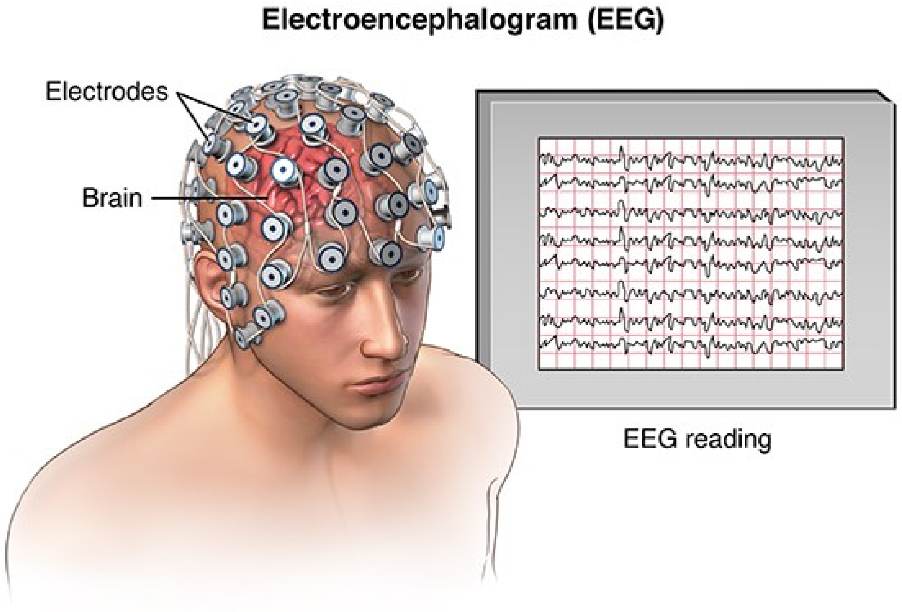
c)



Electroencephalography (EEG)

- **EEG**: electrophysiological monitoring method to record electrical activity of brain
- EEG records electrical activity of massive amounts of neurons from the scalp (a)
- EEG has excellent temporal resolution (can capture events on the order of ms)
- EEG has poor spatial resolution (b) (electrodes far from brain, skull blurs signal)

a)



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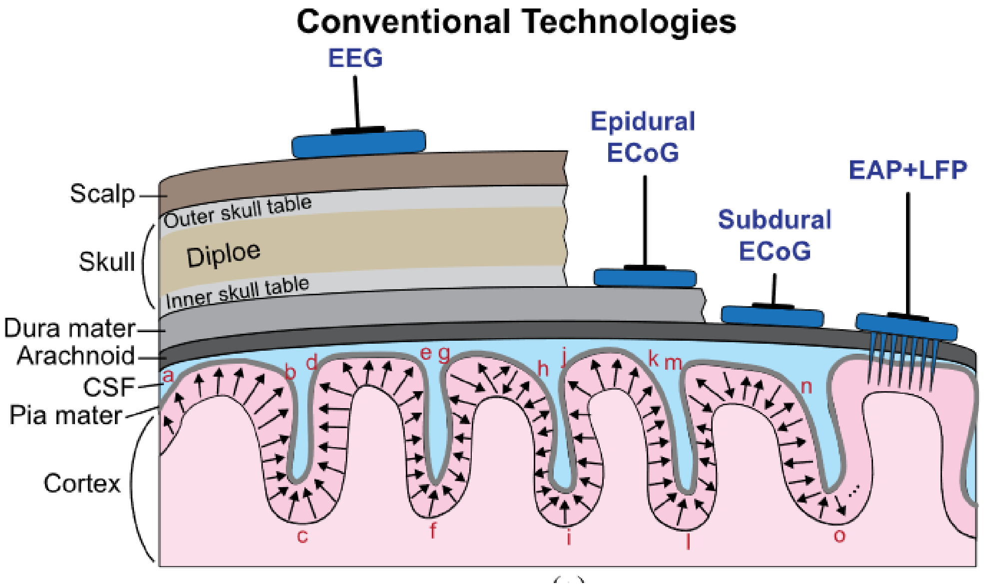
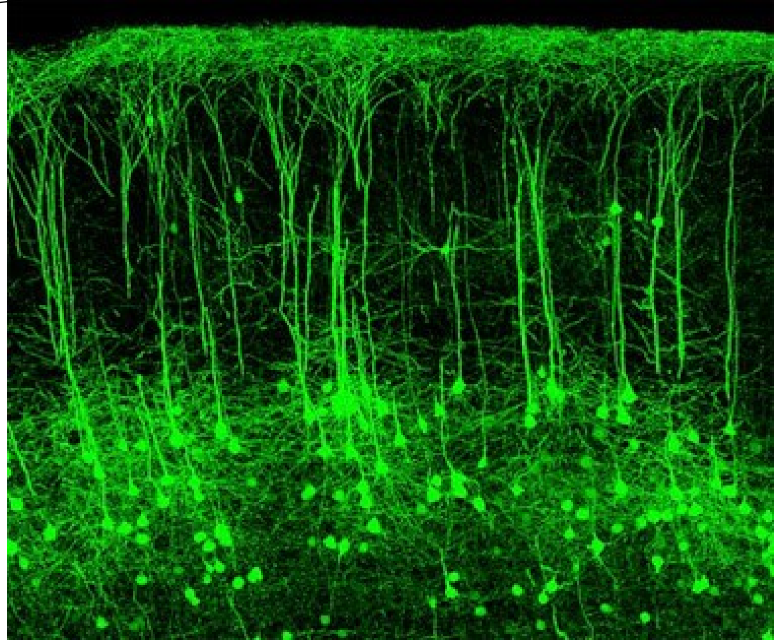


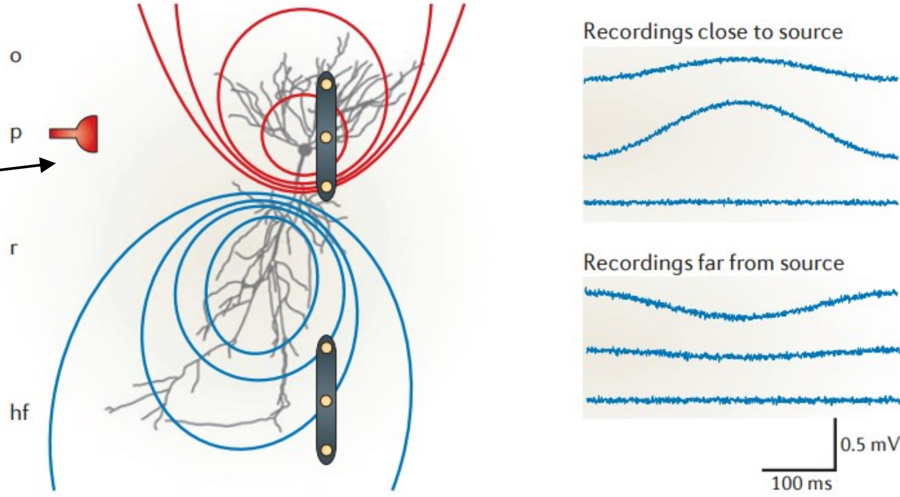
EEG

a)



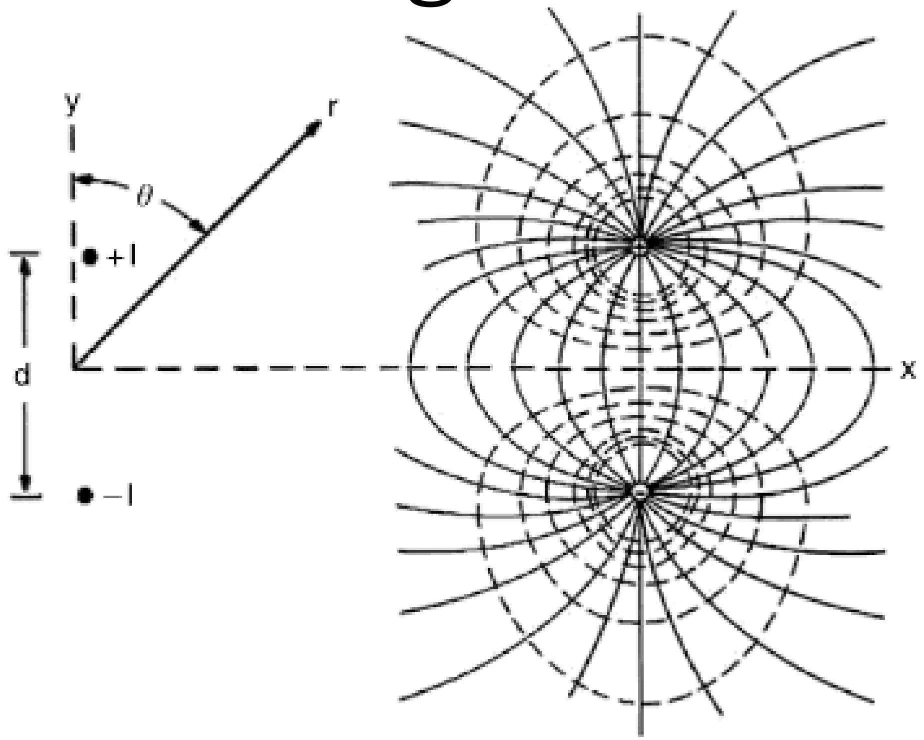
- What exactly are we measuring with EEG?
- Short answer: the *synchronized* activity of large numbers of pyramidal cell neurons (a) in the regions of brain closest to the scalp
- b) EEG signals measured in units of *electrical potential:* millivolts mV or microvolts μV
  - Neurons in brain are connected to other neurons by synapses, and communicate with each other by electrical impulses
  - When a neuron receives a signal from another neuron, electrical potential around the synapse changes
    - Can model each pyramidal neuron as a small *dipole*
  - If enough neurons are communicating in synchrony, the signal can be measured from scalp electrodes due to superposition of many small electric fields (dipoles)

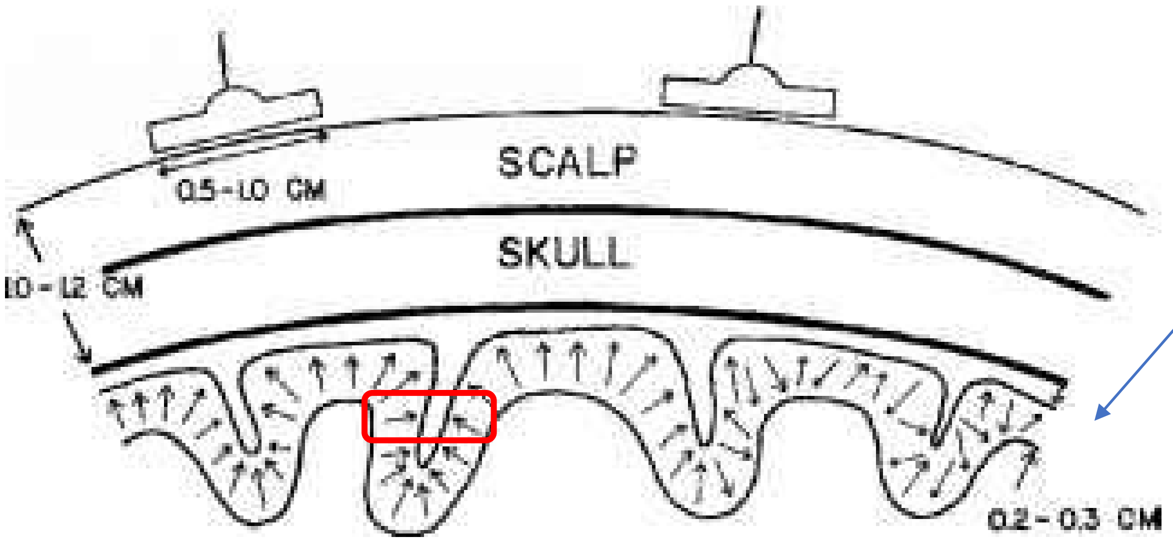
b)



EEG: main factors determining signal strength

- a) schematic showing how the EEG signal Φ measured on scalp depends on orientation θ and distance r from the neuron to the electrode
- b) the folding patterns of the brain itself are also important
  - Electrical dipoles will cancel each other if close together and having opposite orientation (→ ←)





Each small arrow embedded in the cortex is a dipole (neuron)

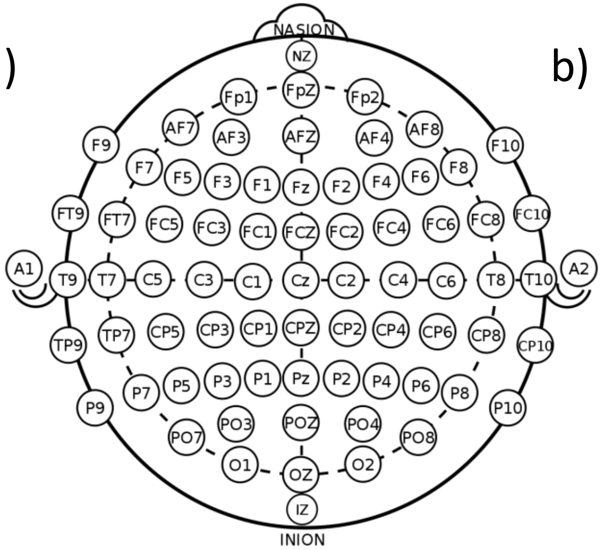
$$\Phi(r,\theta) \cong \frac{Idcos\theta}{4\pi\sigma r^2}$$

Where θ is angle of dipole w.r.t measurement point (electrode), I is dipole current, d is distance between dipole source and sink, σ is resistivity of medium between dipole and electrode, and r^2 is distance between dipole and electrode

EEG recording equipment

- Electrical signals generated by neuronal dipoles are very weak relative to background noise and other physiological signals (muscle twitches, heartbeats)
- EEG electrodes provide an interface between human tissues (scalp) and the wires which conduct current to the amplifiers
  - Typically, electrodes arranged in the ‘10-20 system’ which standardizes their location (a)
  - A *conductive gel* is often used to reduce electrical impedance between scalp and electrode (b)
  - Electric potentials which are common across many electrodes (common-mode signals) such as the heartbeat or AC field are subtracted out before amplification (c)

a)



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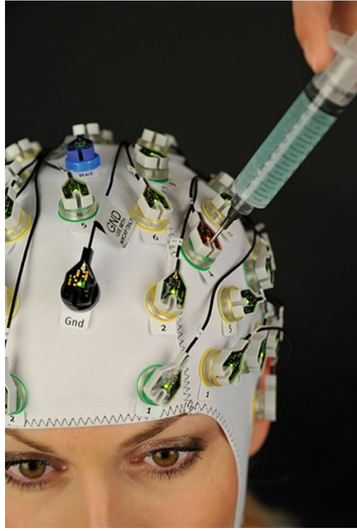
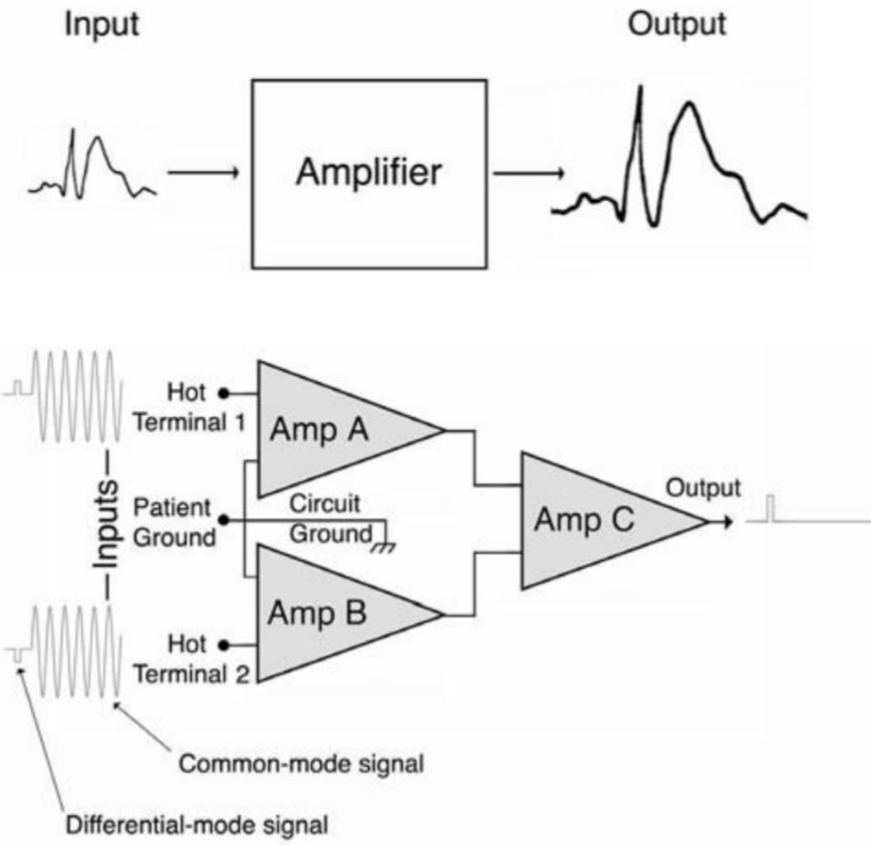
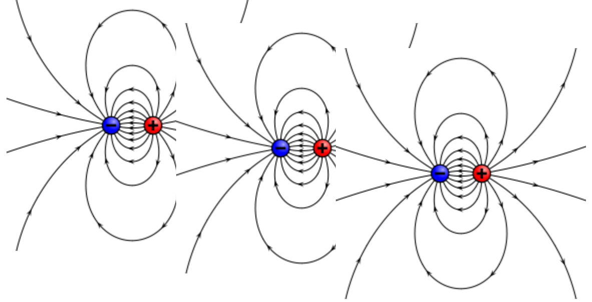


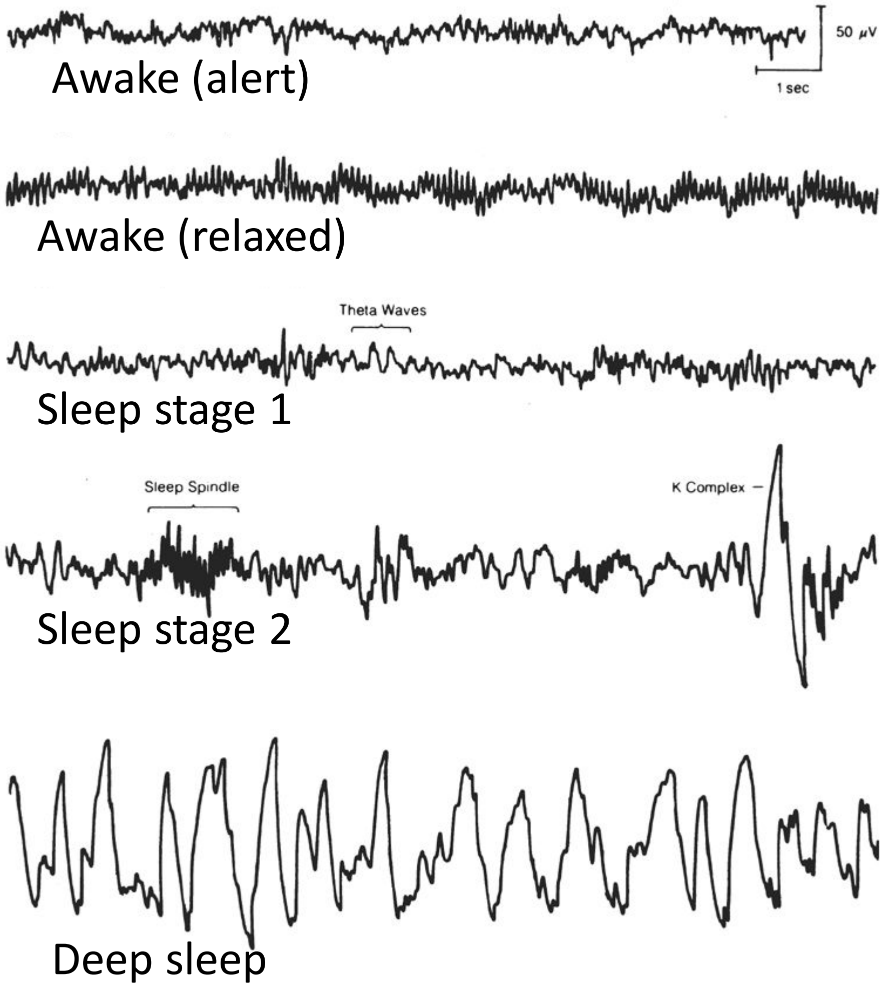
c)



Neuronal synchrony

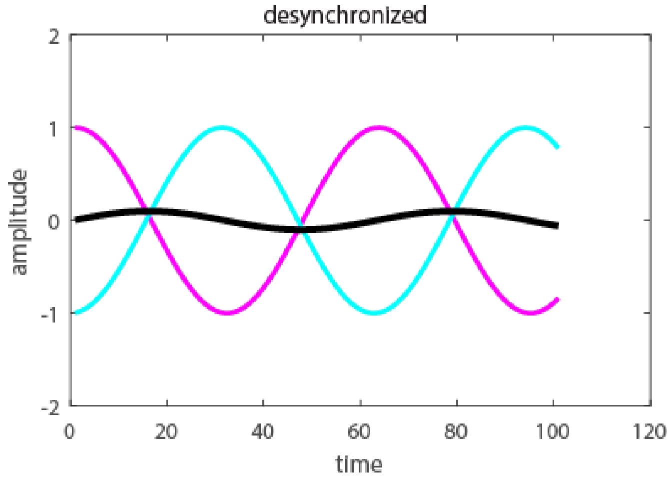
c)





- Have mentioned synchrony repeatedly. Why is it important?
- a) two neurons are desynchronized (out of phase). Their activity will sum to zero
- b) two neurons are highly synchronized. Their activity will sum to a larger amount
- If many electric dipoles (neurons) are close together (c) and activated in synchrony, the signal will be stronger at a distance due to superposition
- The most common example is sleep. During deep sleep, the brain shuts down (mostly) and all neurons are free to synchronize with each other (lower energy state). This manifests in the EEG recording as high amplitude, low frequency waves

a)



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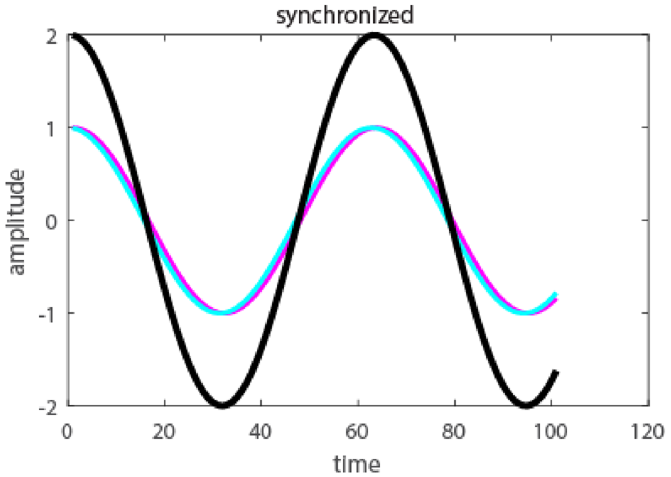
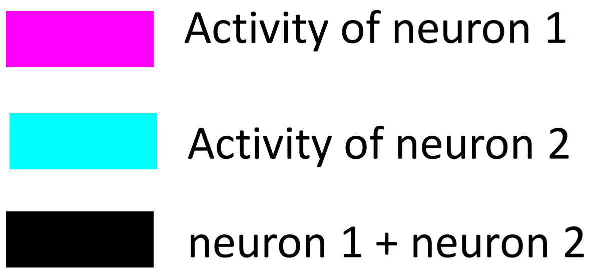
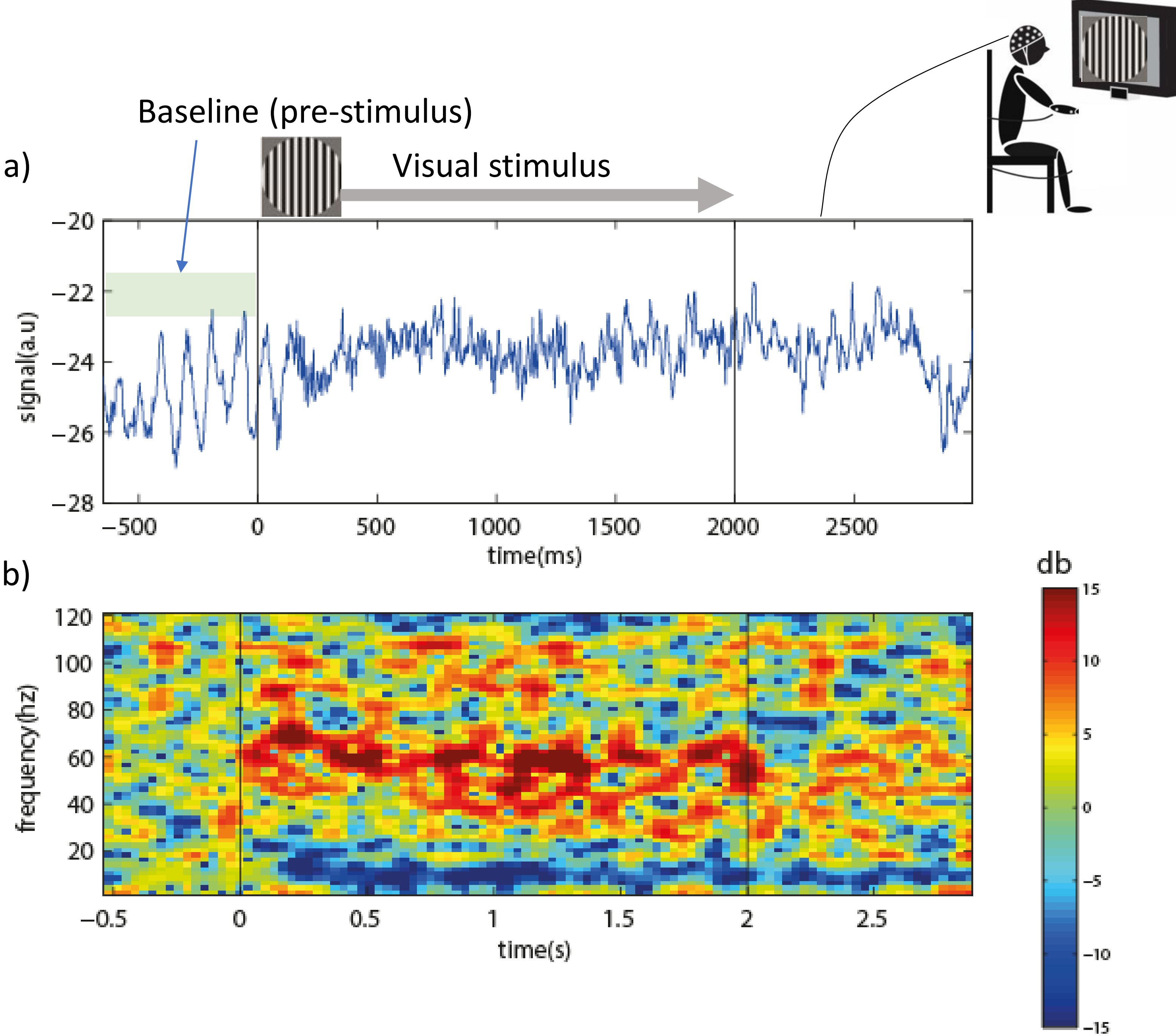




Typical EEG response

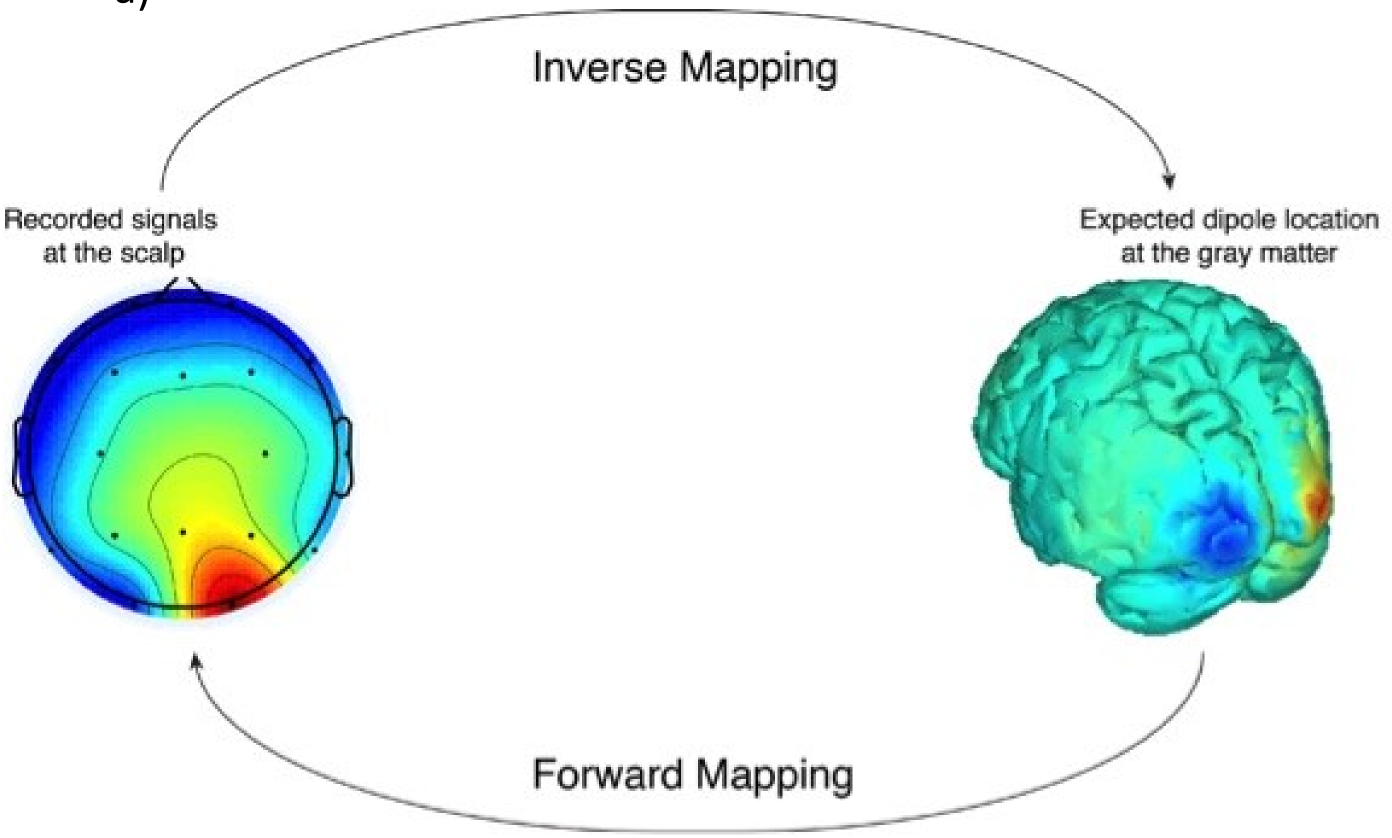
- Measuring fluctuations in electric potential over time yields a *time series* of neuronal activity
- Typical experiment: show stimulus to the subject, observe effects on time series
  - We call this the 'event-related' experiment design
- Example: EEG response to a simple black and white visual stimulus (a)
  - High amplitude, low frequency oscillations during baseline
  - Low amplitude, high frequency oscillations during stimulation
- b) time-frequency decomposition of time series in (a)
  - Normalized relative to baseline
  - Shows how the stimulus leads to a decrease in low frequency (10-20 Hz) amplitude and increase in high frequency (40-80 Hz) amplitude



EEG source localization (inverse solution)

- EEG measures electrical potential generated by synchronous activity of neuronal dipoles using electrodes *on the scalp*
- What we really want is to infer what's happening inside the brain (a)
- This is typically done acquiring MRI images of the subject, segmenting the images, and modeling how electrical fields propagate through the various tissues (b)
- Can then compute an 'inverse solution' based on the scalp signal, giving an estimate of how the brain might have generated observed signal

a)



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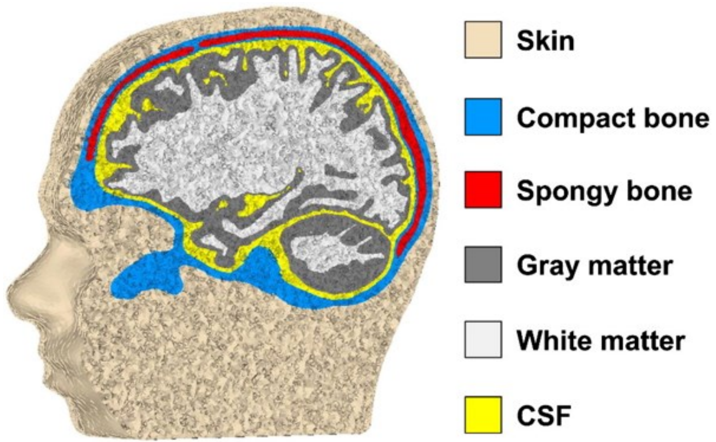


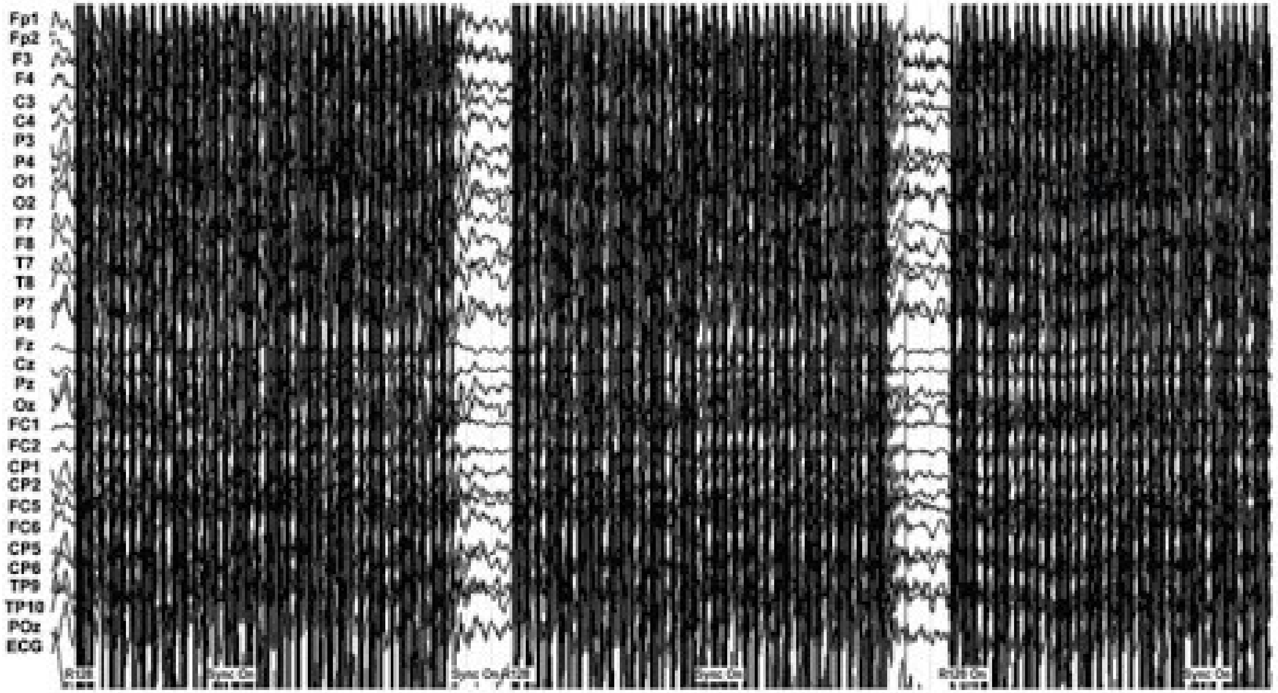
Computing the inverse solution is what we call an 'ill-posed problem' – there is no 'unique solution' in fact an infinite number of dipole configurations in the gray matter may have generated the pattern we observe on the scalp

Simultaneous EEG-fMRI

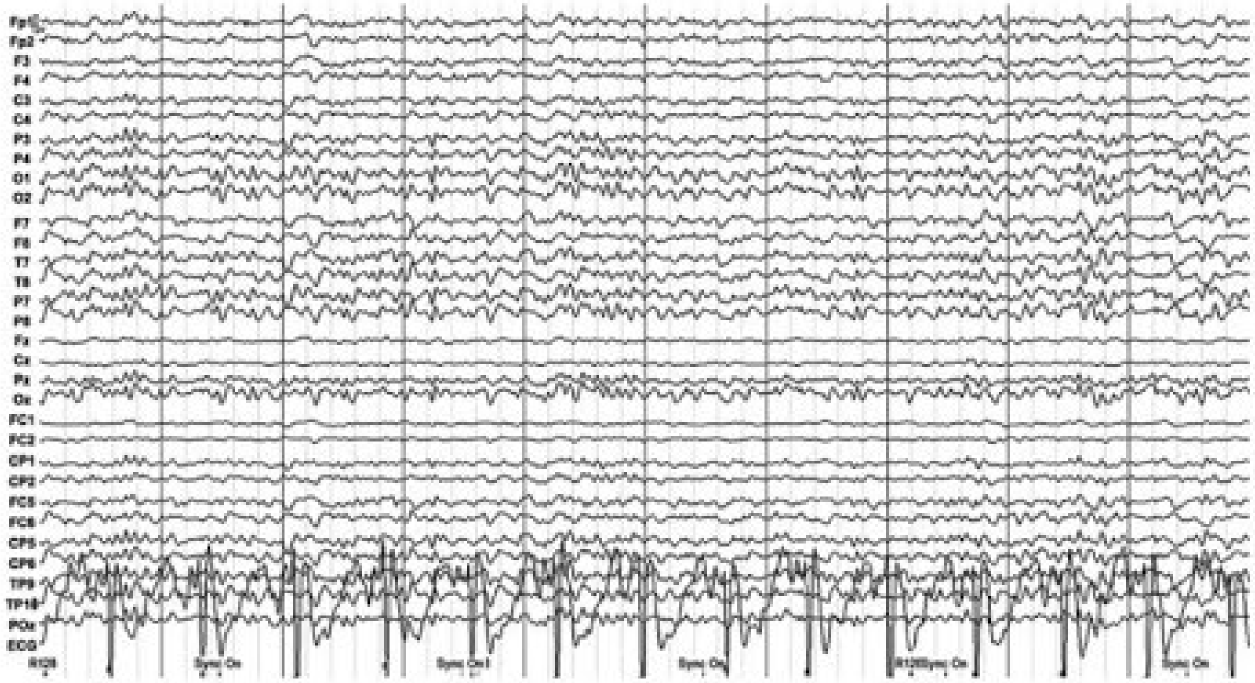
- Can record EEG inside the MRI scanner to obtain the best of both worlds (a)
  - High temporal resolution of EEG
  - High spatial resolution of BOLD fMRI
- Unfortunately, the MRI is a very hostile environment for EEG, causes many artifacts in signal

a)

b)



c)



b) EEG signal recorded inside MRI during fMRI scan. Note the high amplitude artifact signals which are due to the scanner gradients

c) The same EEG signal after subtracting away the artifacts

One of my articles investigating EEG

- As mentioned earlier, EEG signal depends primarily on two factors:
  - 1) distance from dipoles to electrode
  - 2) folding patterns of the brain
- We wanted to see, within a healthy population (a), which factor was more important?
- Collected EEG and MRI data (b) from healthy human participants.
  - Used fMRI to find where in brain the signal was coming from (distance)
  - Used T1 MRI to segment the cortex and get folding patterns
- Showed that people with smaller heads tend to have stronger EEG signals, because skull to scalp distance is smaller (c)

Cortical distance, not cancellation, dominates inter-subject EEG gamma rhythm amplitude

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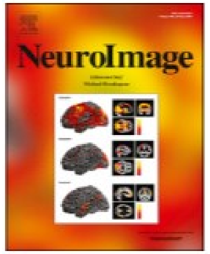

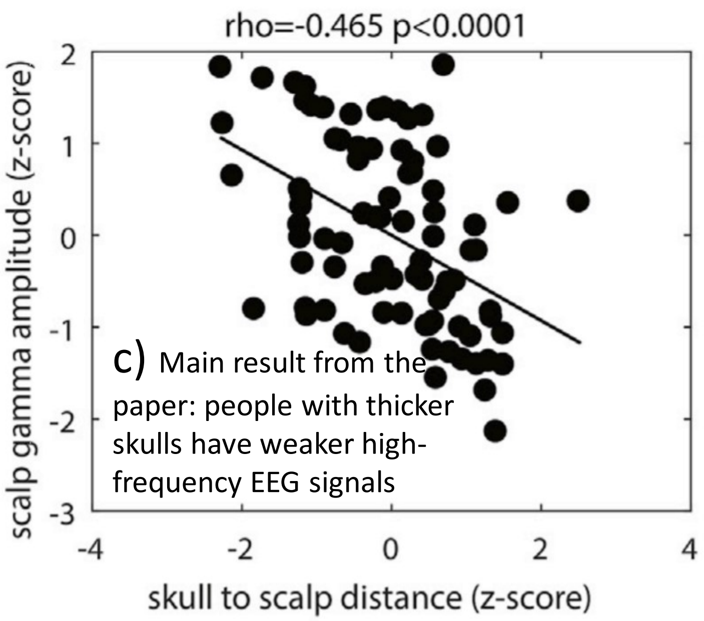

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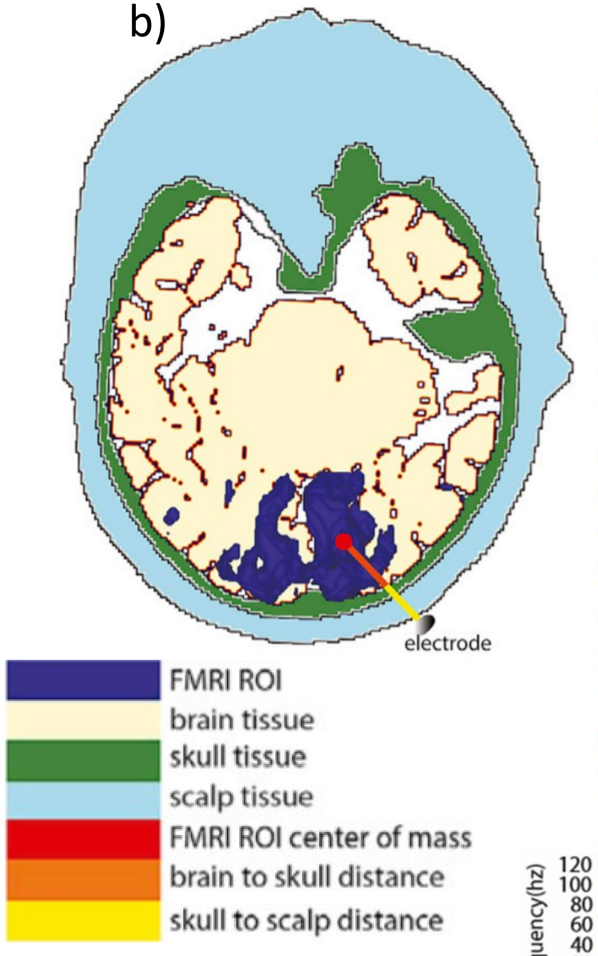
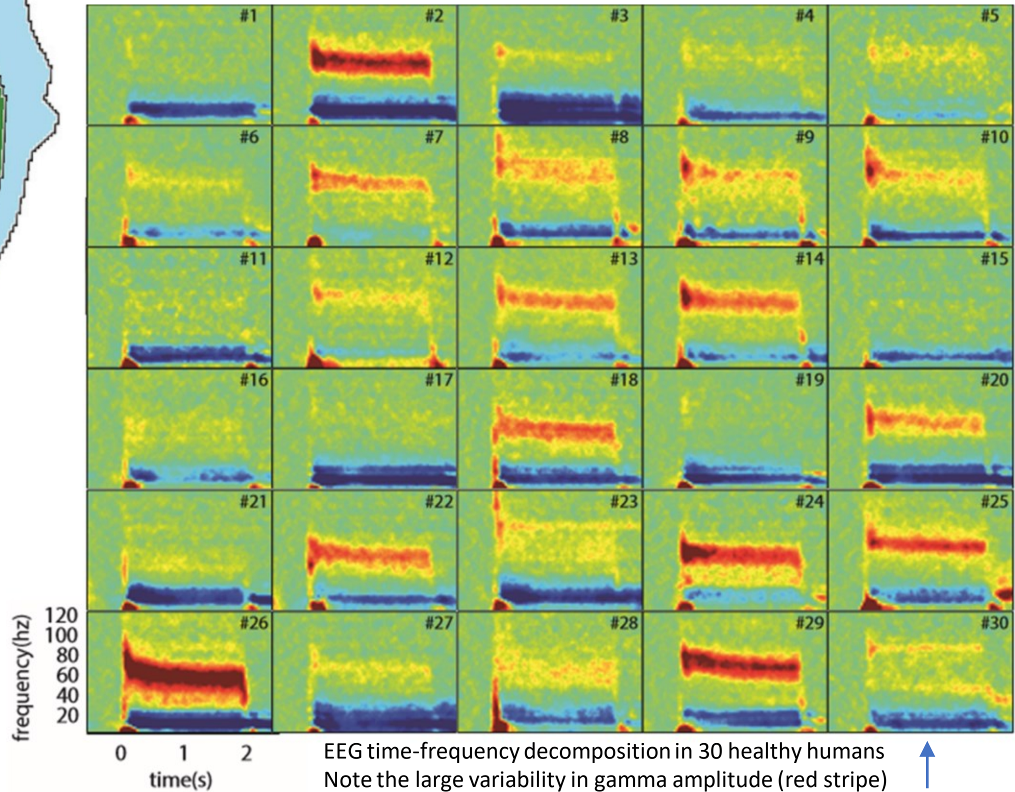


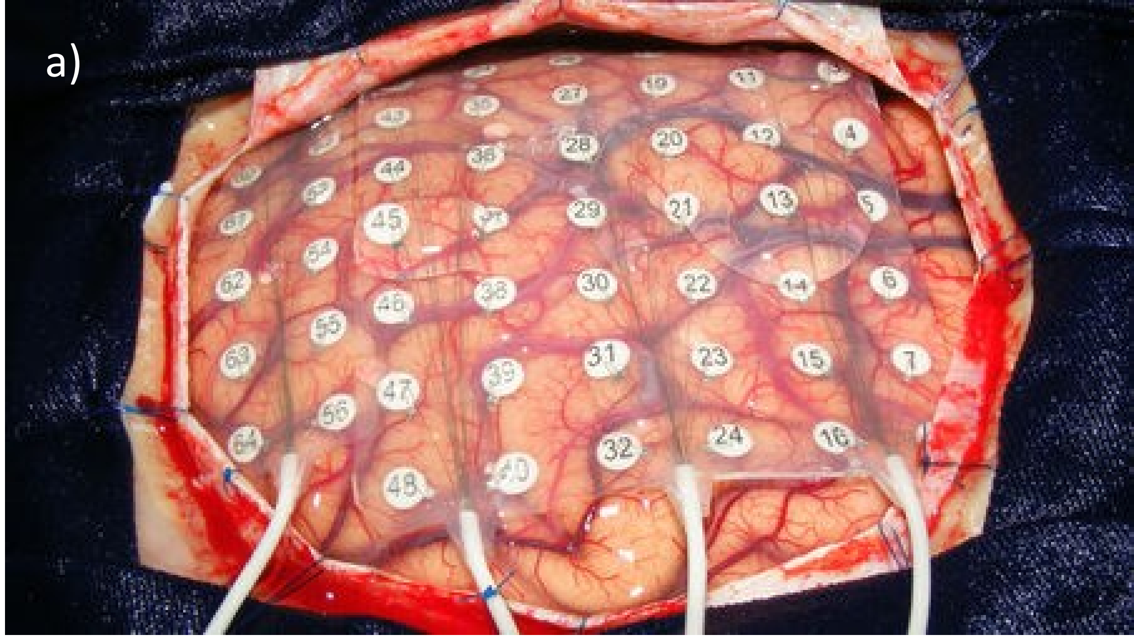
a)

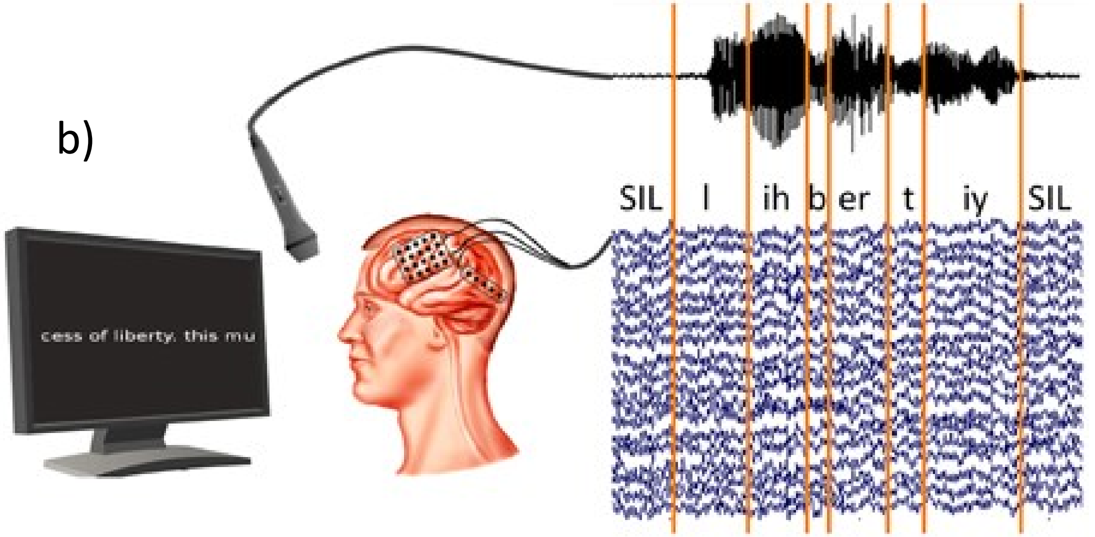


EEG time-frequency decomposition in 30 healthy humans
Note the large variability in gamma amplitude (red stripe)

Electrocorticography (ECoG)

- ECoG – same principle as EEG, but the electrodes are placed directly on brain – involves an invasive surgery (a)
  - Much higher quality signal than EEG because electrodes closer to brain
    - Can observe 'asynchronous' neural activity with ECoG whereas EEG only observes synchronous activity
  - Typically only done in epileptic patients because the procedure is so invasive and dangerous
- Some interesting applications
  - Brain-to-text: decoding what the person is saying from their brain waves (b)
  - Monitoring of epilepsy patients to detect and localize seizures (c)





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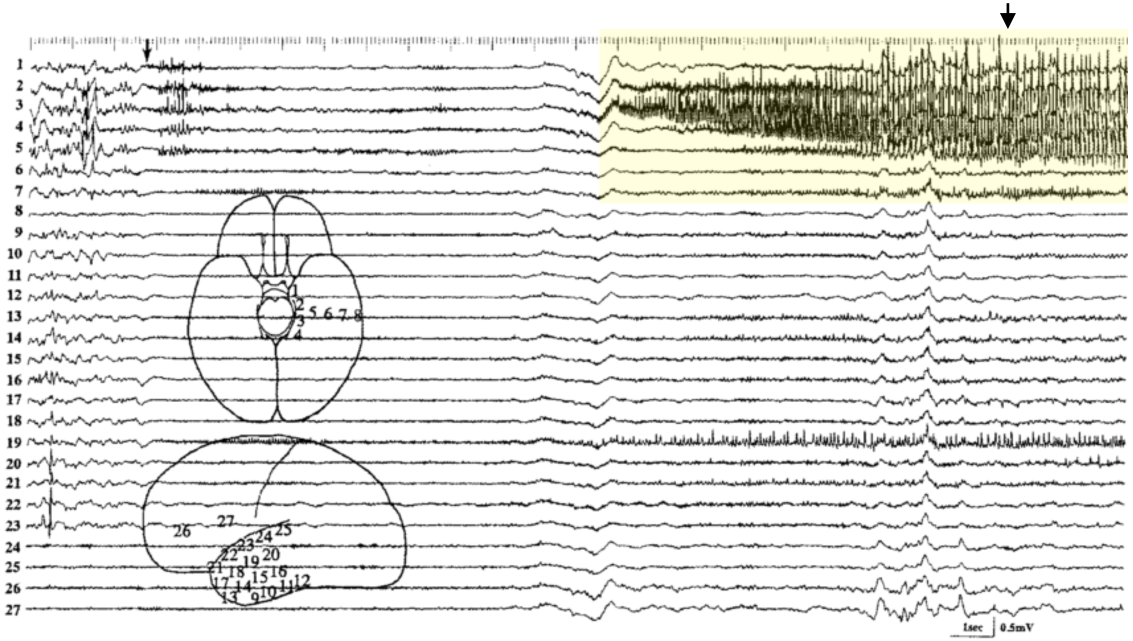

Magnetoencephalography (MEG)

- MEG similar to EEG, but senses magnetic instead of electric field
- Uses array of SQUID sensors to detect weak magnetic field of brain
  - SQUID = superconducting quantum interface device
  - Requires a shielded room (Faraday cage) to eliminate external noise
  - Inverse solution (source localization) slightly more accurate with MEG than EEG because magnetic fields not affected by intervening tissue (skull, etc.)
- MEG is basically a very expensive EEG
  - Few advantages over EEG, but costs 10-20x as much
  - EEG costs ~$50,000, MEG costs $1-1.5 million
  - MEG is dying (no more machines being sold)
    - Why buy a MEG when you can buy an MRI for same price?