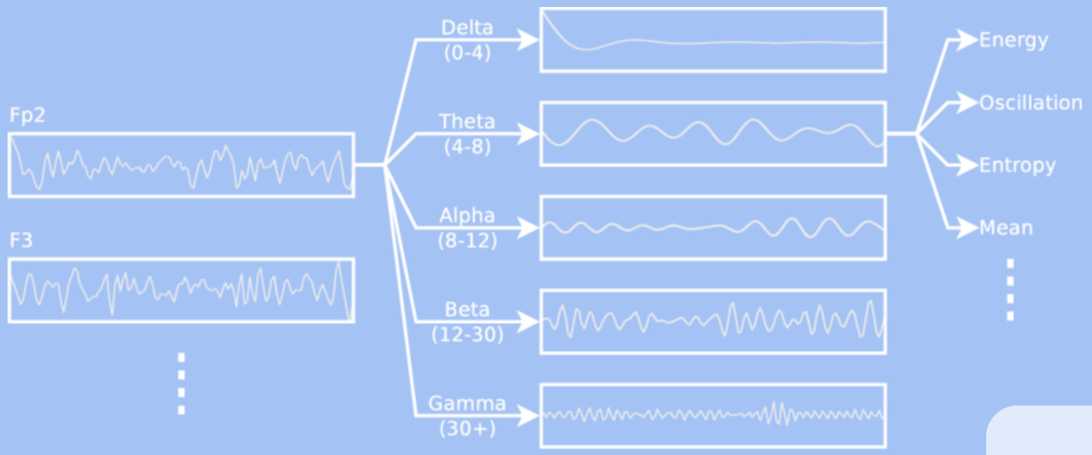
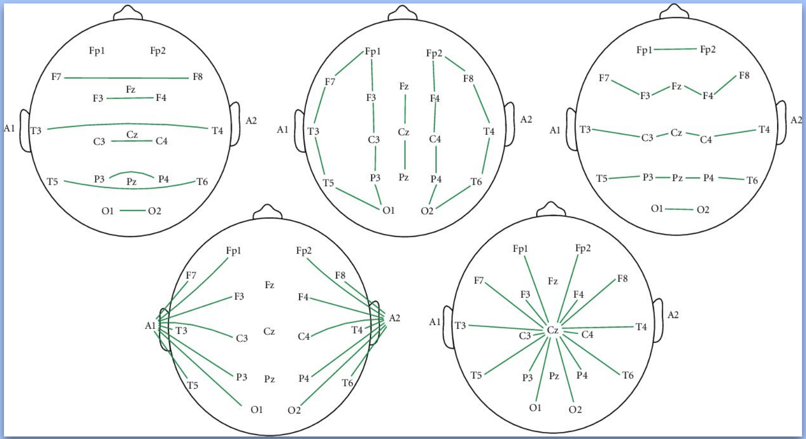
WEEK 10

Uncovering Oscillatory Processes in EEG



What is electroen-cephalography (EEG)?

- Essentially, using a super-advanced voltmeter to detect brain waves
  - A voltmeter measures differences in electrical potential between two points in a circuit



A Quick Physics Review

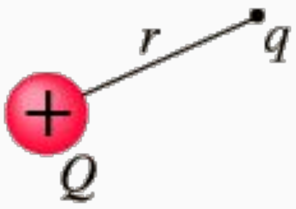
Electric Force and Energy (Coulomb's law)

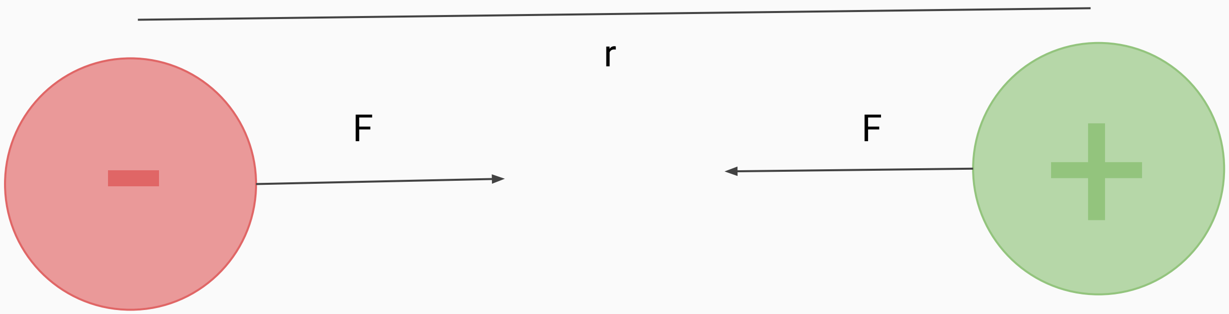
$$F = k\frac{q_1 q_2}{r^2}$$

F = Force (N)
K = Coulomb's Constant (N.m^2.C^2)
$q_{1,2}$= Charge (C)
r = distance (m)

U = Potential Energy (J)

$$U = \frac{kQq}{r}$$



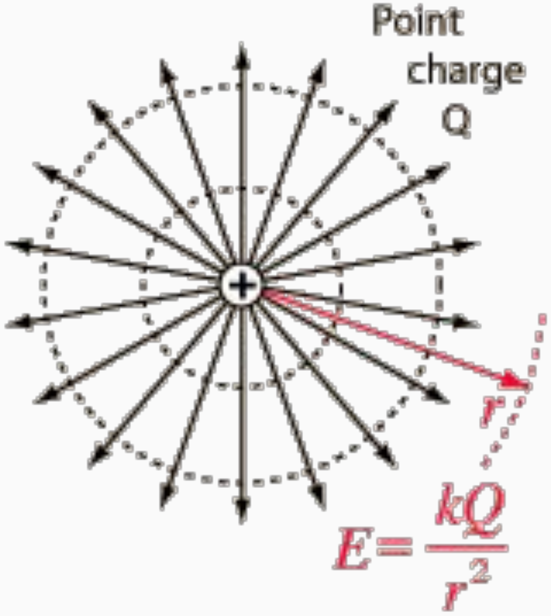


Electric Field: unit charge

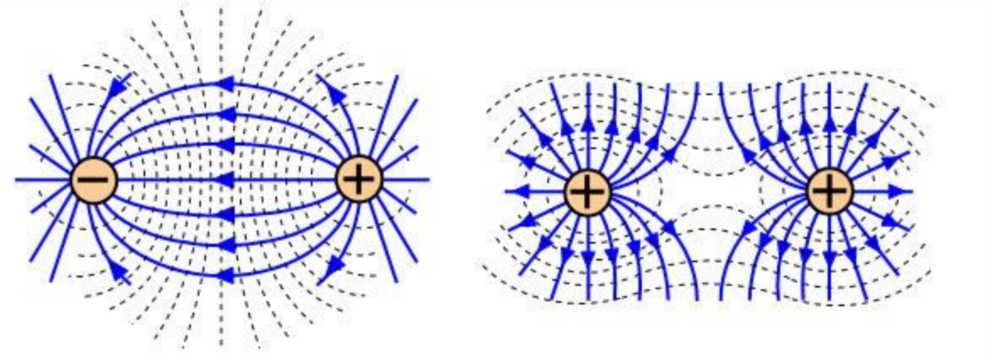
$$E = \frac{F}{q} = \frac{k \cdot \cancel{q} \cdot Q / d^2}{\cancel{q}} = \frac{k \cdot Q}{d^2}$$

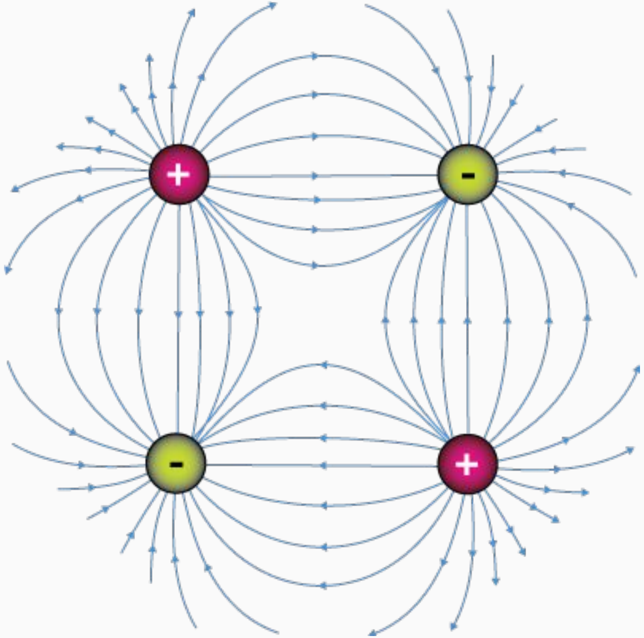
$$\boxed{E = \frac{k \cdot Q}{d^2}}$$

E = Electric field (N/C, V/m)

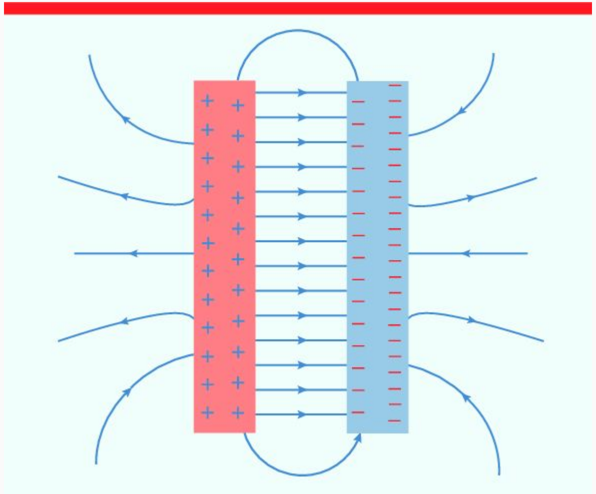


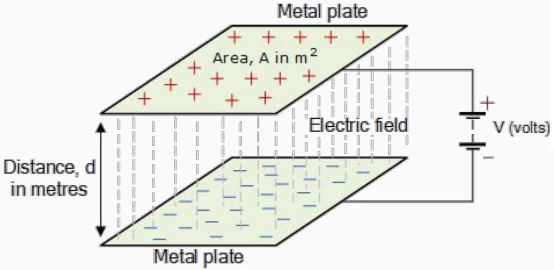
Electric Fields: Multi-charge system





Uniform electric charge: Capacitor





Parallel-plate Capacitor Equations

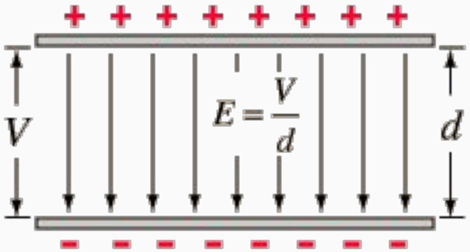
$$Q = CV$$

$$V = Ed$$

$$C = \frac{\varepsilon_0 A}{d}$$

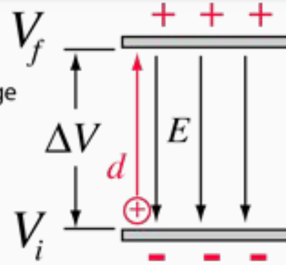
C = Capacitance (F farads)
d = distance between plates (m)
A = area of interaction (m^2)

Work and Voltage in a Uniform Field



$$V_f - V_i = \frac{Fd}{q} = -Ed$$

Moving a positive charge from the bottom to the top plate requires work and raises voltage.



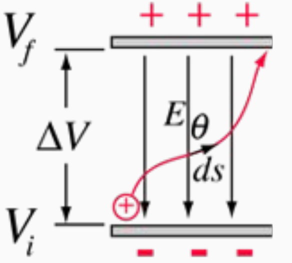
W = -ΔU

$$Ed = \frac{Fd}{q} = \frac{W}{q} = \Delta V$$

For constant electric field.

$$V_f - V_i = -\int \vec{E} \cdot \vec{ds}$$

Moving a positive charge along the curved path indicated would require the integral to calculate, but in this case would give the same voltage difference.



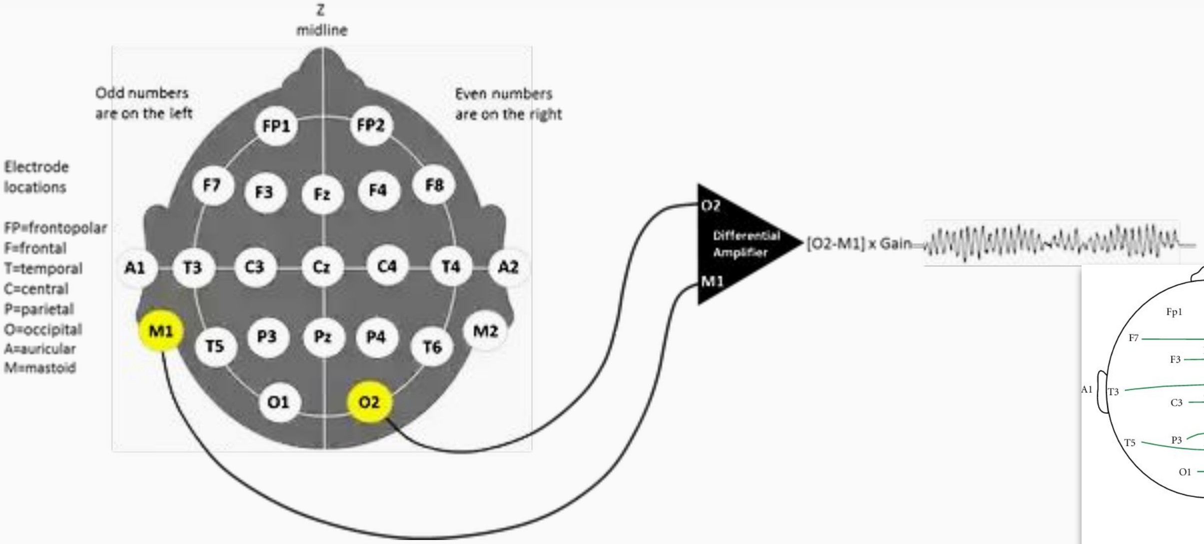
Units: $\frac{N}{C}\,m = \frac{N\,m}{C} = \frac{Joule}{C} = Volts$

Static Electricity Simulations

Try Coulomb's law, Electric Field lines and put the charge in the goal simulations.

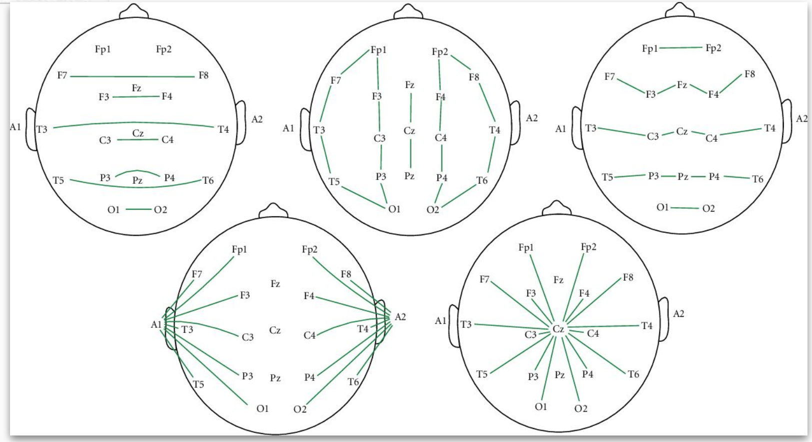
https://www.physicsclassroom.com/Physics-Interactives/Static-Electricity

How does EEG work?

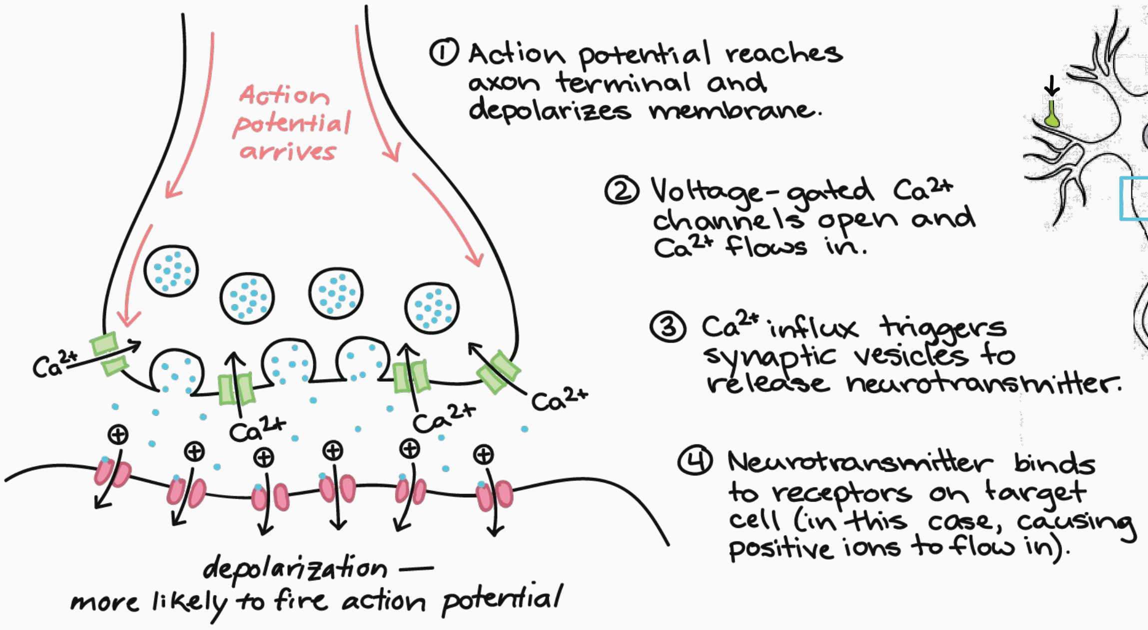


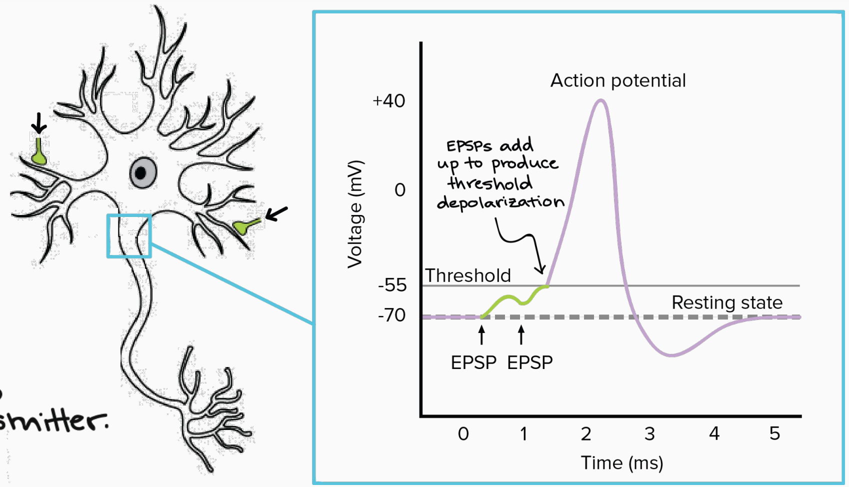
Amplifier increases signal 1,000-100,000x and subtracts noise

Montages:
Referential or Bipolar



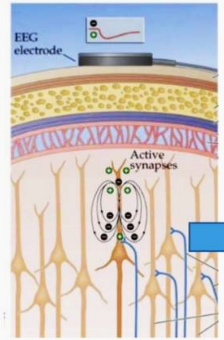
Post-Synaptic Potentials

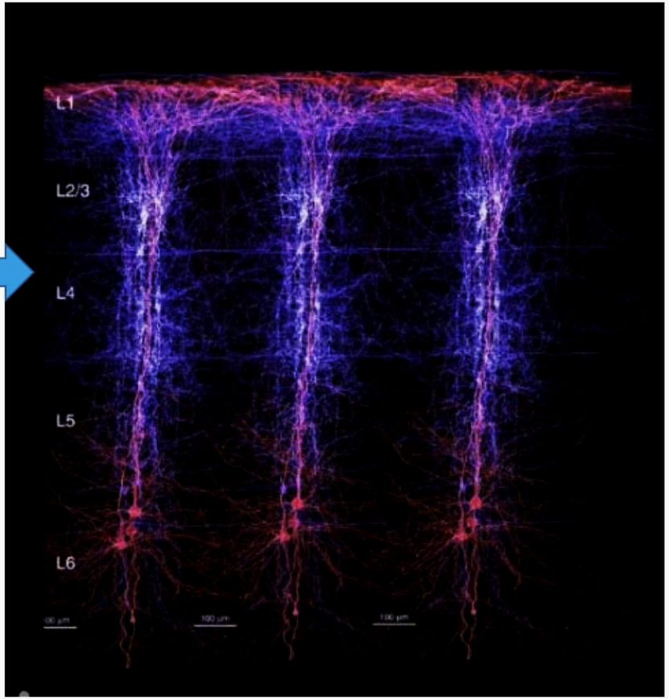




What's in an EEG recording?

- Post-synaptic excitation (of dendrites) from **hundreds of thousands of neurons** firing in synchrony
    - less neurons or less synchrony → more flatline EEG
- Neurons must be aligned in a parallel configuration to be detected—i.e., **neurons must be located in gyri**, not sulci. What we actually detect are the **oscillating fields of pyramidal neurons**





In summary, you can measure EEG when:

1. Many neurons are firing at once
2. Neurons don’t cancel each other out
3. Neurons are close to the skull
4. The electrical field is perpendicular to the scalp

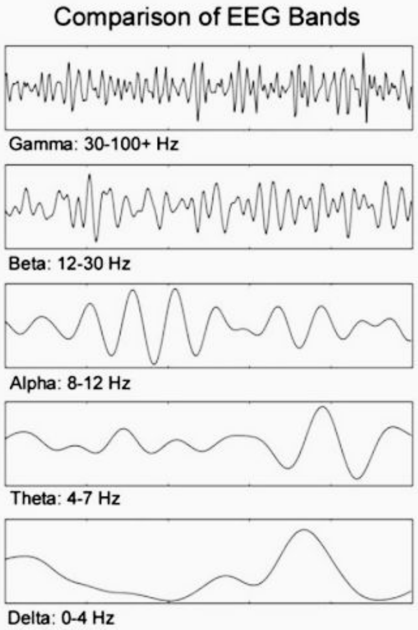
How is synchronous activity generated?

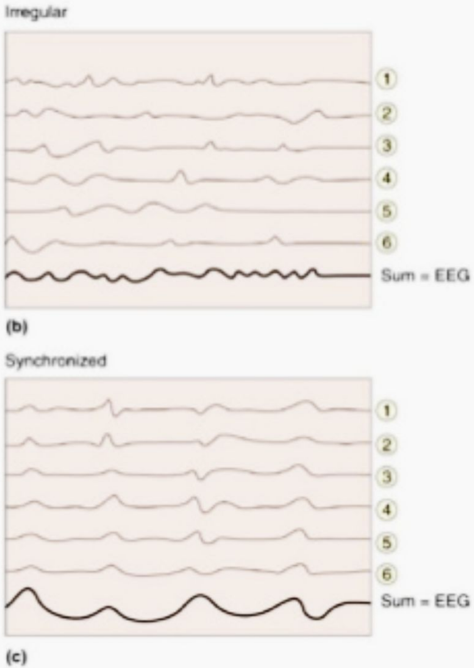
Event-related potentials

- Can be endogenous (e.g. mental math) or exogenous (e.g. seeing a face)
- Examples are: P300, N170, N200

Oscillatory processes

- Reflecting groups of neurons firing together at specific speed





How are different frequencies created?

Small amplitude

30+ Hz
Gamma Perceptual binding, increased cognitive demand

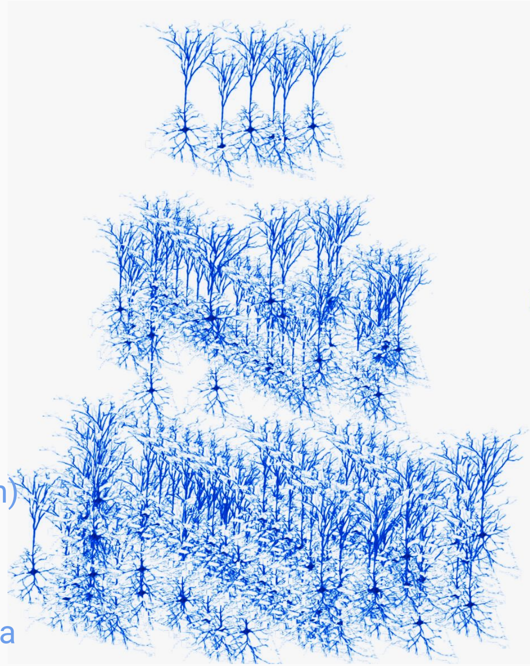
13-29 Hz
Beta & Gamma Higher levels of arousal and attention

8-12 Hz
Alpha Calm, attentive, motor movement, eyes closed

4-7 Hz
Theta Sleep, limbic activity, internal awareness (meditation)

0.1-3 Hz
Delta Deep sleep, structural pathology, anesthesia or coma

Large amplitude

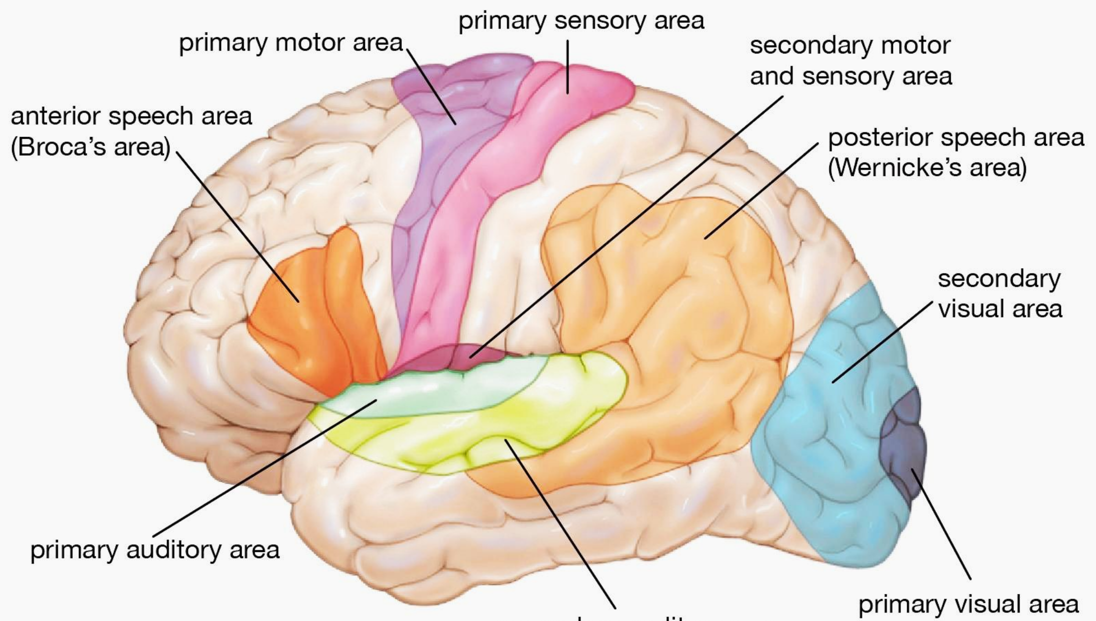


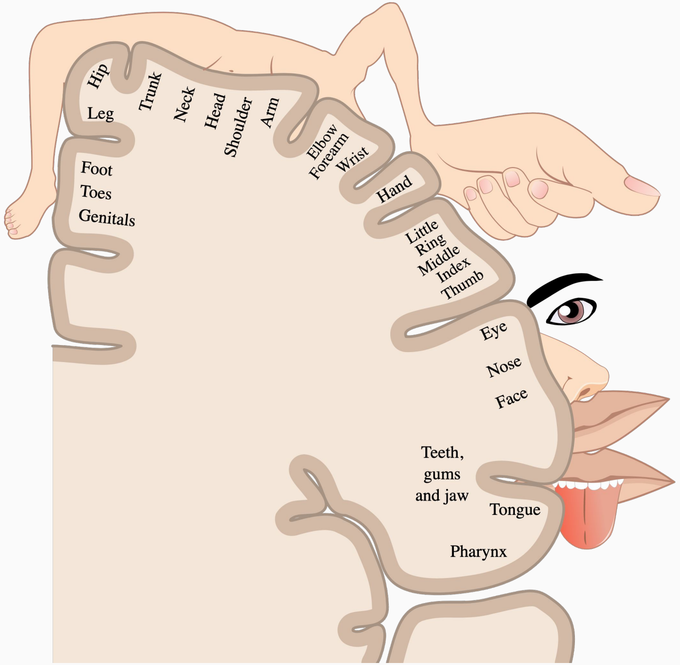
Smaller population of neurons, local activity

large population of neurons, local/regional activity

Very large population of neurons, broader activity (across regions)

Spatial Characteristics





Bridging electrodes and brain anatomy

> Neuroimage. 2009 May 15;46(1):64-72. doi: 10.1016/j.neuroimage.2009.02.006.
Epub 2009 Feb 20.

Automated cortical projection of EEG sensors: anatomical correlation via the international 10-10 system

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Affiliations + expand

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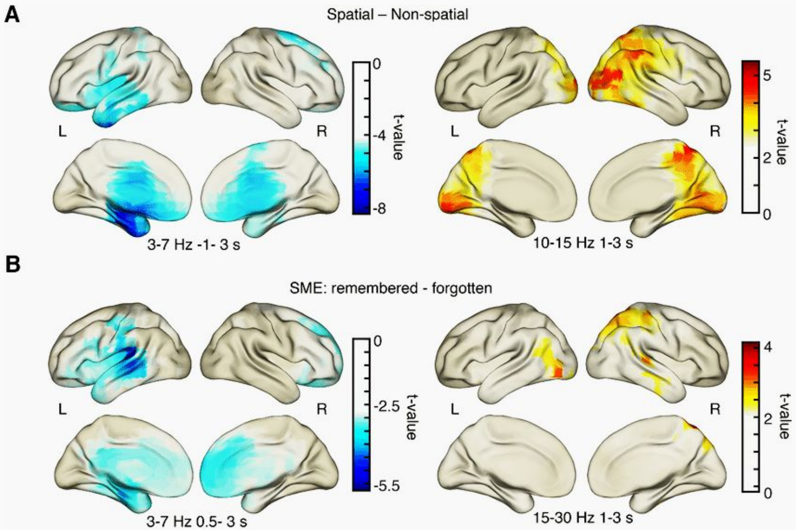
Abstract

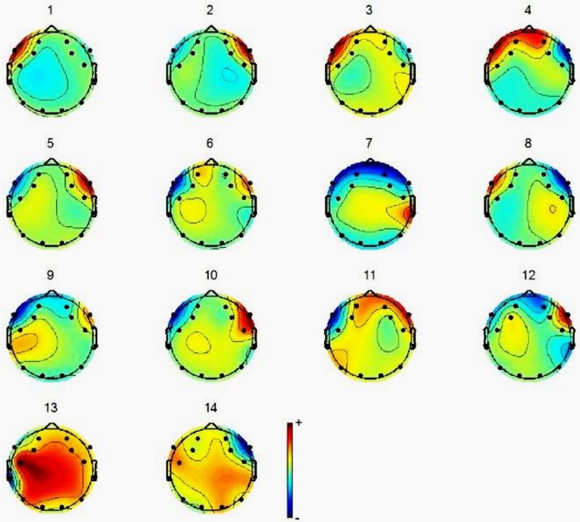
Several studies have described cranio-cerebral correlations in accordance with the 10-20 electrode placement system. These studies have made a significant contribution to human brain imaging techniques, such as near-infrared spectroscopy and trans-magnetic stimulation. With the recent development of high resolution EEG, an extension of the 10-20 system has been proposed. This new configuration, namely the 10-10 system, allows the placement of a high number (64-256) of EEG electrodes. Here, we describe the cranio-cerebral correlations with the 10-10 system. Thanks to the development of a new EEG-MRI sensor and an automated algorithm which enables the projection of electrode positions onto the cortical surface, we studied the cortical projections in 16 healthy subjects using the Talairach stereotactic system and estimated the variability of cortical projections in a statistical way. We found that the cortical projections of the 10-10 system could be estimated with a grand standard deviation of 4.6 mm in x, 7.1 mm in y and 7.8 mm in z. We demonstrated that the variability of projections is greatest in the central region and parietal lobe and least in the frontal and temporal lobes. Knowledge of cranio-cerebral correlations with the 10-10 system should enable to increase the precision of surface brain imaging and should help electrophysiological analyses, such as localization of superficial focal cortical generators.

Source Localization: The Inverse Problem

Popular technique: **minimum norm estimation**

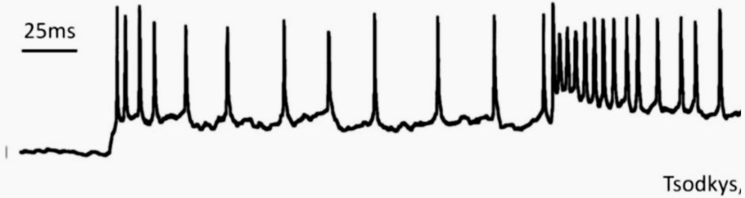
- Quite complicated, software exists to do this for us and produce lovely images like the ones below



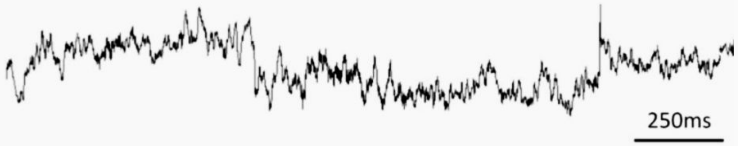


Temporal Characteristics

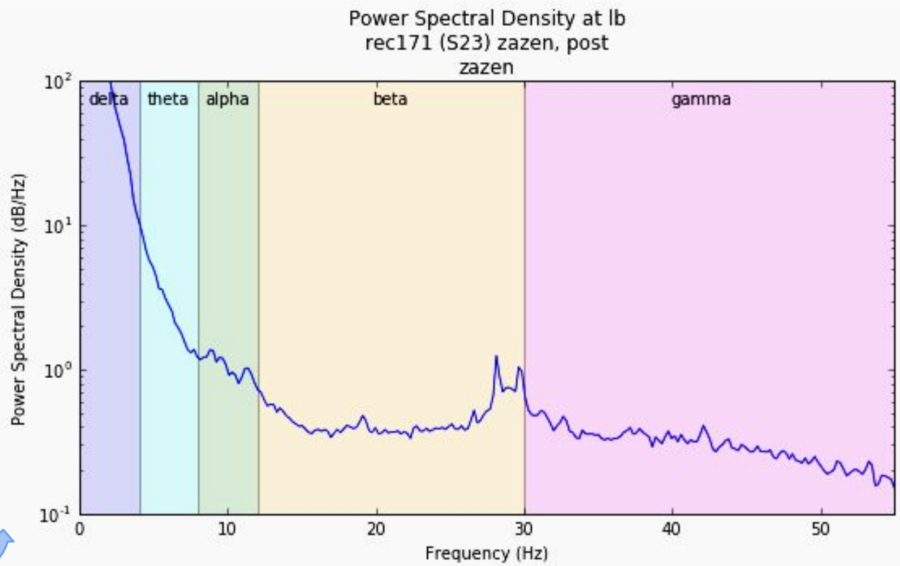
- Typical spiking behavior of a single neuron



- Typical signal measured at a scalp site



Power Spectral Analysis



Noise

- We want the **true neural signals**, but EEG can pick up artefacts like eye-blinks, muscle movement, heart beat, and environmental noise (like from electrical power lines, which are often 60Hz—we can suppress this signal with **notch filters**)
- To remove noise:
  - Use extensive electrode references, like in the double banana bipolar montage
  - Control the experimental environment and collect better data!

Notes on EEG

- As you can imagine, EEG recordings may look very different between people, especially when age or health are varied
    - Thus, it is very important to **keep in mind the experimental subjects** when interpreting EEG data

Time for an exercise on power spectral analysis!

Go to our GitHub page for this week, and locate the exercise