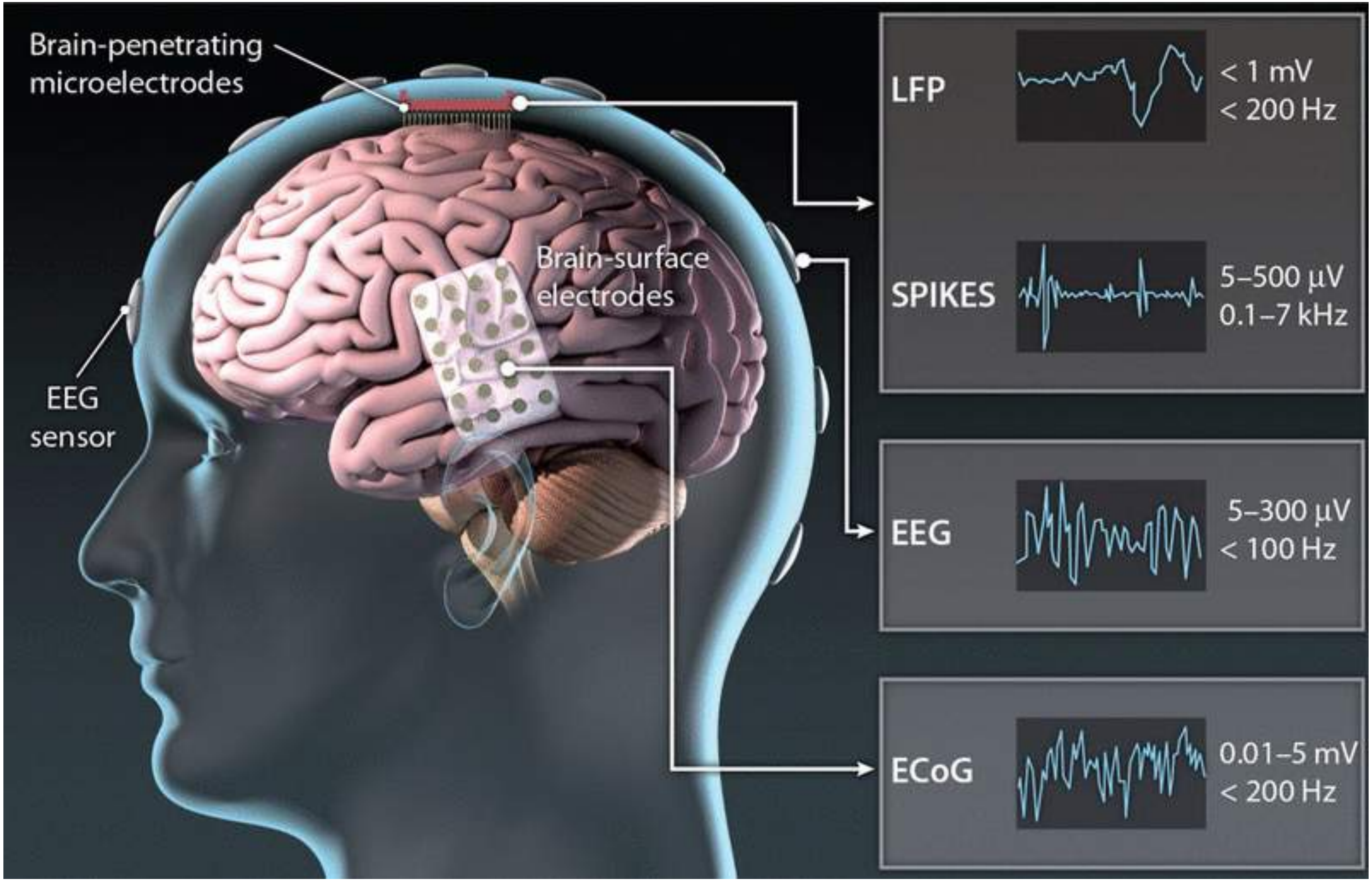
Brain Signal Acquisition

Background

- The brain communicates using spikes-- produced when the neuron receives enough input current from other neurons via synaptic connections.

- Recording brain activity are based on detecting changes in electrical potentials in neurons
    - invasive techniques based on implanting electrodes

- Or on detecting changes in large populations of neurons
    - noninvasive techniques such as electroencephalography or EEG


Brain-penetrating microelectrodes
Brain-surface electrodes
EEG sensor
LFP
< 1 mV
< 200 Hz
SPIKES
5–500 μV
0.1–7 kHz
EEG
5–300 μV
< 100 Hz
ECoG
0.01–5 mV
< 200 Hz

Recording signals from brain

<u>Invasive Approaches:</u>

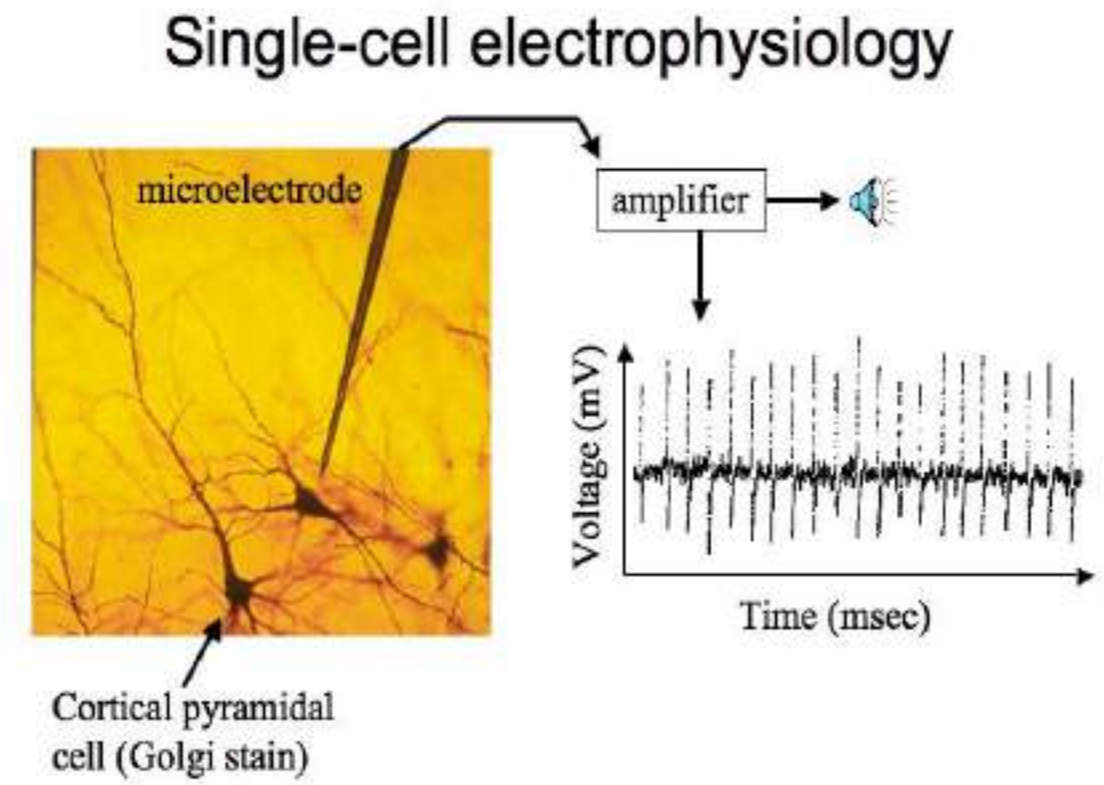
- Techniques that allow recording from individual neurons in the brain are typically invasive.

- They involve some form of surgery,
  - A part of the skull is removed, an electrode or implant placed in the brain, and the removed part of the skull then replaced.
  - The recording itself is not painful because the brain has no internal pain receptors, but the surgery and recovery process can cause pain and involves risks such as infection.

- A major advantage of invasive recordings is that they allow recording of action potentials at the millisecond timescale.

Invasive Approaches

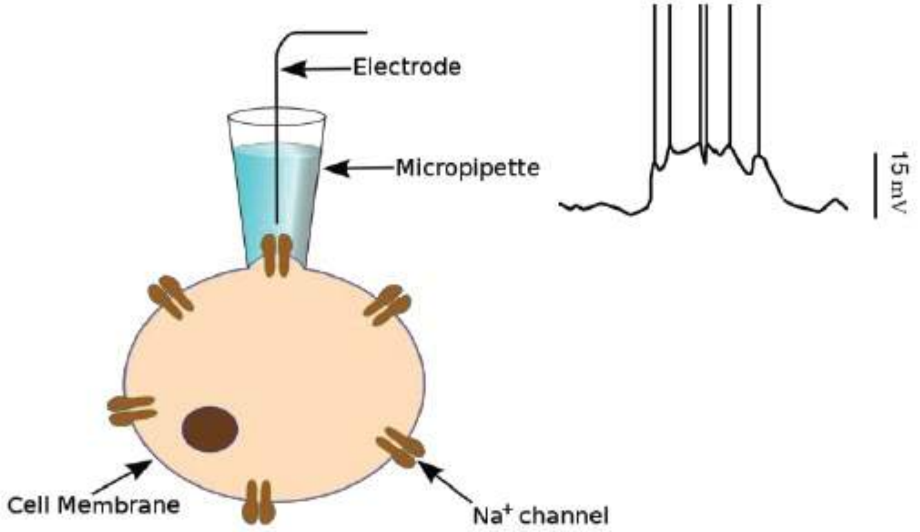
- **<u>Microelectrode:</u>**
- A *microelectrode* is simply a very fine wire or other electrical conductor used to make contact with brain tissue.
- A typical electrode is made of tungsten or platinum- iridium alloy and is insulated except at the tip, which measures around 1µm in diameter (A neuron's cell body diameter is in the range of tens of µm).



Invasive Approaches

- **<u>Intracellular Recording:</u>**
- Measures the voltage or current across the membrane of the neuron.
- The most common technique, known as *patch clamp recording.*

- Very Delicate → Intracellular recordings are typically performed only on slices of brain tissue



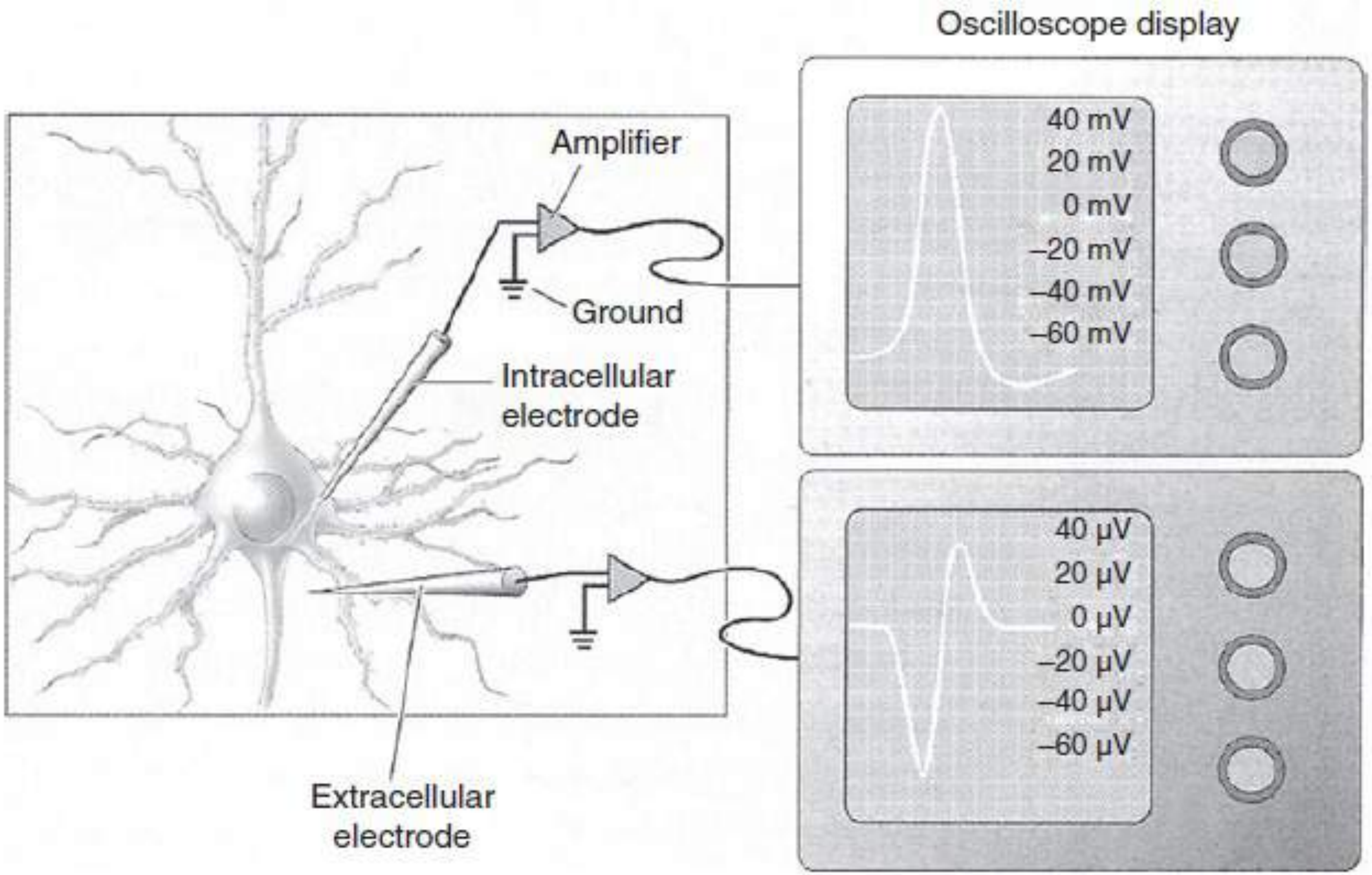
Invasive Approaches

- **Extracellular Recording:**
- Recording of a single neuron (or single“unit”): a tungsten or platinum-iridium microelectrode with a tip size of less than 10 microns is inserted into the target brain area.

- The magnitude of the recorded signal is usually less than a millivolt and thus requires the use of amplifiers to detect the signal.

- The signal from the amplifier is fed to a computer, which performs additional processing such as filtering noise and isolating the spikes (action potentials).

Invasive Approaches



(from Bear et al., 2007).

Invasive Approaches

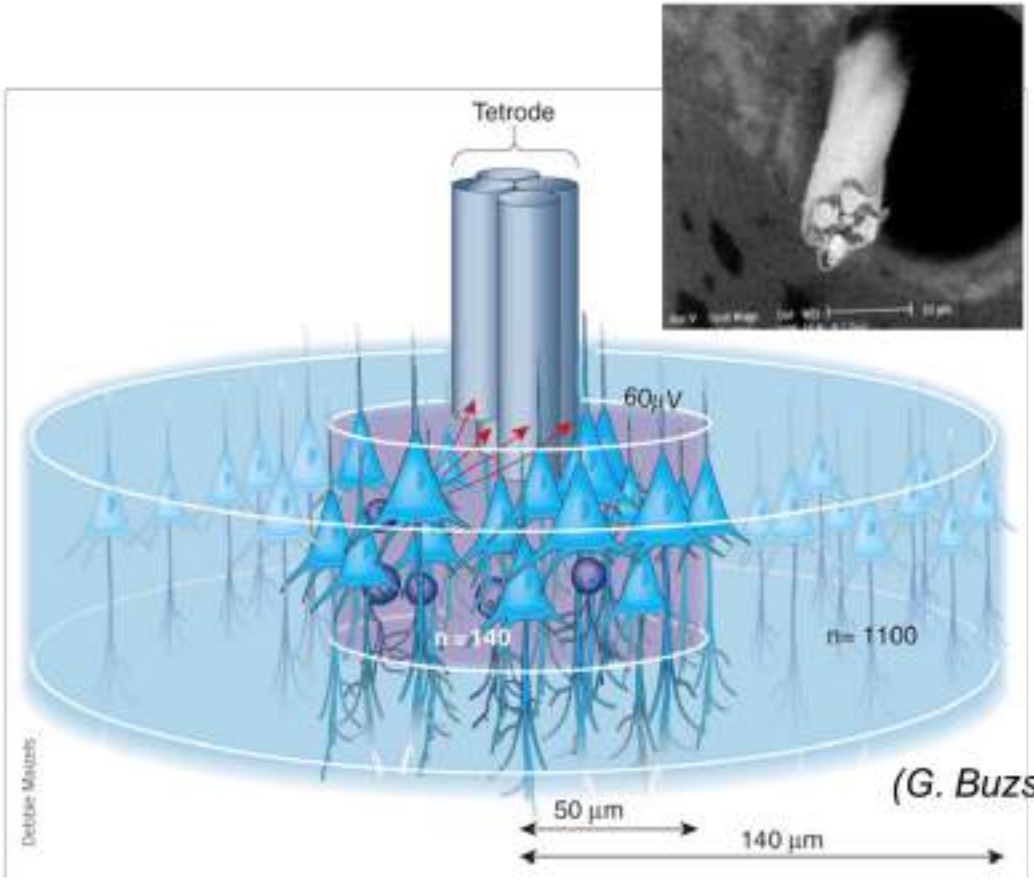
- When the neuron produces a spike, positive ions flow away from the extracellular electrode into the neuron, causing the initial negative deflection in the display. This is followed by a positive deflection as the action potential decreases and positive charges flow out of the neuron toward the extracellular electrode.

Invasive Approaches

Tetrodes and Multi-Unit Recording:

- To record from multiple neurons simultaneously by using more than one electrode.
- Four wires are tightly wound together in a bundle.

Tetrode recordings allow the monitoring of single neurons during behavior

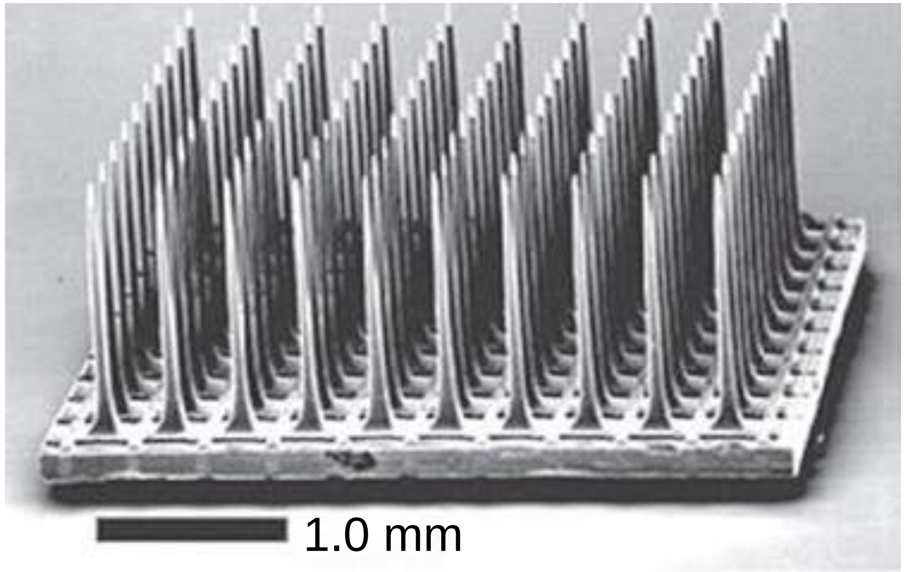


(G. Buzsáki, 2005)

Invasive Approaches

Multielectrode Arrays:

- To record from larger numbers of neurons, microelectrodes can be arranged in a grid-like structure to form a multielectrode array of $m \times n$ electrodes.



(adapted from Hochberg et al., 2006).

Invasive Approaches

- The most common types of implantable arrays are microwire, silicon-based, and flexible microelectrode arrays
- Increased spatial resolution
- The ability to record simultaneously from several dozens of neurons
- Opens the door to extracting complex types of information such as position or velocity signals that could be useful for controlling prosthetic devices.

Brain Signal Acquisition

Partially Invasive Approach

Electrocorticography (ECoG):

- *Electrocorticography* (ECoG) is a technique for recording brain signals that involves placing electrodes on the surface (cortex) of the brain.
- The procedure requires making a surgical incision into the skull to implant the electrodes on the brain surface

Partially Invasive Approach

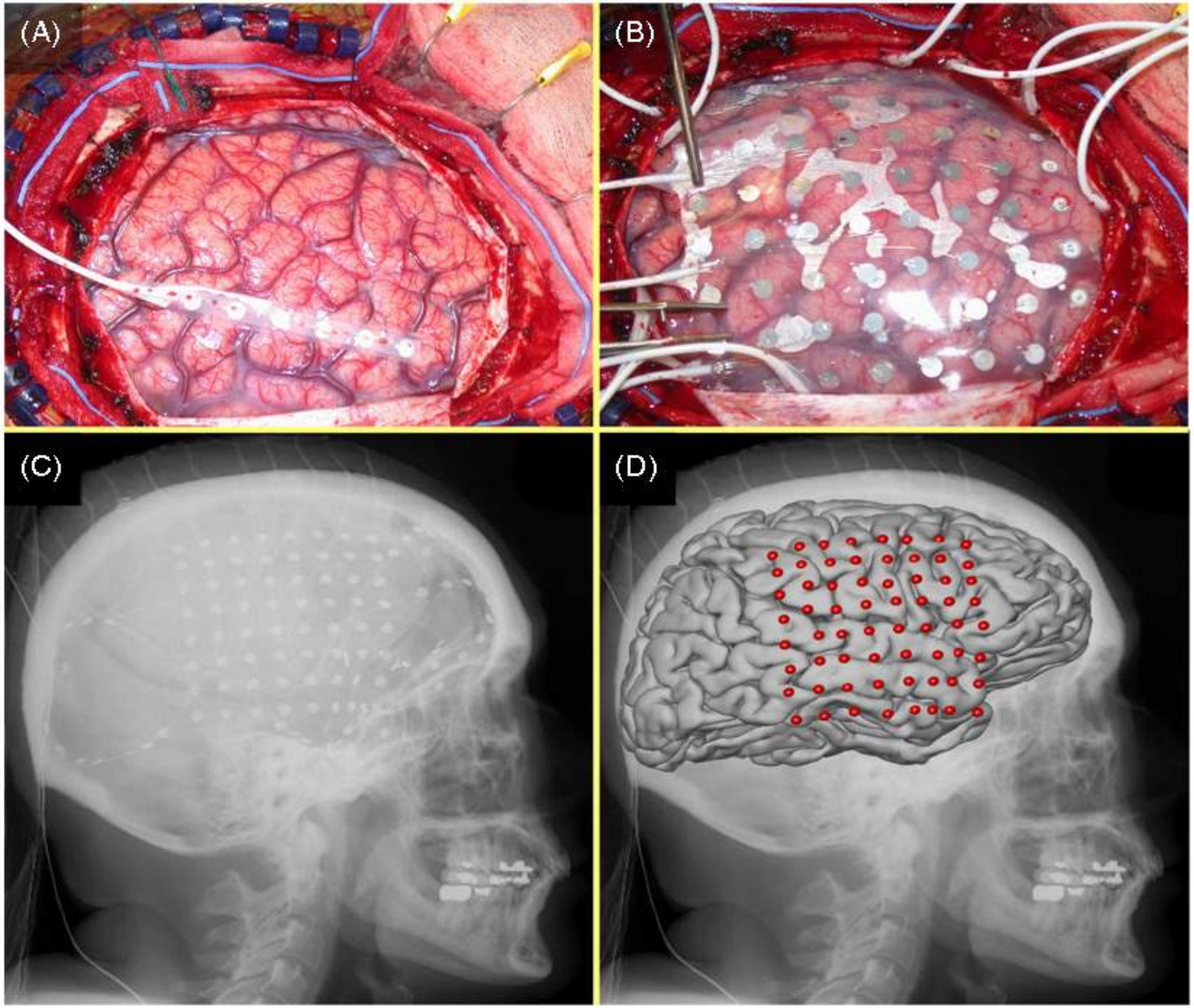
- ECoG electrodes can record the electrical fluctuations caused by the coherent activity of large populations of neurons (several tens of thousands).

- Safer than arrays implanted inside the brain.

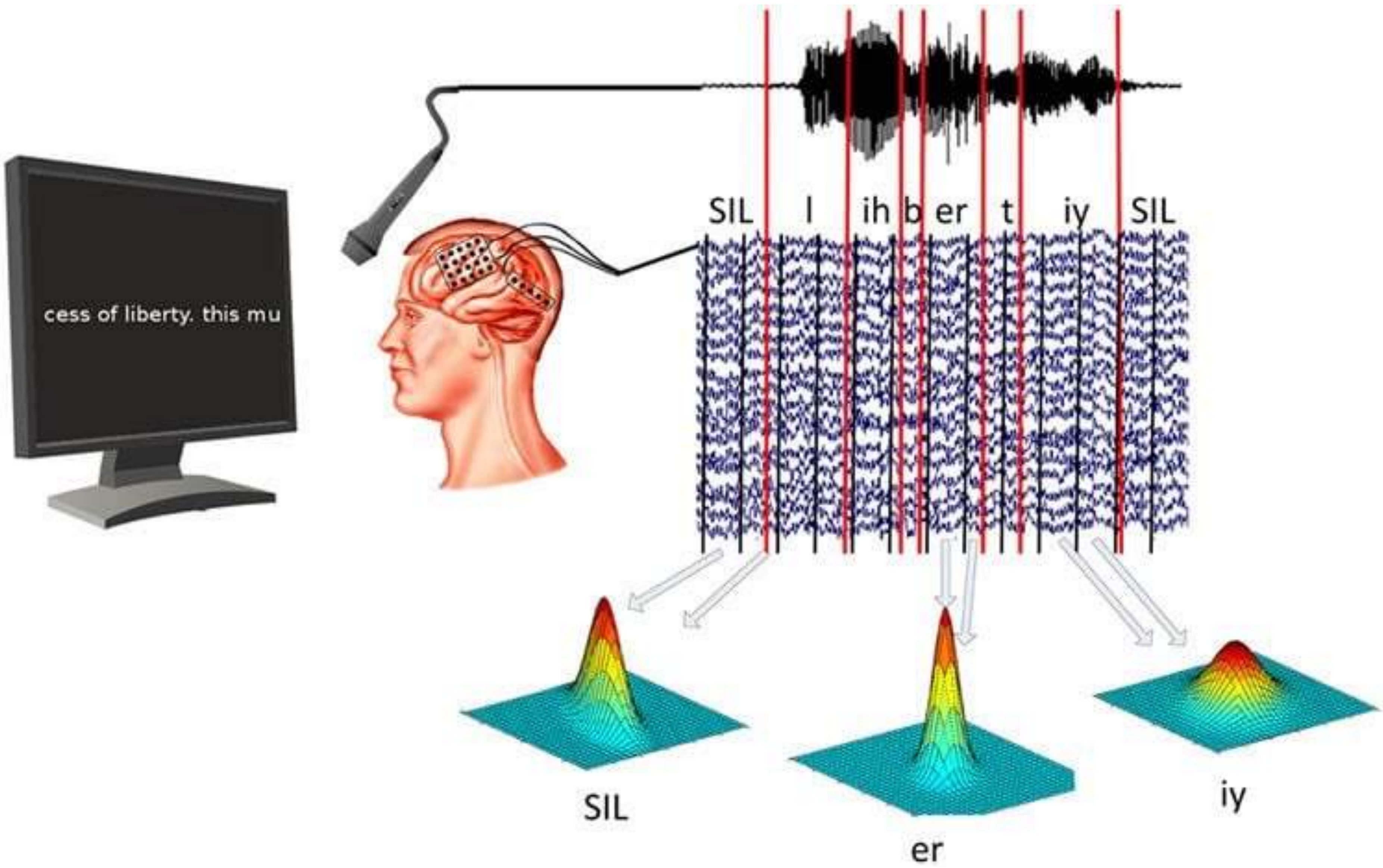
- ECoG electrodes may also be less likely to wear out compared to brain penetrating electrodes

- ECoG offers greater spatial resolution

https://www.youtube.com/watch?v=KEk3m4FwVt8



(from (Miller et al., 2007).



Automatic Speech Recognition from Neural Signals: A Focused Review" by Christian Herff and Tanja Schultz in *Frontiers in Neuroscience*. Published online September 27 2016 [doi:10.3389/fnins.2016.00429](https://doi.org/10.3389/fnins.2016.00429)

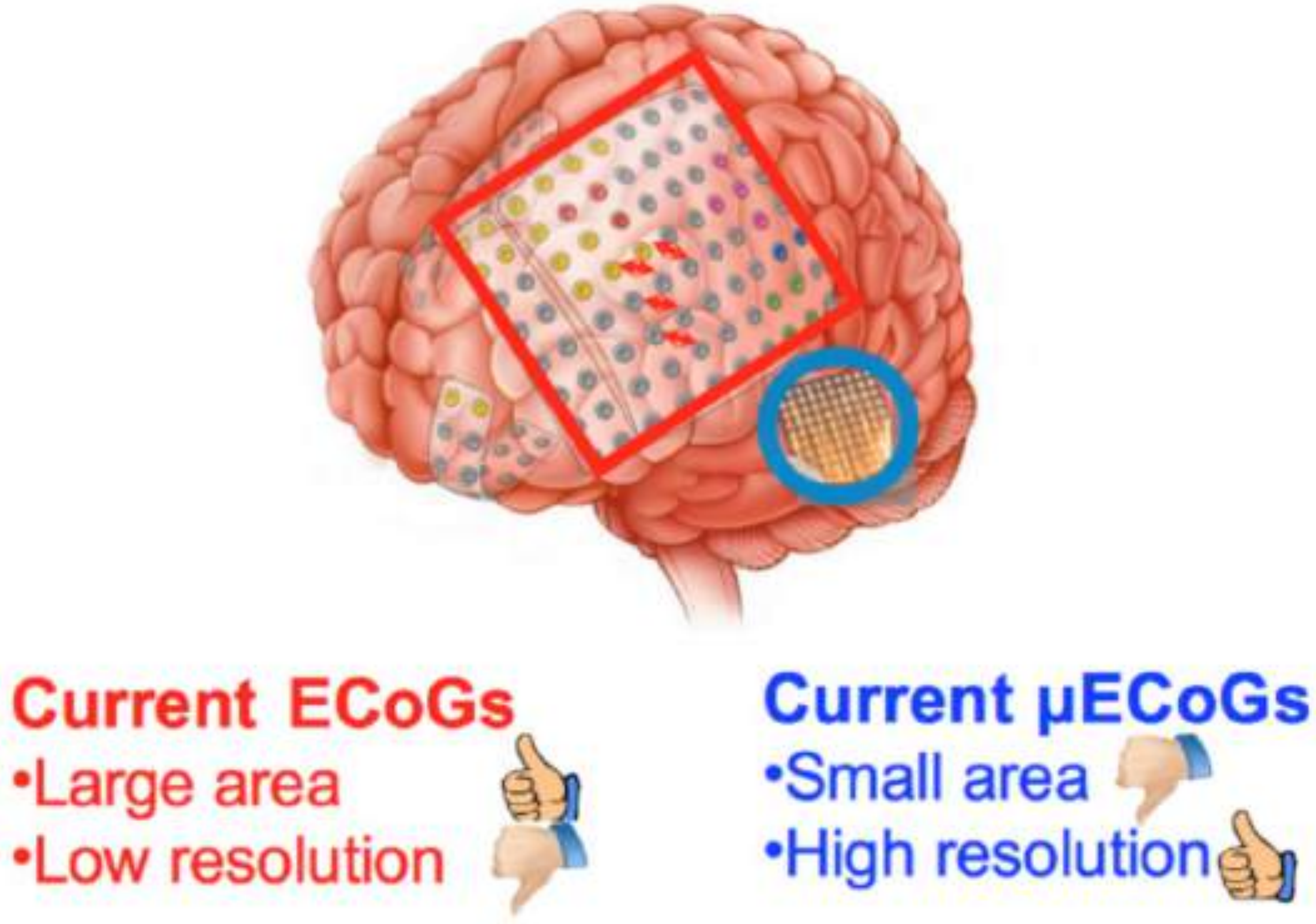
ECoG and audio data are recorded at the same time. Speech decoding software is then used to determine timing of vowels and consonants in acoustic data. ECoG models are then trained for each phone individually by calculating the mean and covariance of all segments associated with that particular phone.

Partially Invasive Approach

MicroECoG:

- One disadvantage of ECoG, is the relatively large size of ECoG electrodes
- These microelectrodes are only a fraction of a millimeter in diameter and spaced only 2–3 mm apart in a grid
- Allows detection of neural activity at a much finer resolution than traditional ECoG.
- Decoding fine movements, such as the movements of individual fingers, or even speech, without actually penetrating the brain.

Partially Invasive Approach



Partially Invasive Approach

<u>Optical Recording: Voltage-Sensitive Dyes and Two-Photon Calcium Imaging:</u>

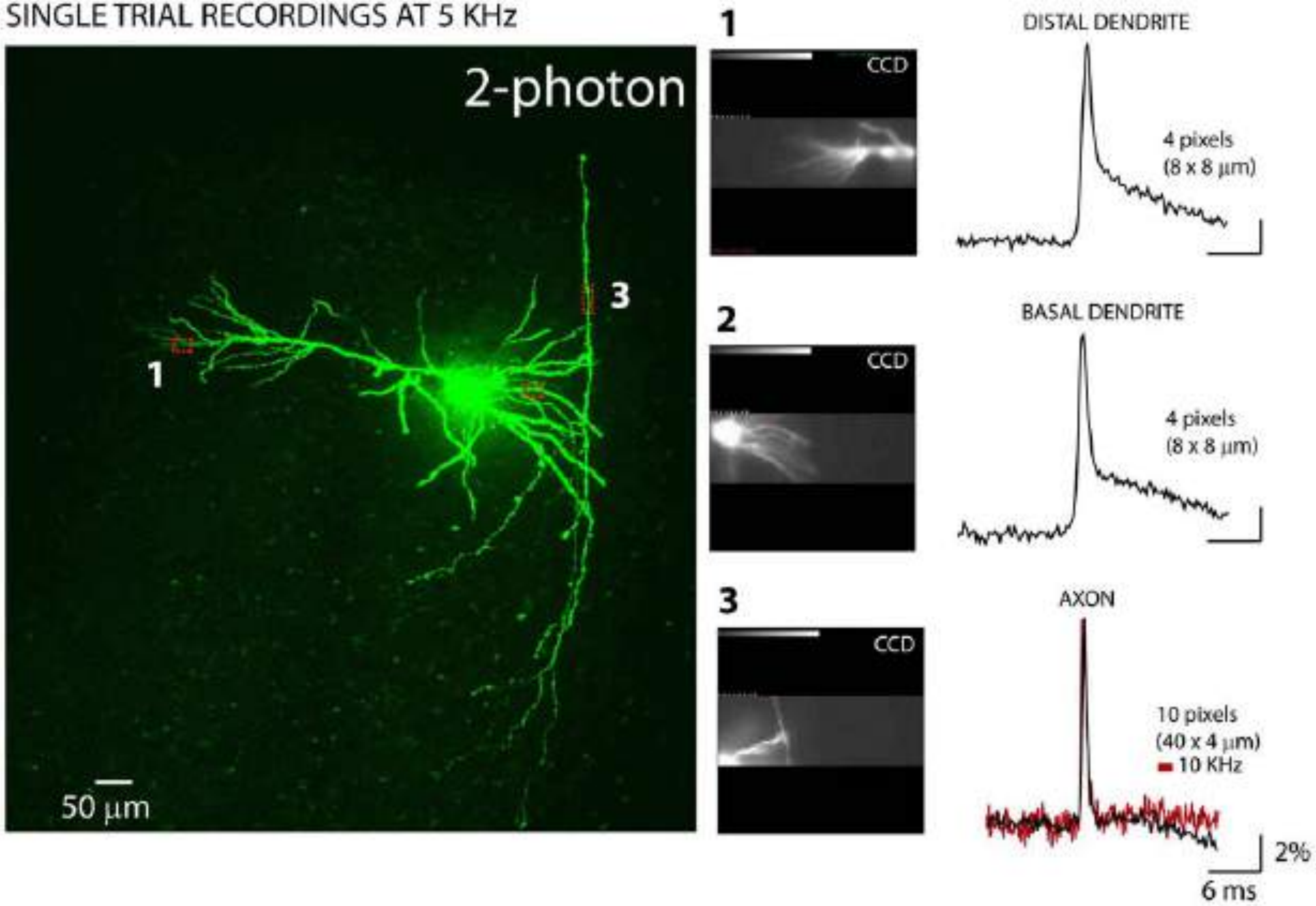
- Voltage-sensitive dyes
- Voltage-sensitive dye changes its absorbance and fluorescence intensity when membrane potential changes in a stained brain or heart tissue.
- By using voltage-sensitive dyes as chemical probes and capturing changes in light intensity with the use of a high-speed imaging device, it is possible to image in real time the activity of where, when, and how much excitation or inhibition occurred, in the brain and heart.

Partially Invasive Approach

Voltage-sensitive dyes
https://www.scimedia.com/applications/neuro/vsd/data/

- Neurons are stained with a voltage-sensitive dye
- Dye responds to changes in membrane potential by changing its absorption and/or fluorescence
- Recorded optical signals correspond to summed responses from several simultaneously active neurons.
- Useful for imaging macroscopic features of the brain.

VOLTAGE-SENSITIVE DYE IMAGING



(image: Scholarpedia http://www.scholarpedia.org/article/Voltage-sensitive_dye).

Partially Invasive Approach

- Two-photon calcium imaging
- https://elifesciences.org/articles/26839#content
- Based on the fact that electrical activity in neurons is typically associated with changes in calcium concentration.
- Two-photon calcium imaging allows us to observe the activity of multiple neurons up to ~500 μm below the cortical surface without cortical invasion.
- Photon calcium imaging involves:

  (1) using pressure ejection to load neurons with fluorescent calcium-indicator dyes

  (2) monitoring changes in calcium fluorescence during neural activity using two-photon microscopy.

Oregon Green calcium sensitive dye stained neurons

Transgenic mouse expressing green fluorescent protein (GFP) in a subpopulation of neurons

Image from Kherlopian et al., 2008).

Brain Signal Acquisition

Non Invasive Approaches

<u>Electroencephalography (EEG)</u>

- EEG signals reflect the summation of postsynaptic potentials from many thousands of neurons that are oriented radially to the scalp.
- EEG predominantly captures electrical activity in the cerebral cortex, whose columnar arrangement of neurons and proximity to the skull favor recording by EEG.

Non Invasive Approaches

- The spatial resolution is typically poor (in the square centimeter range)
  - Due to lots of muscles between the source of signal and the electrodes placed on the scalp.
- The **temporal resolution is good** (in the milliseconds range)
- The measured signals are in the range of a few tens of microvolts, necessitating the use of powerful amplifiers and signal processing to amplify the signal and filter out noise.
- Artifacts in the EEG signal
  - eye movements, eye blinks, eyebrow movements, talking, chewing, and head movements

Non Invasive Approaches

- EEG recording involves the subject wearing a cap or a net into which the recording electrodes are placed
- A conductive gel or paste is injected into the holes of the cap before placing the electrodes.
- Over the years, new technology and innovations have introduced different types of electrodes. There are several types of electrodes: gel, water, and dry electrodes.

Gel electrodes:

- The gel electrodes are the most widely used type of electrodes. They are part of routine, clinical EEG recordings and have been the gold standard in EEG research for a long time.
- The electrode is commonly made of silver with a coating of silver chloride (Ag/AgCl).
- When a gel containing many chloride ions is applied between the skin and this electrode, conduction is improved and the skin-electrode interface impedance is reduced.
- Therefore, the gel between the skin and electrode allows for good-quality recording of biopotentials. These gel electrodes are disc-shaped and have a hole in the middle where gel can be applied with a syringe.
- The preparation time of a gel EEG cap requires time as the skin needs to be abrased and all electrodes need to be filled individually by a trained technician.

Gel electrodes:

Advantages of gel electrodes

- Allow for high-density EEG recordings.
- Very high signal quality.
- Less susceptible to mains interference and movement artifacts than dry and water electrodes.
- Stable recordings for a long time.
- It can be integrated with other research equipment (i.e. fNIRS)

Disadvantages of gel electrodes

- Skin needs to be prepared by lightly scratching the skin to reduce impedance.
- Inconvenient for researchers: Preparation time can be long, the head cap requires cleaning, and drying of the cap takes time.
- Inconvenient for participants: Hair needs to be cleaned and scratching the skin can feel uncomfortable.
- Requires a skilled technician.
- Conductive gel can dry out over time during recordings over 5 hours.

Gel electrodes:

Dry electrodes:

- Dry electrodes were first studied in the 90s, and are proposed as an alternative to overcome the common issues with wet electrodes.
- Dry EEG electrodes consist of an inert conductive material that mechanically couples with the skin for signal transduction, and eliminates the need for gel or skin preparation.
- Dry electrodes are composed using various materials and shapes, such as gold-plated electrodes, bristle-type electrodes, comb-like and multi-pin electrodes, silicone conductive rubber, or foam-based sensors.
- Since dry electrodes do not use a conductive gel or abrasive paste, there is a higher electrode impedance seen with dry electrodes than with wet electrodes. Also, this can lead to poor contact noise, increased signal instability, and more sensitivity to movement artifacts.

Dry electrodes:

Advantages of dry electrodes

- Quicker setup time than gel electrodes.
- Does not require skin preparation.
- Suitable for at-home testing.
- (Almost) no clean-up required.
- Possible without a trained technician in some situations.

Disadvantages of dry electrodes

- Difficulty keeping electrodes affixed onto the skin.
- Increased signal instability and higher impedances.
- More susceptible to mains interference and movement artifacts than gel electrodes.
- Limited actions are possible to improve the skin-electrode contact quality.
- Uncomfortable to the wearer.

Dry electrodes:



Water electrodes:

- Water electrodes are a novel type of electrodes, that like dry electrodes, have a really short preparation time and do not require the use of a conductive gel.
- These electrodes can also be called **semi-dry electrodes**. The key feature of water electrodes is that they use water or an electrolyte liquid. Some water electrodes use water sponges with tap water or saline water to increase the conduction between the skin surface and the electrode.
- Other water electrodes slowly and continuously release a tiny amount of electrolyte liquid to the scalp in a contained matter.
- Since these methods do not require the application of gel or abrasion of the skin, it also has a faster preparation time and clean-up than gel electrodes.

Water electrodes:

Advantages of water electrodes

- Quicker setup time than gel electrodes.
- Quicker clean-up than gel electrodes.
- Suitable for at-home testing.
- Possible without a trained technician in some situations.
- Overcomes problems with high impedance and signal instability seen in dry electrodes with water.

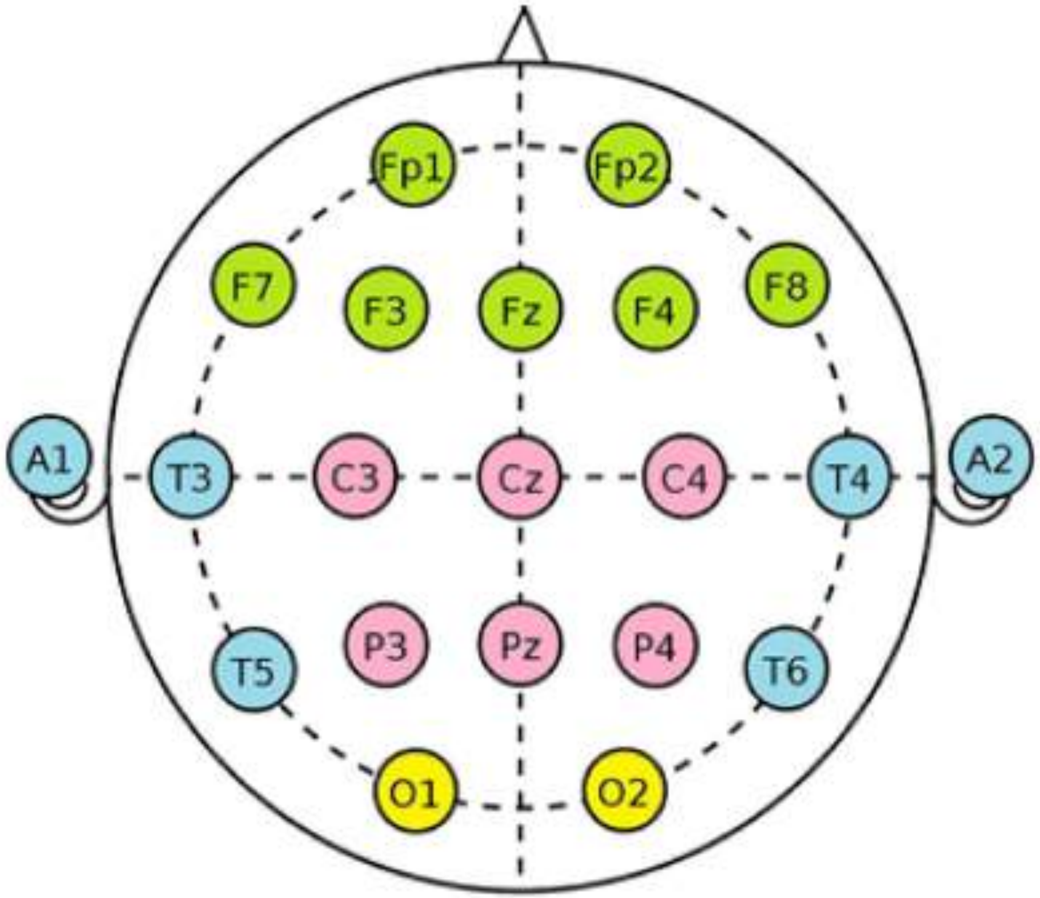
Disadvantages of water electrodes

- Dry out quicker compared to gel electrodes, so they need to be remoistened more often.
- More susceptible to mains interference and movement artifacts than gel electrodes.
- Limited actions are possible to improve the skin-electrode contact quality.

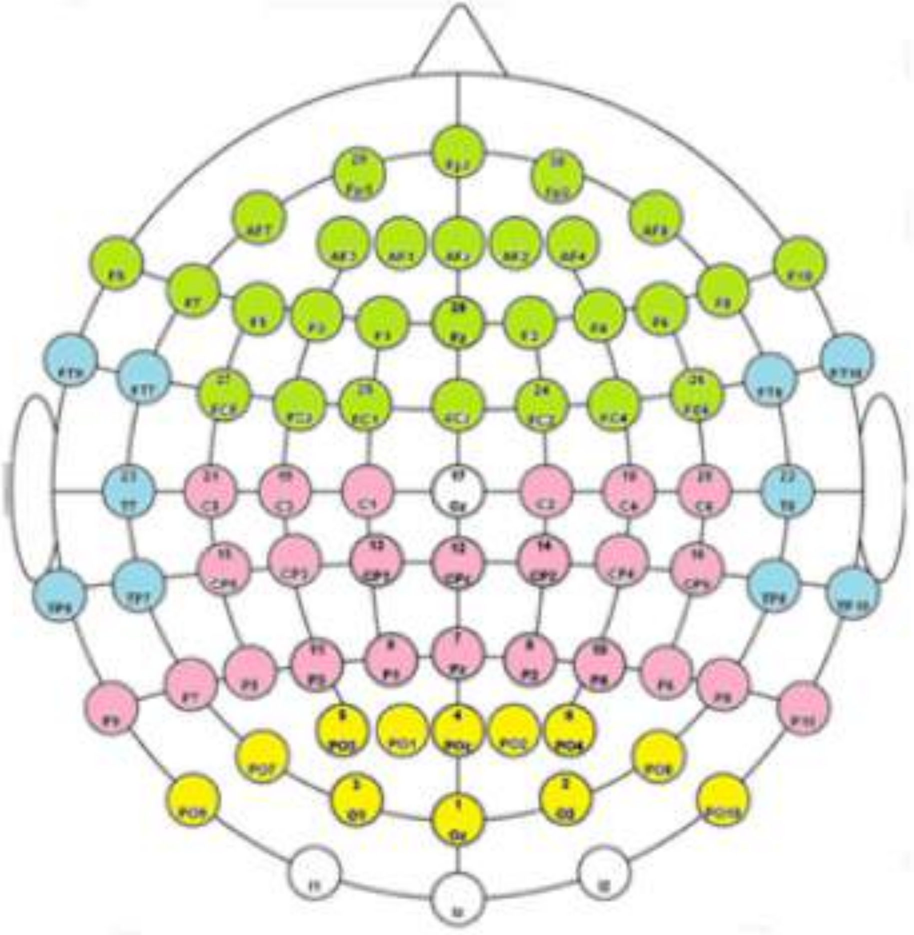
Water electrodes:

International 10–20 system

- The international 10–20 system is a convention used to specify standardized electrode locations on the scalp.
- C = central, P = parietal, T = temporal, F = frontal, Fp = frontal polar, O = occipital, A = mastoids
- Odd numbers on the left side and even numbers on the right side.



10-20 Electrode System



10-10 Electrode System

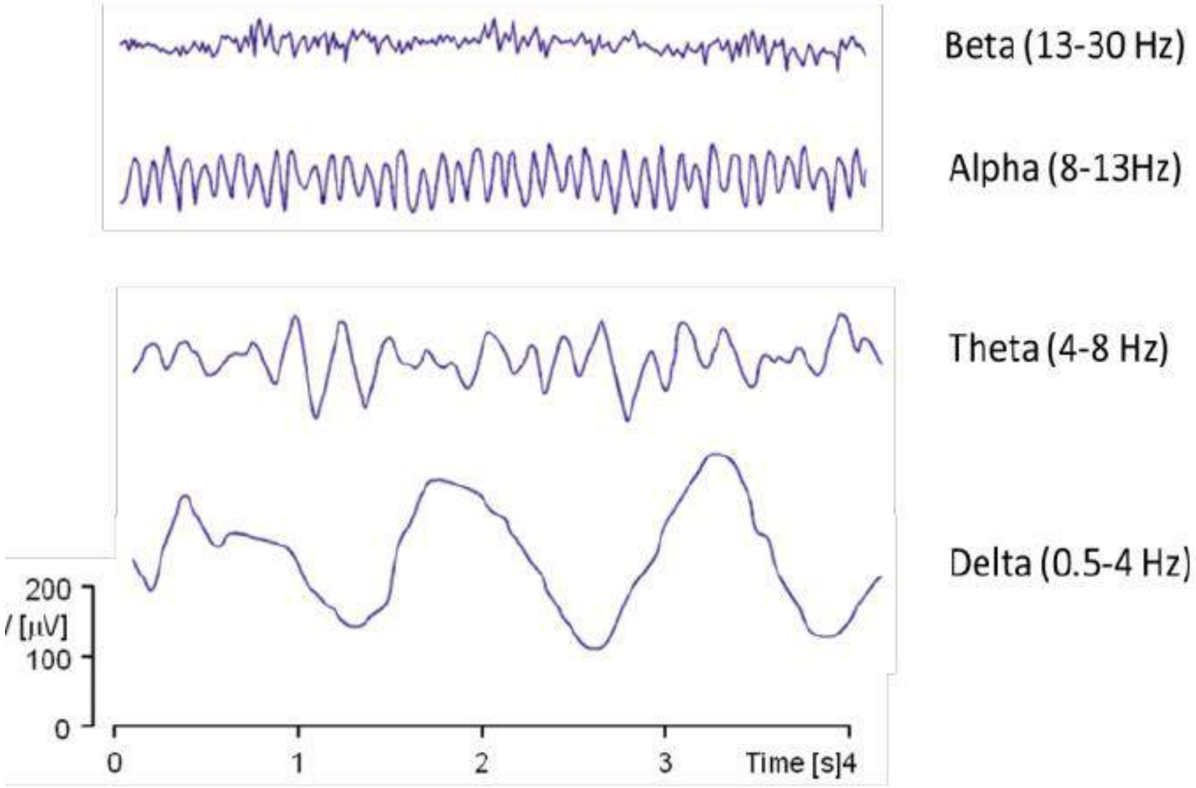
Frontal Lobe Temporal Lobe Parietal Lobe Occipital Lobe

International 10–20 system

- The mastoids reference electrode locations behind each ear (A1 and A2).
- Other reference electrode locations are nasion, at the top of the nose, level with the eyes; and inion, at the base of the skull on the midline at the back of the head.
- In a typical setup, each EEG electrode is connected to one input of a differential amplifier, and the other input is connected to a reference electrode

- The amplification of voltage between the active electrode and the reference is typically 1,000–100,000 times.
- The amplified signal is passed through a filter and then digitized via an A/D (analog to digital) converter.
- After digitization, the EEG signal may be additionally filtered by a 1–50 Hz bandpass filter.
  - Excludes noise and movement artifacts in the very low and very high frequency ranges.

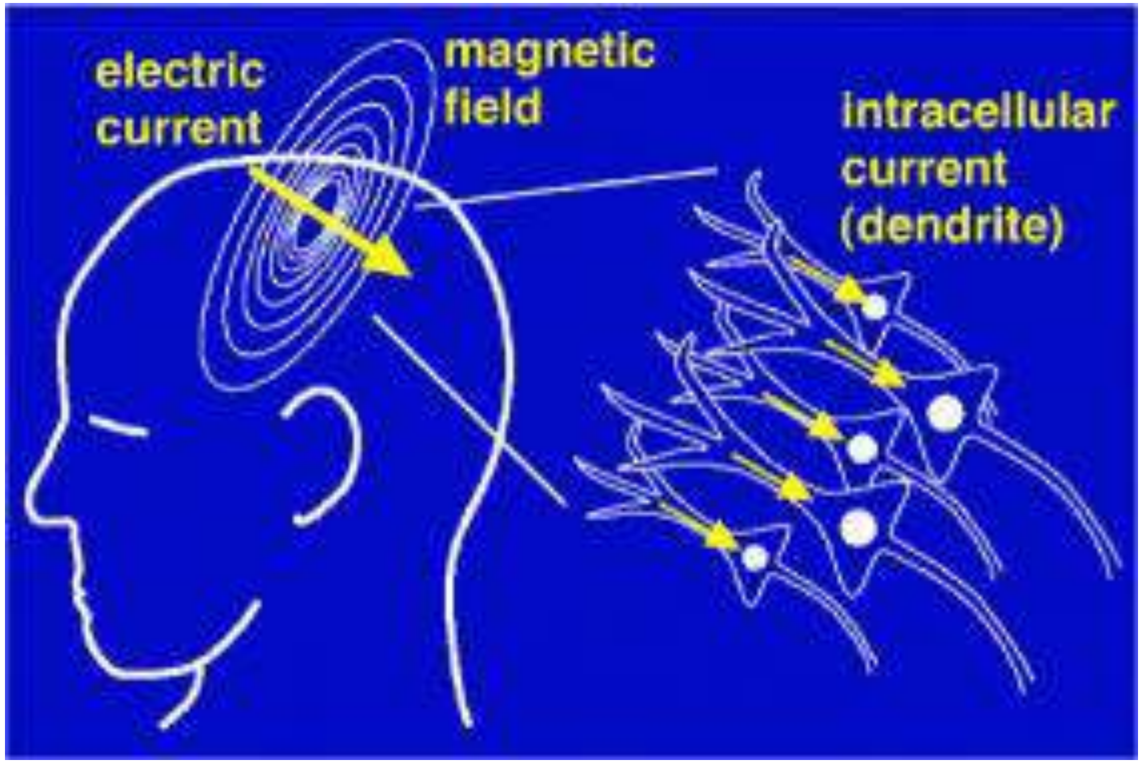
- EEG recordings are well-suited to capturing oscillatory brain activity or “brain waves” at a variety of frequencies
    - Alpha waves (8 to 13 Hz)
    - Beta waves (13 to 30 Hz)
    - Delta waves (0.5-4 Hz)
    - Theta waves (4-8 Hz)
    - Gamma waves (30-100 Hz or more)



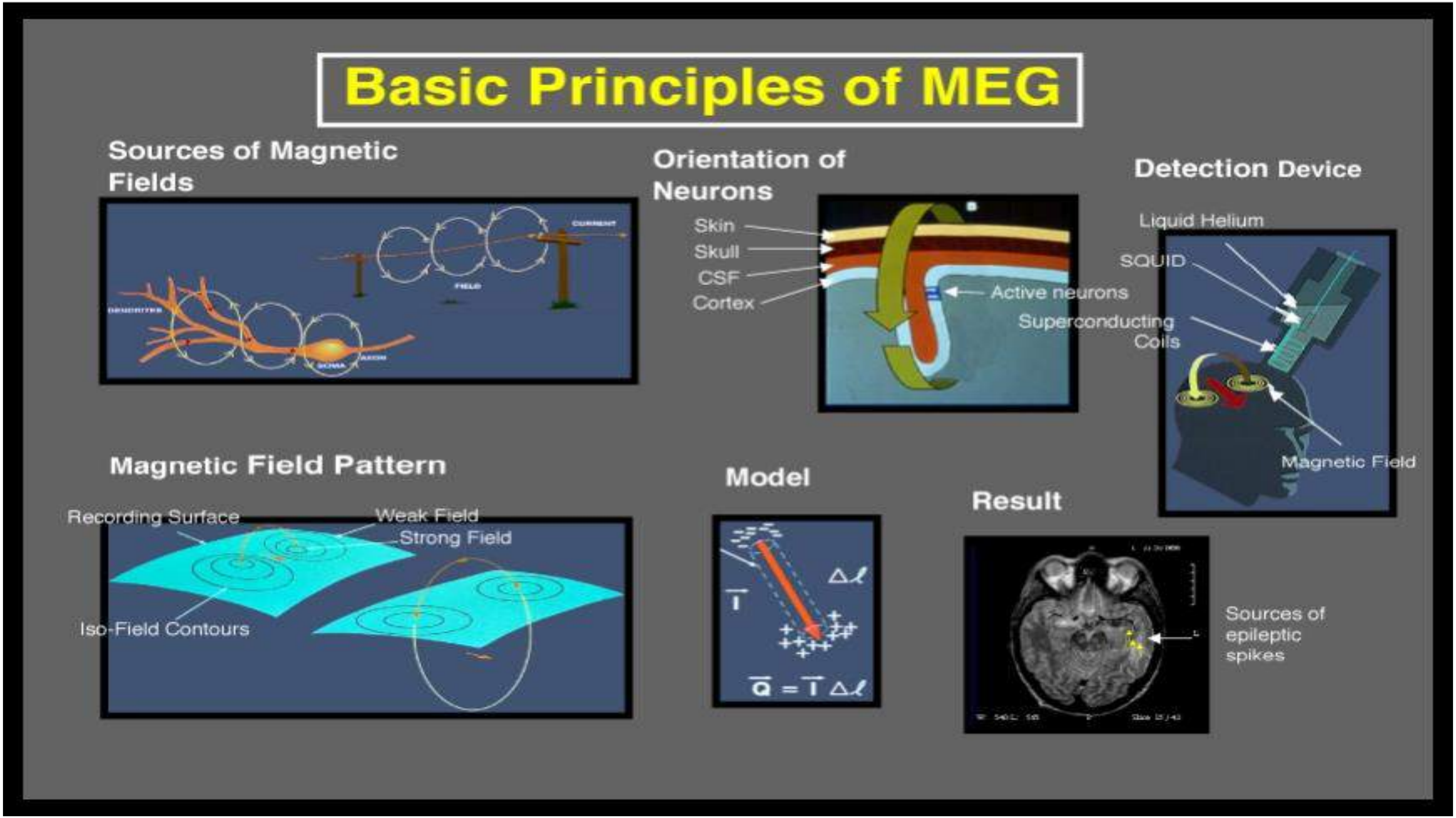
Non Invasive Approaches

Magnetoencephalography (MEG):

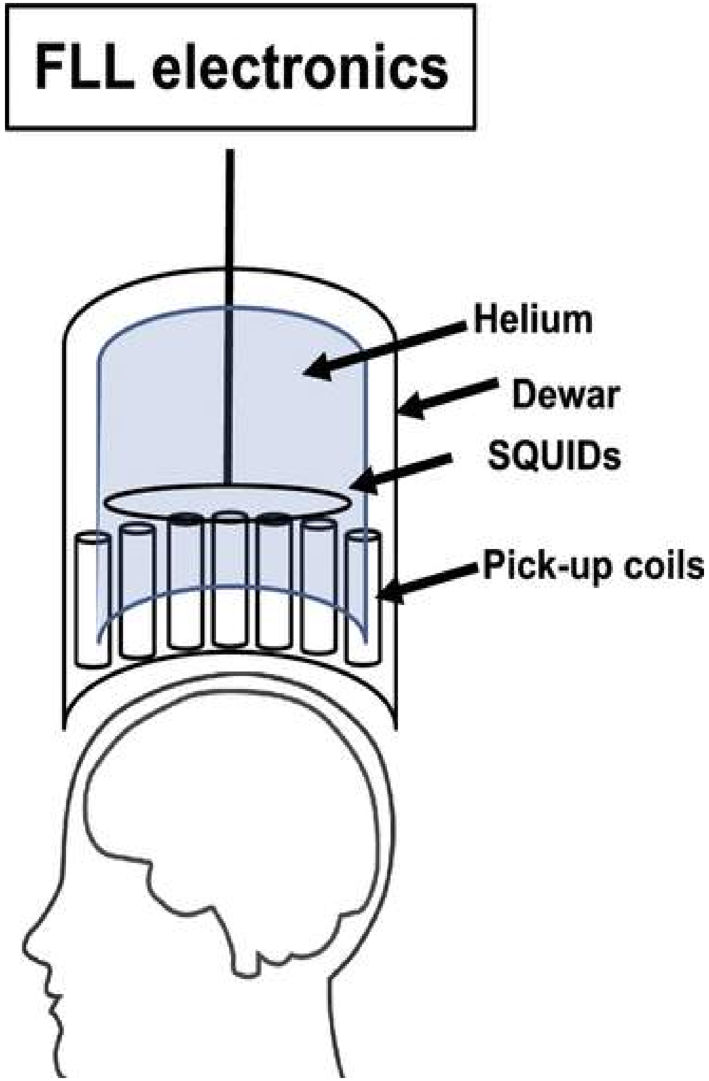
- Measures magnetic fields produced by activity of thousands of cortical neurons oriented perpendicular to the cortical surface
- Magnetic fields not distorted by skull and scalp
- Better spatial resolution than EEG
- Expensive and bulky
- Magnetically shielded rooms



(image A: Wikimedia Commons;
image B: http://dateline.ucdavis.edu/photos_images/dateline_images/040309/DondersMEGOle_W2.jpg).



Basic Principles of MEG
Sources of Magnetic Fields
Orientation of Neurons
Skin
Skull
CSF
Cortex
Active neurons
Detection Device
Liquid Helium
SQUID
Superconducting Coils
Magnetic Field
Magnetic Field Pattern
Recording Surface
Weak Field
Strong Field
Iso-Field Contours
Model
$\Delta\ell$
$\overline{I}$
$\overline{Q} = \overline{I}\,\Delta\ell$
Result
Sources of epileptic spikes



- MEG has very exquisitely sensitive sensors, filtering, and a method to shield the sensors from recording outside noise.
- conventional MEG systems use sensitive magnetic field sensors called superconducting quantum interference devices or SQUIDs.
- SQUIDs are made from materials that become superconductors at extremely low temperatures, meaning that the material can conduct electricity without resistance.
- Many of the MEG systems today use niobium for the SQUIDs because it can reliably reach a superconductive state at low temperatures and return back to room temperature.
- Pick-up coils are linked to the SQUID by an input coil and are kept in a superconducting state by liquid helium at −269°C.
- The SQUID then produces a small voltage current that can be detected through what is called a flux-locked loop (FLL) electronics system.
- The electrical output can then be transformed into a digital signal through optical cables. This output is usually displayed on a computer system connected to the MEG.

Source: https://journals.physiology.org/doi/full/10.1152/jn.00530.2020

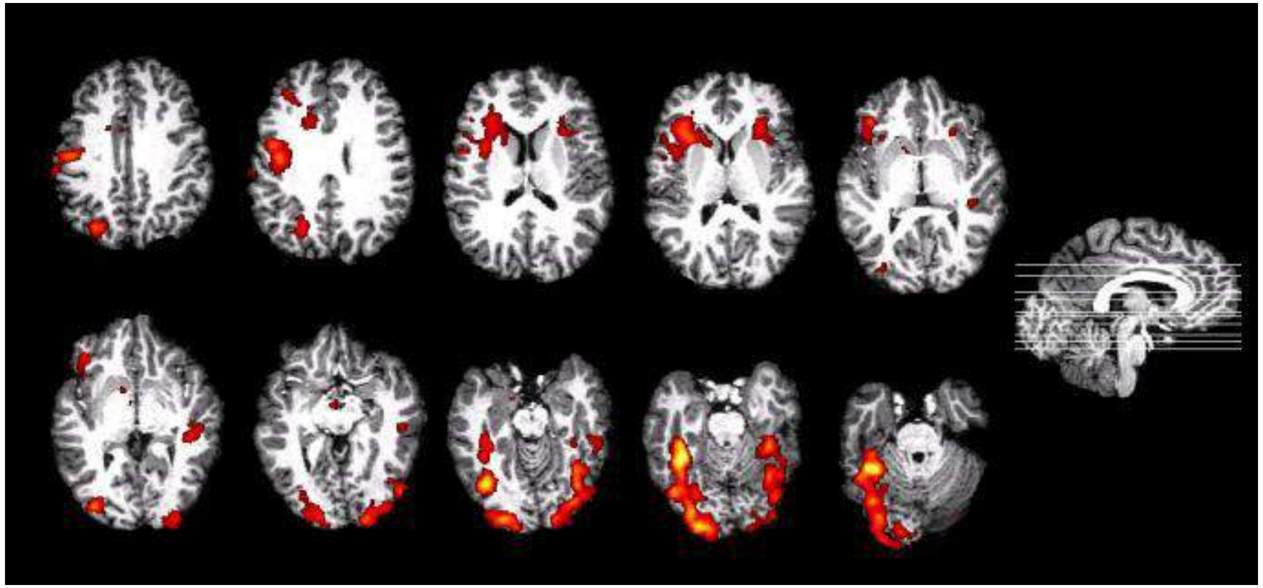
Non Invasive Approaches

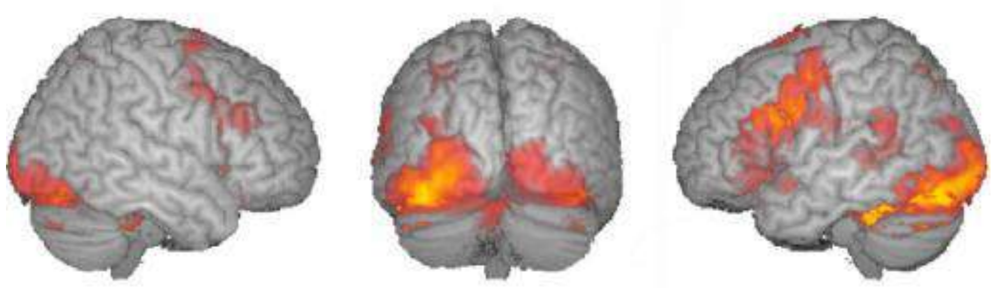
Functional Magnetic Resonance Imaging (fMRI) :

- Measures changes in blood flow due to increased activation of neurons in an area
- Relies on paramagnetic properties of oxygenated and deoxygenated hemoglobin in the blood
- Produces images showing blood-oxygenation-level-dependent signal changes (BOLD)

Non Invasive Approaches

- In the 1890s it has been known that changes in blood flow and blood oxygenation in the brain (collectively known as **hemodynamics**) are closely linked to neural activity.
- When neurons become active, local blood flow to those brain regions increases, and oxygen-rich (oxygenated) blood displaces oxygen-depleted (deoxygenated) blood. Oxygen is carried by the hemoglobin molecule in red blood cells.
- Deoxygenated hemoglobin is more magnetic (paramagnetic) than oxygenated hemoglobin (Hb), which is virtually resistant to magnetism (diamagnetic).



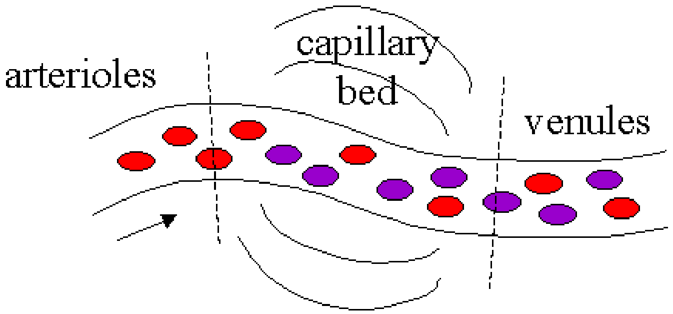


Example fMRI Images (word reading task)

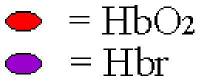
Blood Oxygen Level Dependent (BOLD) Signal

↑neural activity ➔ ↑ blood flow ➔ ↓ deoxyhemoglobin ➔ ↑ MR signal

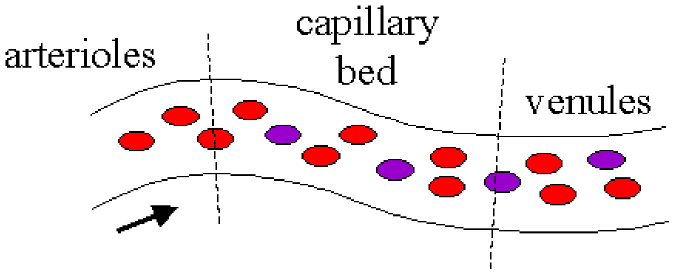
Basal state



- normal flow
- basal level [Hbr]
- basal CBV
- normal MRI signal



Activated state



- increased flow
- decreased [Hbr] (*lower field gradients around vessels*)
- increased CBV
- increased MRI signal (*from lower field gradients*)

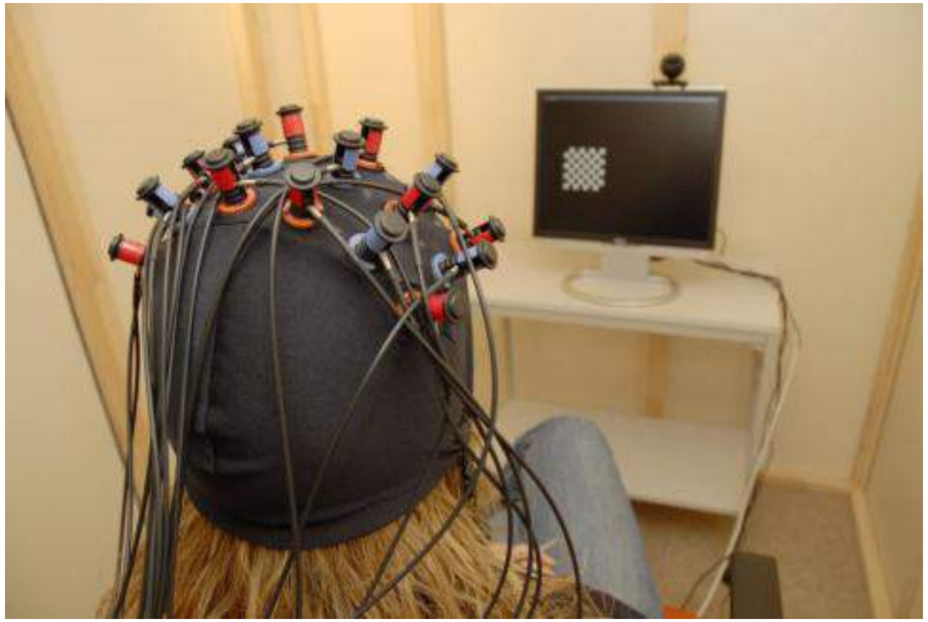
- **CBV:** Cerebral Blood Volume
- **CBF:** Cerebral Blood Flow
- **HBr:** Deoxy- Hemoglobin

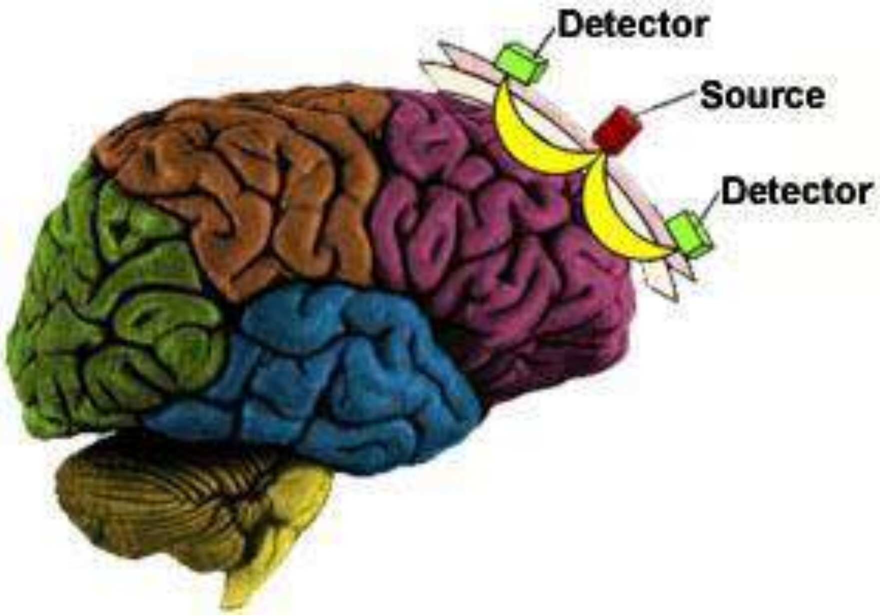
Source: Jorge Jovicich

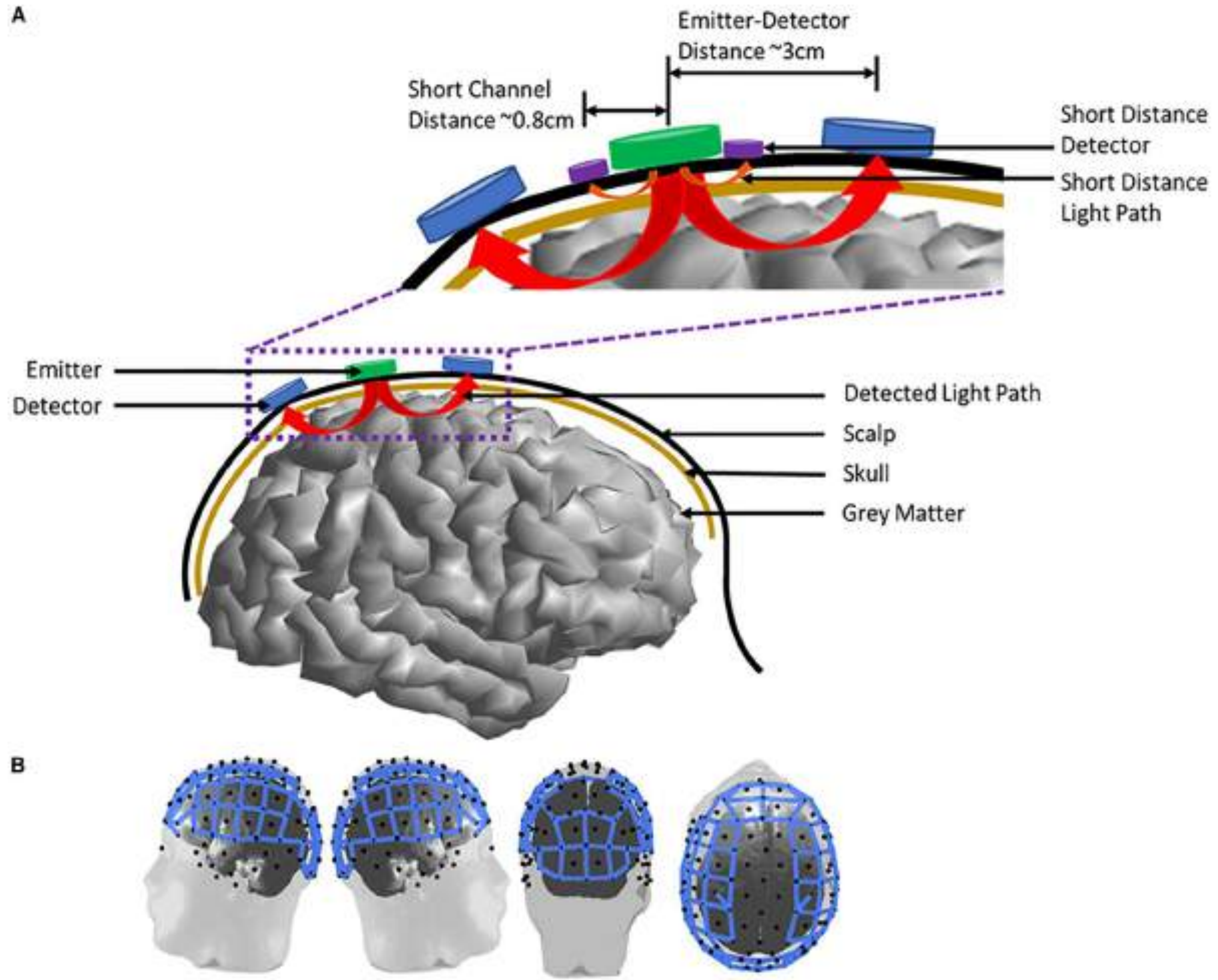
Non Invasive Approaches

<u>Functional Near-Infrared Spectroscopy (fNIRS)</u>

- Measures change in blood oxygenation level caused by increased neural activity in the brain.
- Based on detecting near-infrared light absorbance of hemoglobin in the blood with and without oxygen.
- Maps neural activity using "*optodes*" (emitters and detectors)




Detector
Source
Detector



Source: https://www.frontiersin.org/articles/10.3389/fnins.2020.00724/full

Non-Invasive Approaches

- **Positron Emission Tomography (PET):**
- Measures emissions from radioactively labeled, metabolically active chemicals that have been injected into the bloodstream for transportation to the brain.
  - The labeled compound is called a *radiotracer*.
- Sensors in the PET scanner detect the radioactive compound
  - As a result of metabolic activity caused by brain activity.
- Generate two-or three-dimensional images indicating the amount of brain activity.

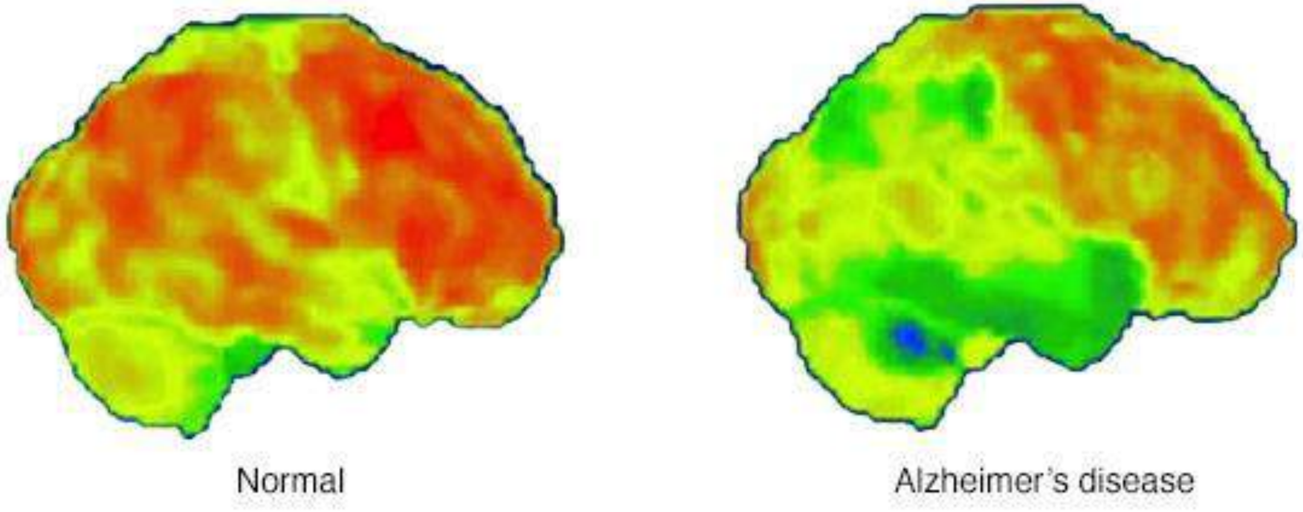
Non-Invasive Approaches

- **<u>Positron Emission Tomography (PET):</u>**

What does a PET scan check for?

- Cancer, including breast cancer, lung cancer and thyroid cancer.
- Coronary artery disease, heart attack or other heart problems.
- Brain disorders, such as brain tumors, epilepsy, dementia and Alzheimer’s disease.

Positron Emission Tomography (PET):

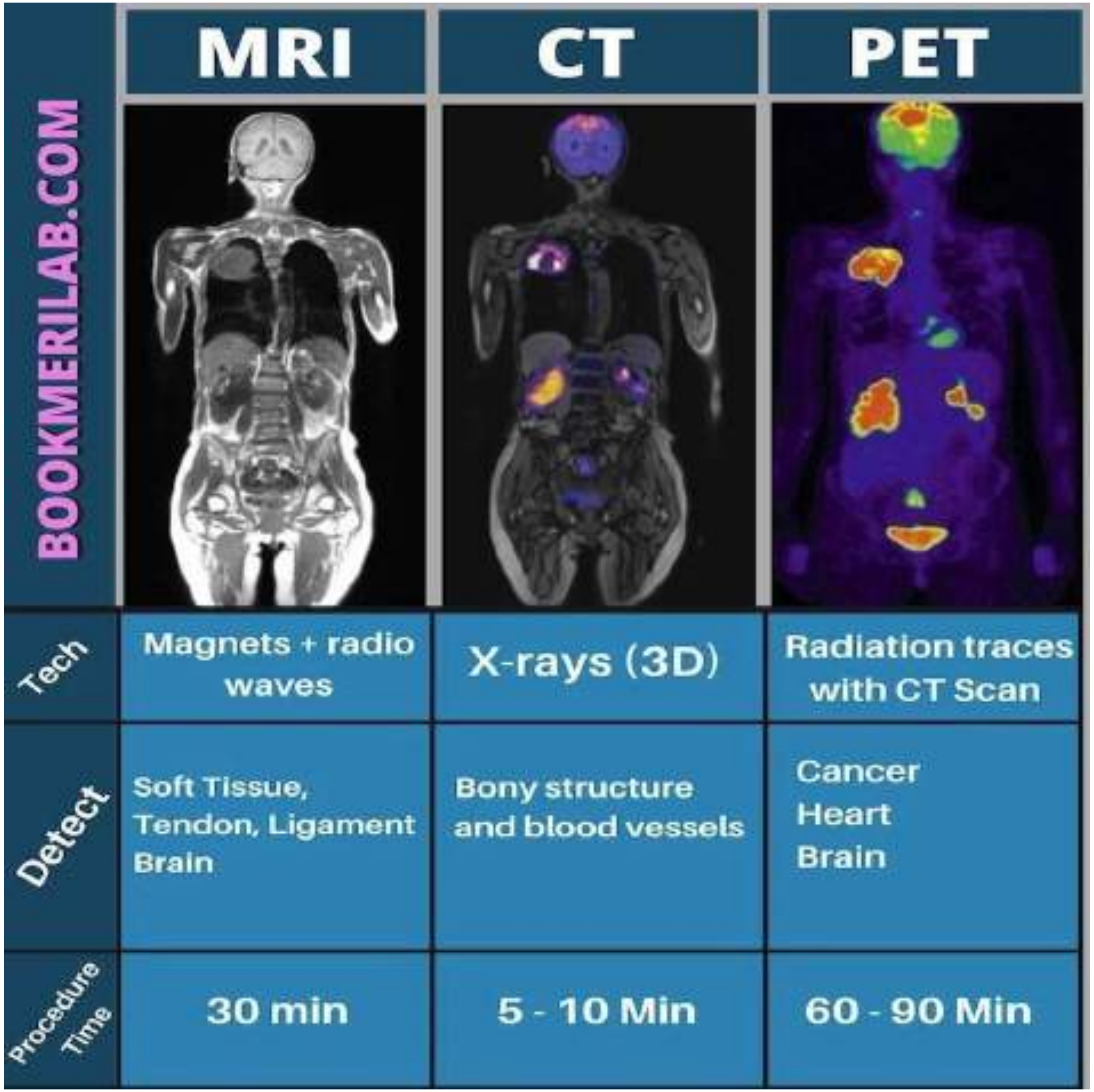


A PET scan can compare a normal brain (left) with one affected by Alzheimer's disease (right). An increase in blue and green colors shows decreased brain metabolic activity due to Alzheimer's disease.

Positron Emission Tomography (PET):

Source: Internet

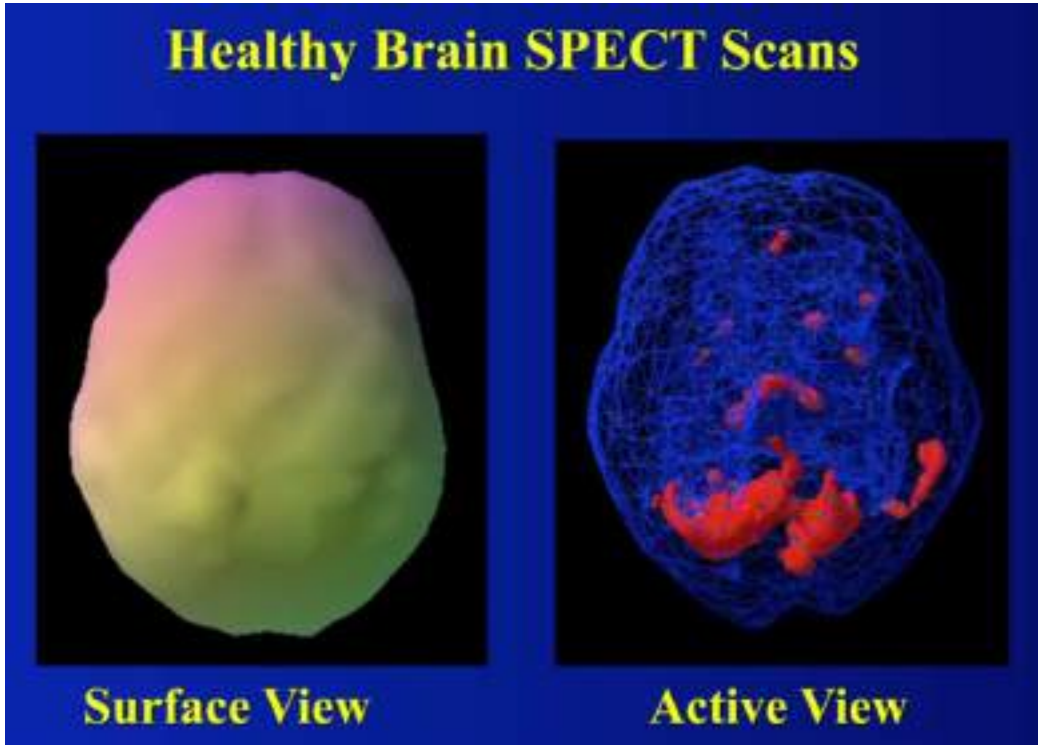
Comparison between MRI, CT and PET Scan



Source: Internet

Non Invasive Approaches

- **<u>Single-photon emission-computed tomography (SPECT):</u>**
- SPECT is a nuclear medicine technique that uses gamma rays to study the brain.
- A radioactive substance is injected into the patient's body and is scanned using a SPECT machine.
- Allows doctors to see how blood flows into tissues and organs.
  - Active, inactive, or overactive.
- Averages the brain activity over a few minutes and generates an image.



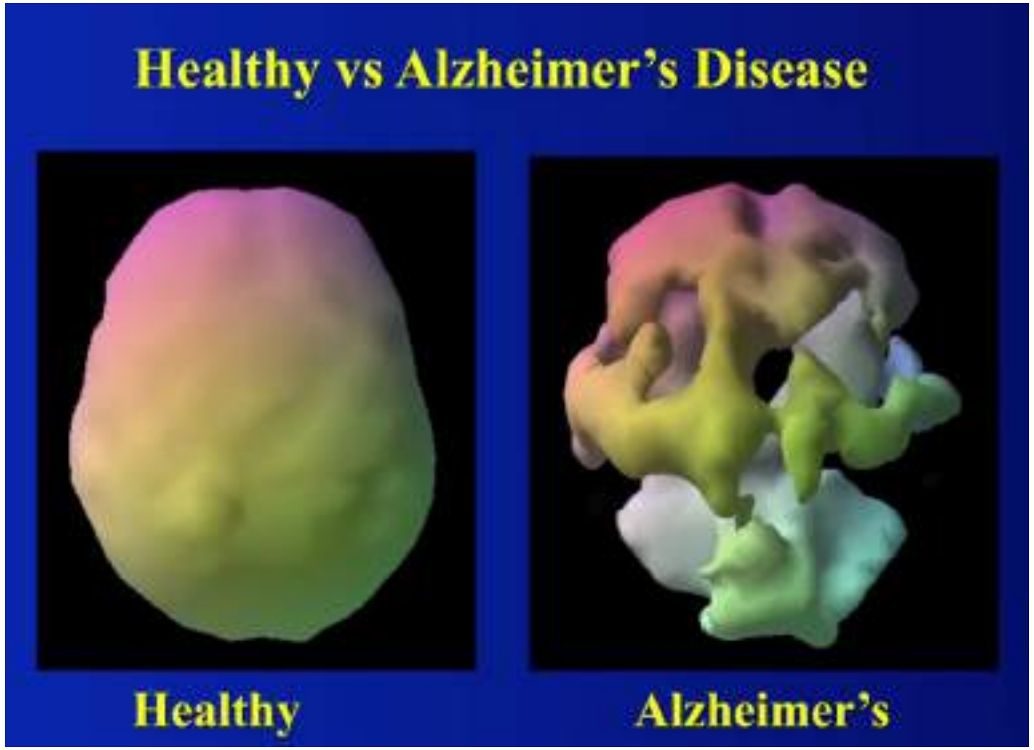


Image credit: https://hamnaqasim.medium.com/brain-scans-a-lesson-to-learn-9dfe67abd841

What spatial and temporal scale is relevant for studying systems neuroscience questions?

Adapted from: PS Churchland and TJ Sejnowski, Perspectives on cognitive neuroscience, 1988 Science, Vol 242, Issue 4879, 741-745

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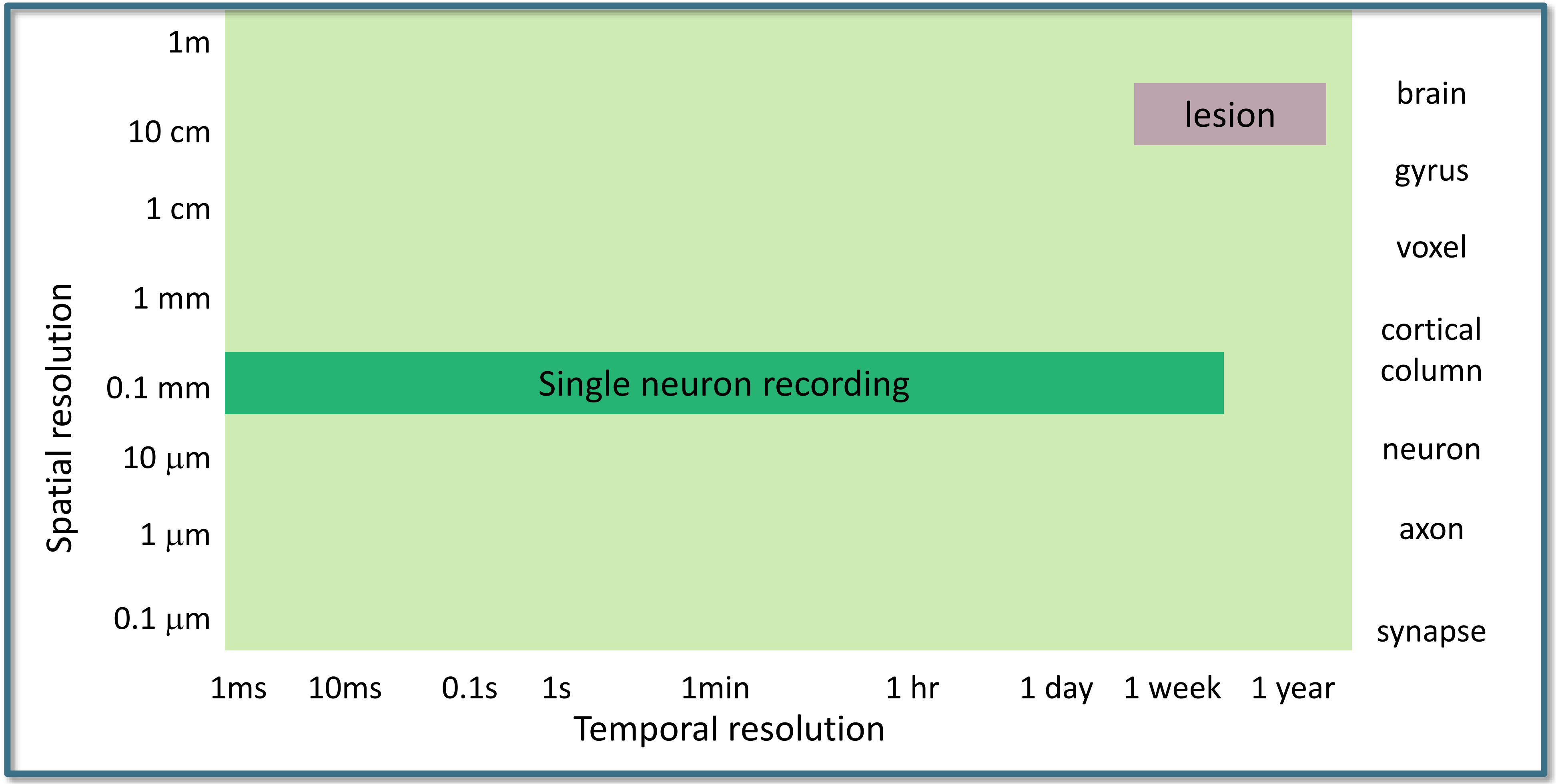

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Science, Vol 242, Issue 4879, 741-745

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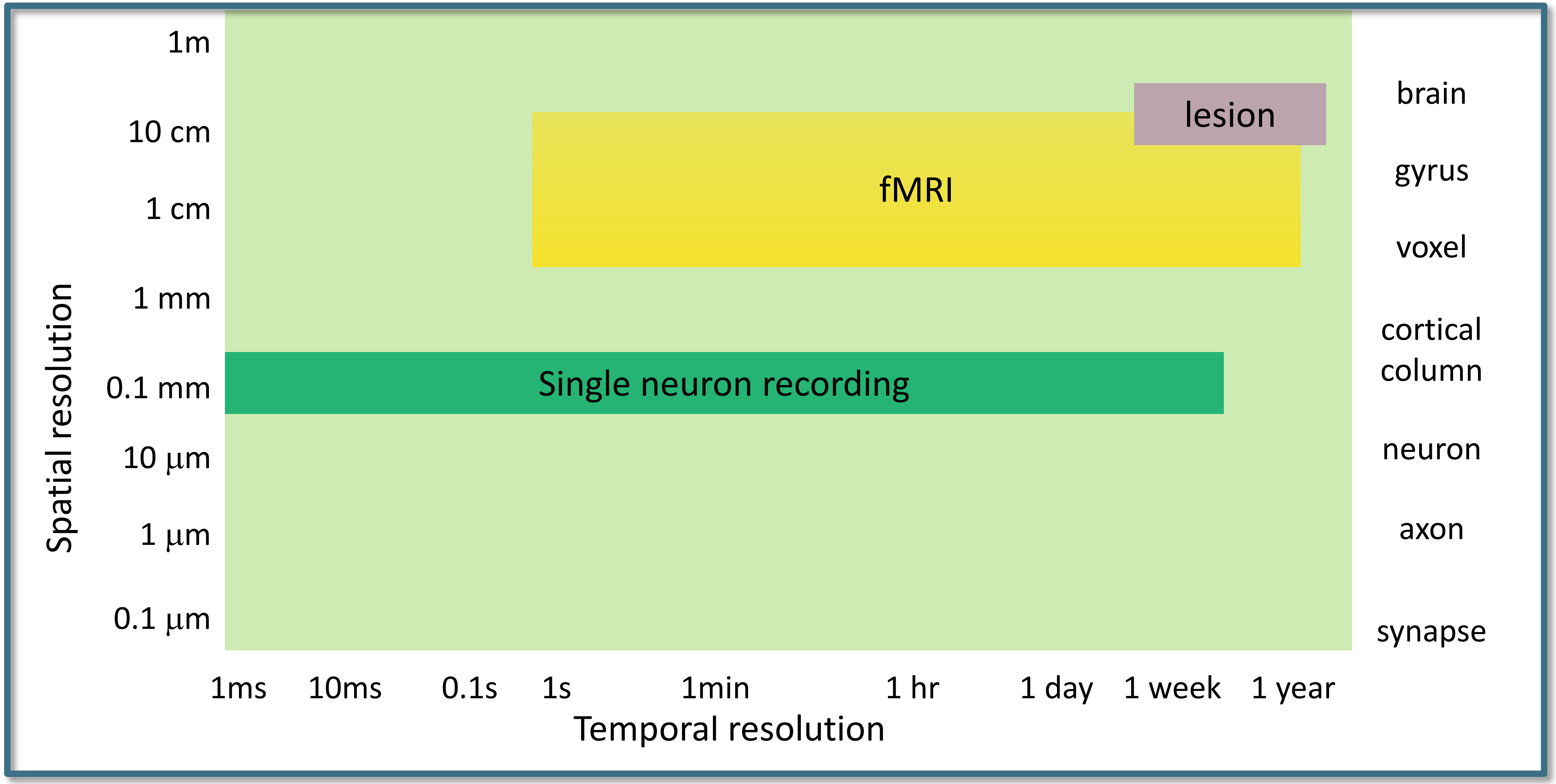

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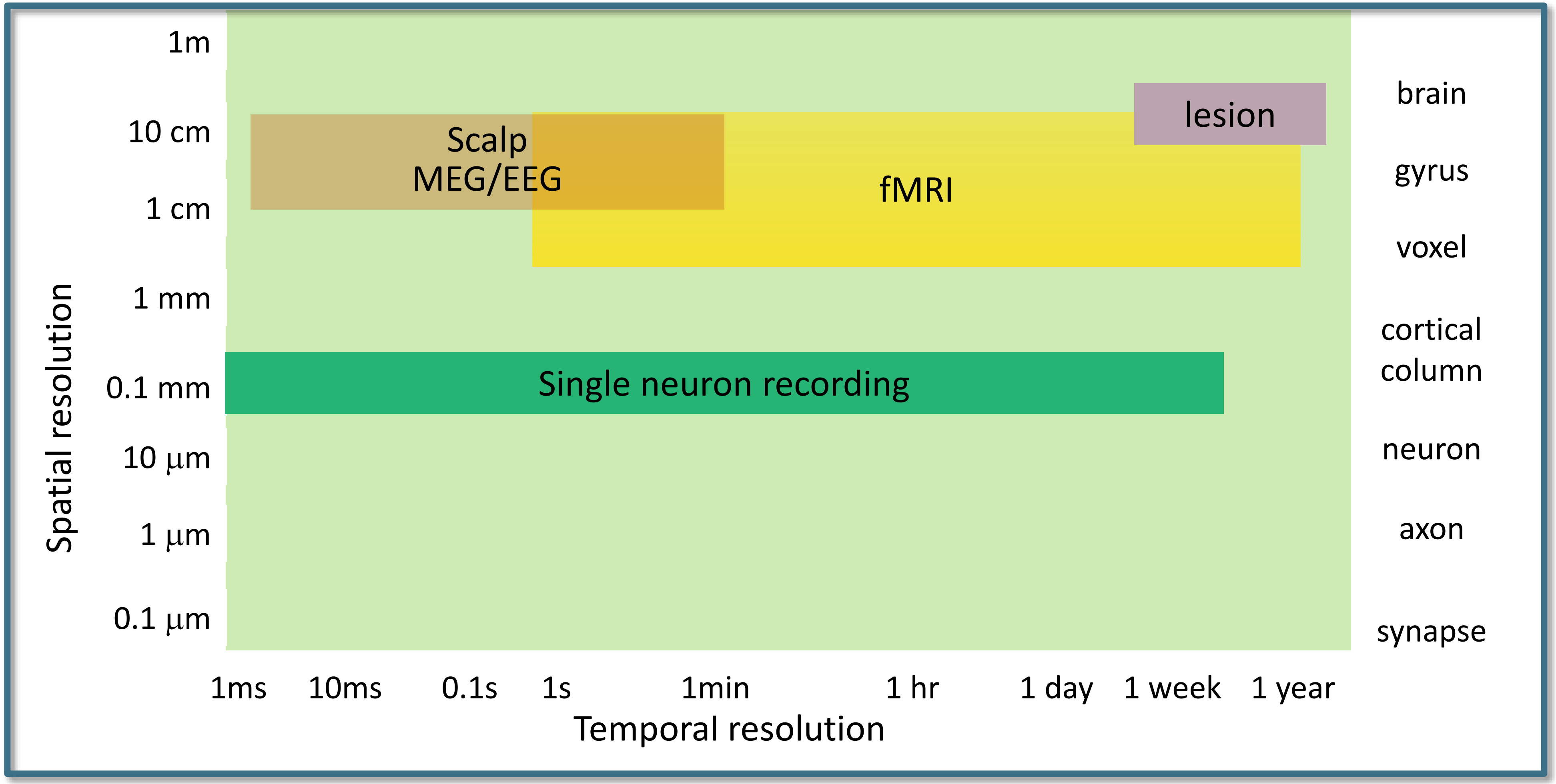

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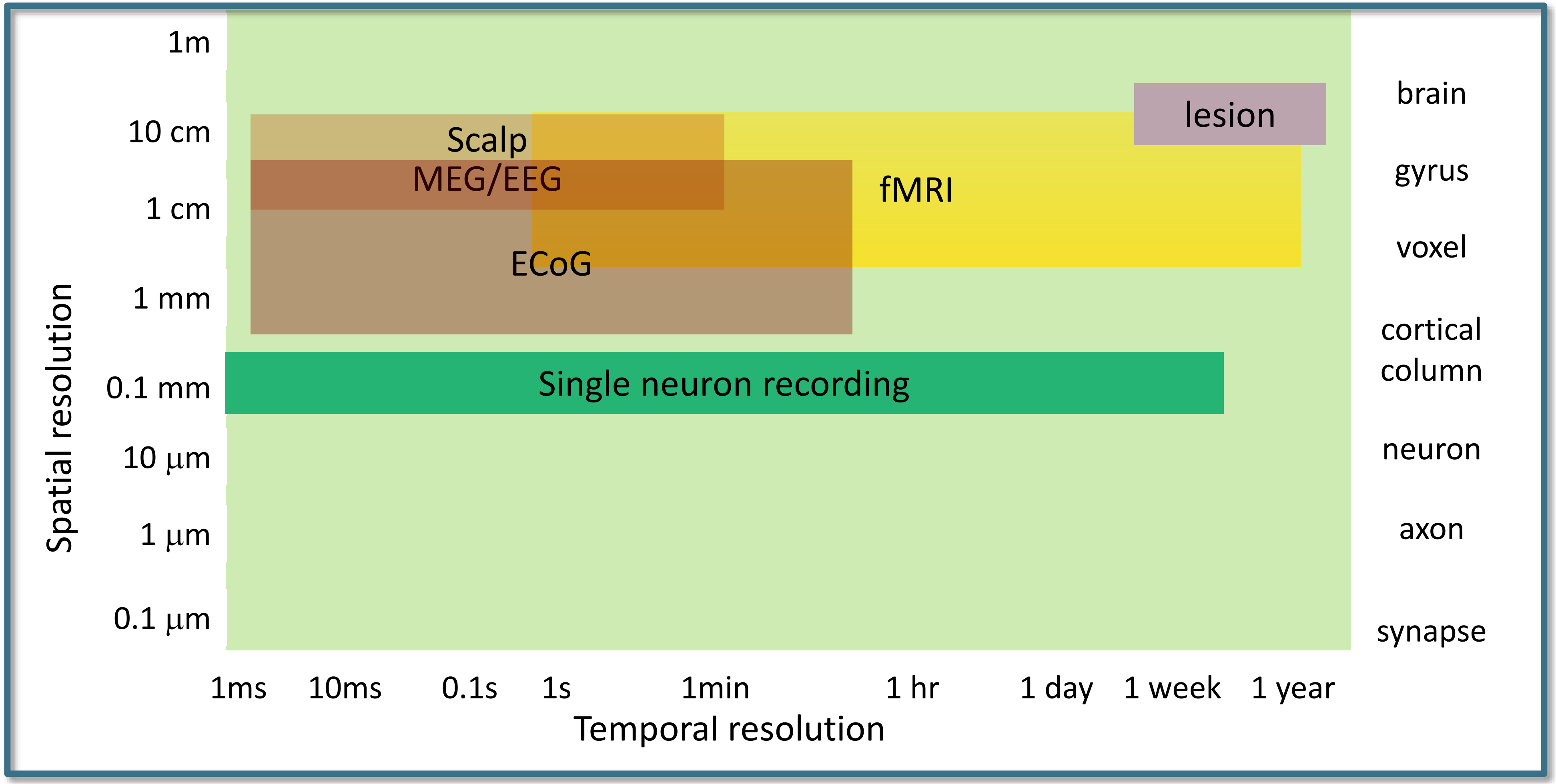

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Brain Computer Interaction

EEG Variables

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EEG

- Electroencephalogram (EEG) signals are useful for diagnosing various mental conditions such as epilepsy, memory impairments and sleep disorders.
- EEGs can indicate the general conscious state of a person, e.g., asleep, awake, anaesthetized, since each state is correlated with particular EEG patterns.
- A flat EEG (no electrical activity) is clinical evidence of death.

Why EEG?

- Hardware costs are significantly lower than those of most other techniques.
- EEG sensors can be used in more places than fMRI, SPECT, PET, MRS, or MEG, as these techniques require bulky and immobile equipment.
- EEG has very high temporal resolution, on the order of milliseconds rather than seconds, commonly recorded at sampling rates between 250 and 2000 Hz thus a valuable tool for research and diagnosis.
- EEG is relatively tolerant of subject movement, unlike most other neuro imaging techniques. There even exist methods for minimizing, and even eliminating movement artifacts in EEG data.
- EEG is silent, which allows for better study of the responses to auditory stimuli.
- EEG does not involve exposure to high-intensity (>1 Tesla) magnetic fields, as in some of the other techniques, especially MRI and MRS. These can cause a variety of undesirable issues with the data, and also prohibit use of these techniques with participants that have metal implants in their body, such as metal-containing pacemaker.
- EEG can be used in subjects who are incapable of making a motor response.
- EEG is a powerful tool for tracking brain changes during different phases of life. EEG sleep analysis can indicate significant aspects of the timing of brain development, including evaluating adolescent brain maturation.

EEG Disadvantages

- Low spatial resolution on the scalp. fMRI, for example, can directly display areas of the brain that are active, while EEG requires intense interpretation just to hypothesize what areas are activated by a particular response.
- EEG poorly determines neural activity that occurs below the upper layers of the brain (the cortex).
- Unlike PET and MRI, cannot identify specific locations in the brain at which various neurotransmitters, drugs, etc. can be found.
- Often takes a long time to connect a subject to EEG, as it requires precise placement of dozens of electrodes around the head and the use of various gels, saline solutions, and/or pastes to keep them in place. Where as a general rule it takes considerably less time to prepare a subject for MEG, fMRI, MRS, and PET.

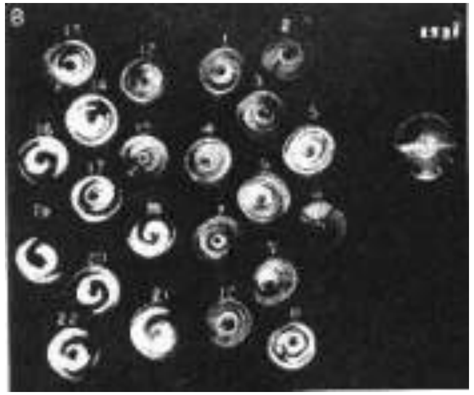
EEG Pioneers

In 1929, Hans Berger

- Recorded brain activity from the closed skull
- Reported brain activity changes according to the functional state of the brain
  - Sleep
  - Hypnothesis
  - Pathological states (epilepsy)

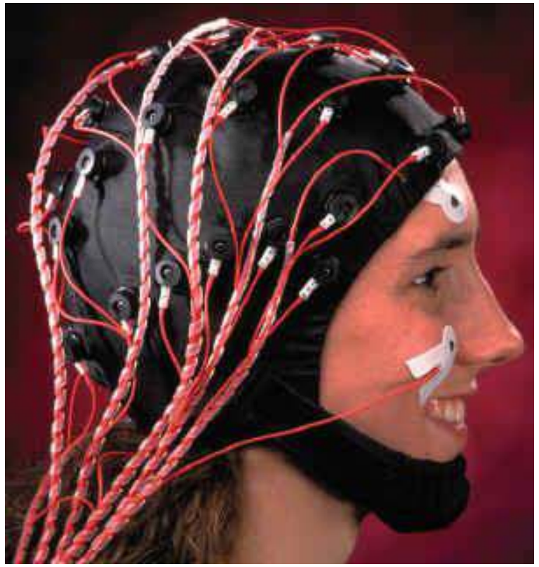
In 1957, Gray Walter

- Makes recordings with large numbers of electrodes
- Visualizes brain activity with the toposcope
- Shows that brain rhythms change according to the mental task demanded



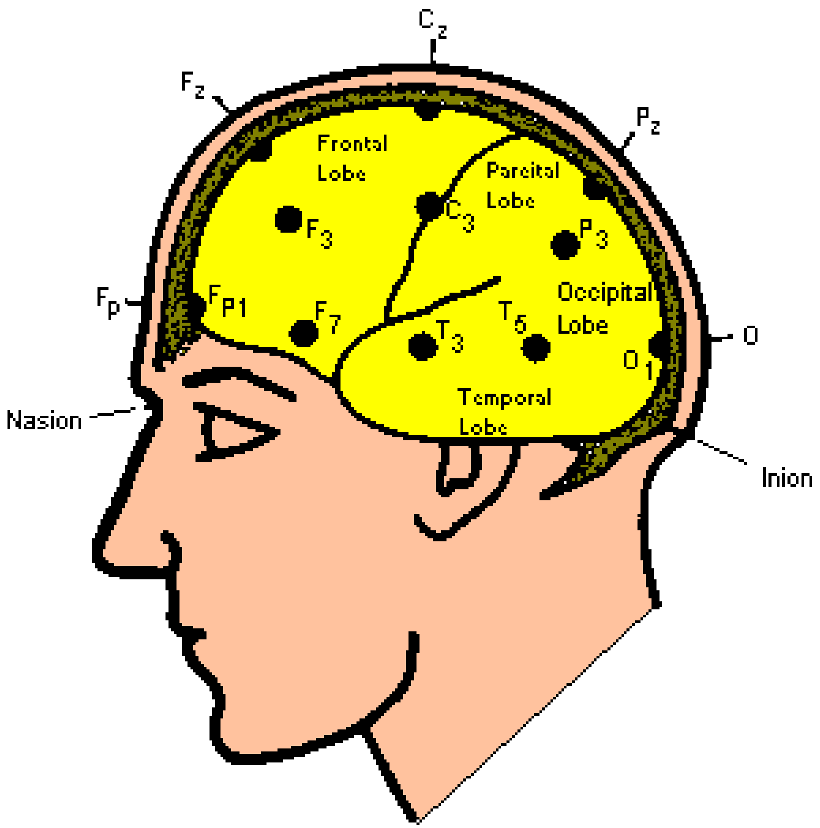
EEG CAPS

- EEGs require electrodes attached to the scalp with sticky gel
- Require physical connection to the machine



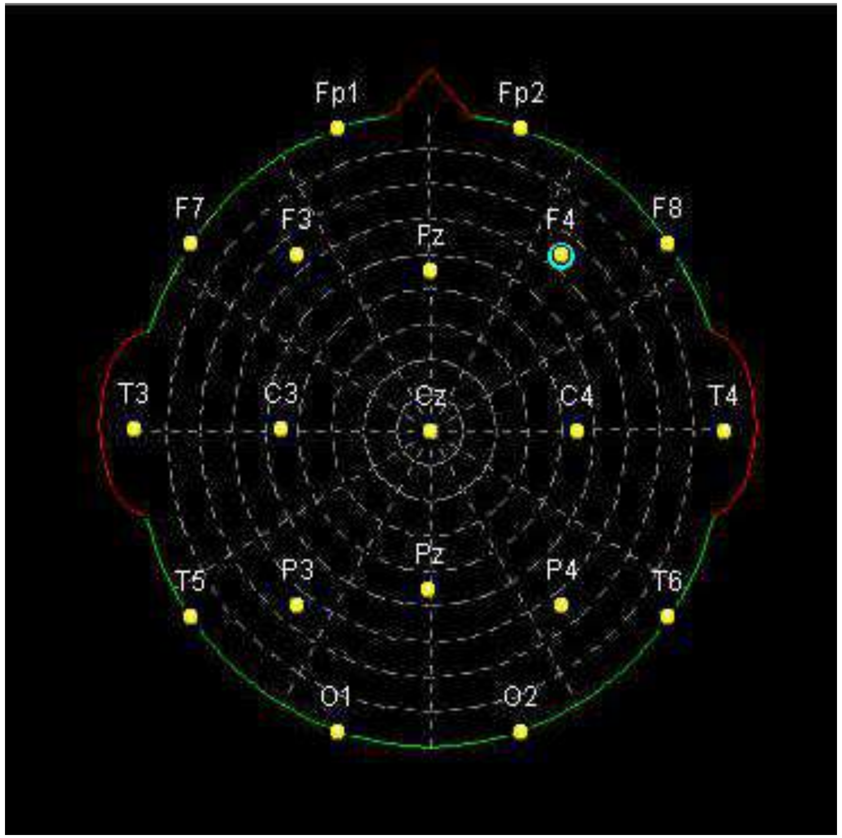
Electrode Placement

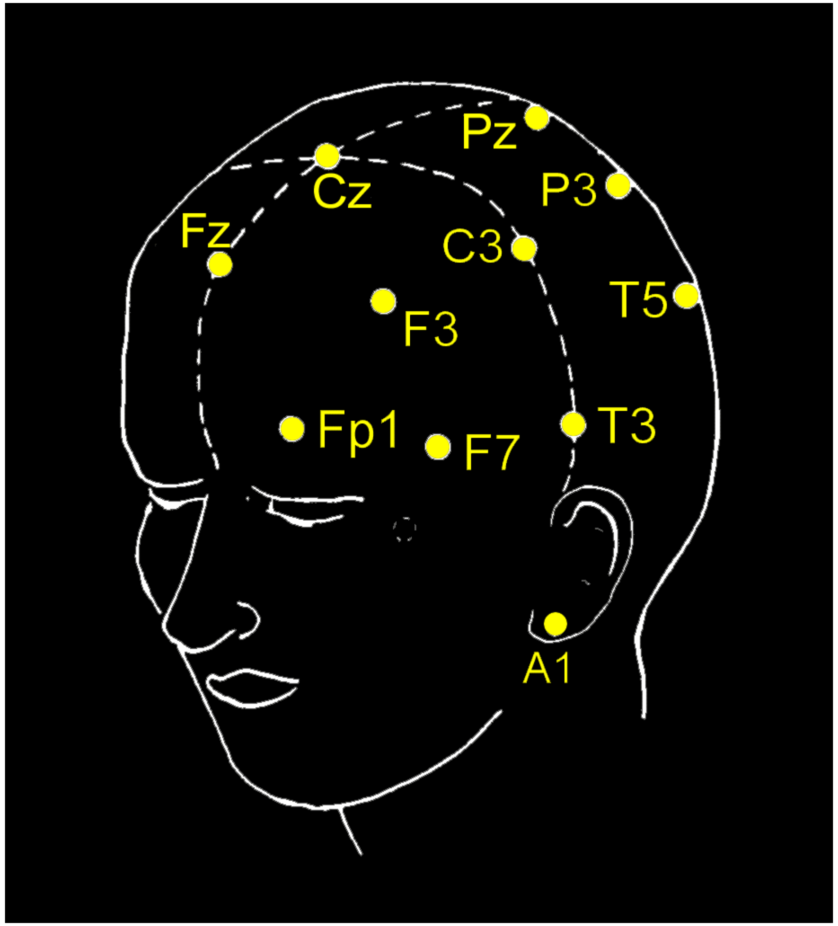
- Standard “10-20 System”
- Spaced apart 10-20%
- Nasion – point between the forehead and the skull
- Inion – Bump at the back of the skull
- Letter for region
  - F - Frontal Lobe
  - T - Temporal Lobe
  - C - Center
  - O - Occipital Lobe
- Number for exact position
  - Odd numbers - left
  - Even numbers - right



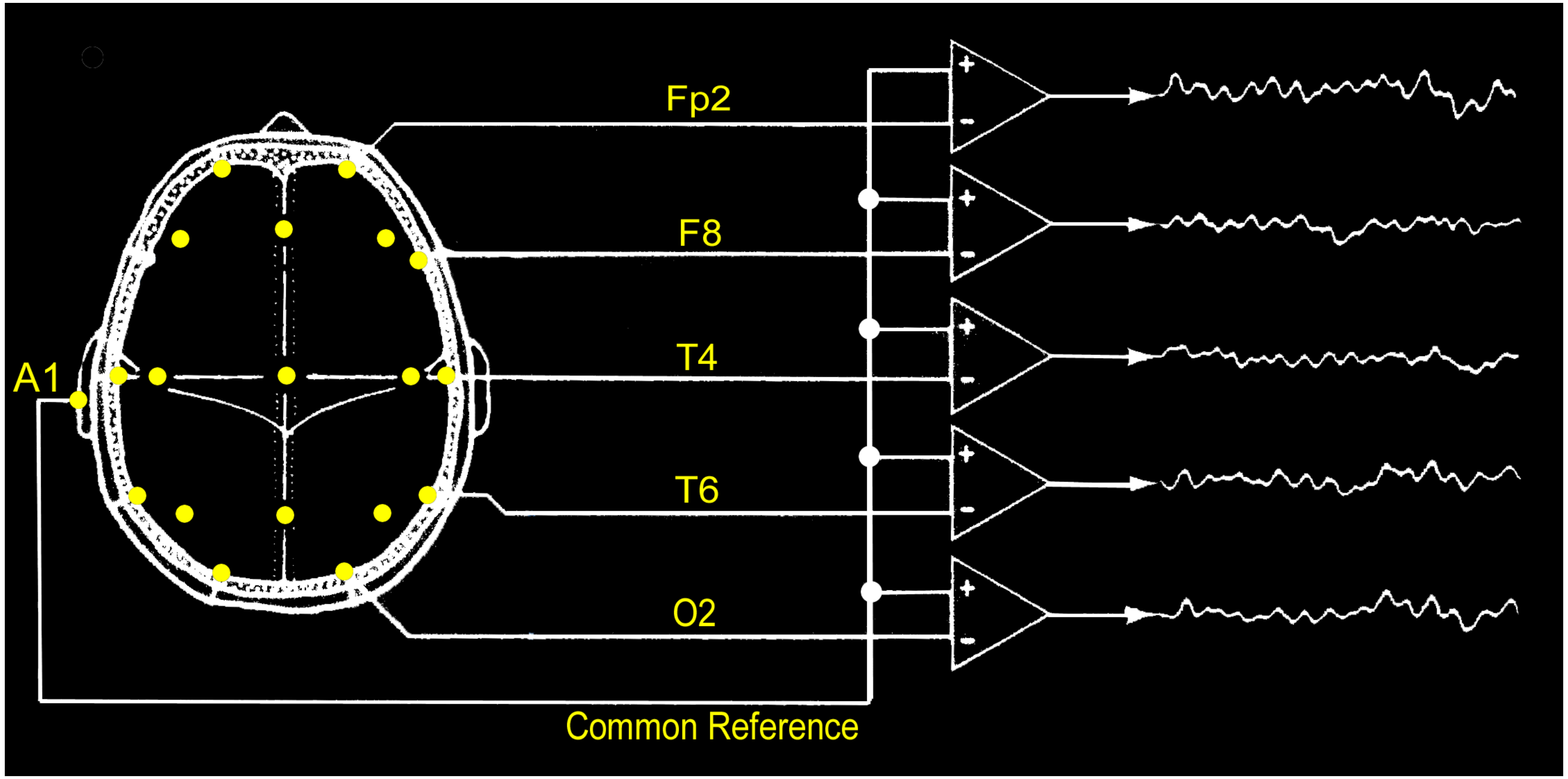
Electrode Placement

- International 10/20 system





EEG Channels



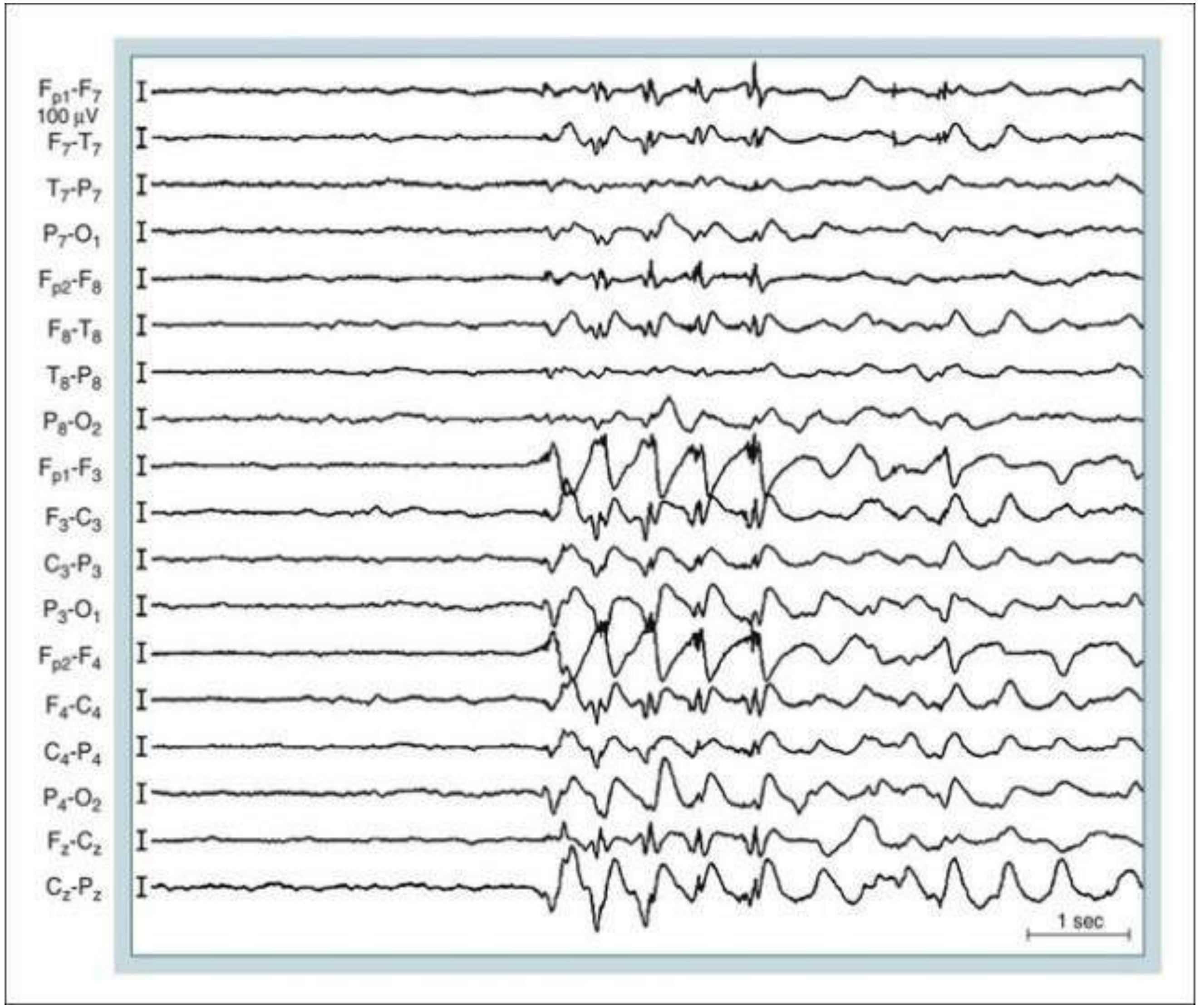
Channel: Recording from a pair of electrodes (here with a common reference: A1 – left ear)

Multichannel EEG recording: up to 64 channels recorded in parallel

Representation of EEG channels:

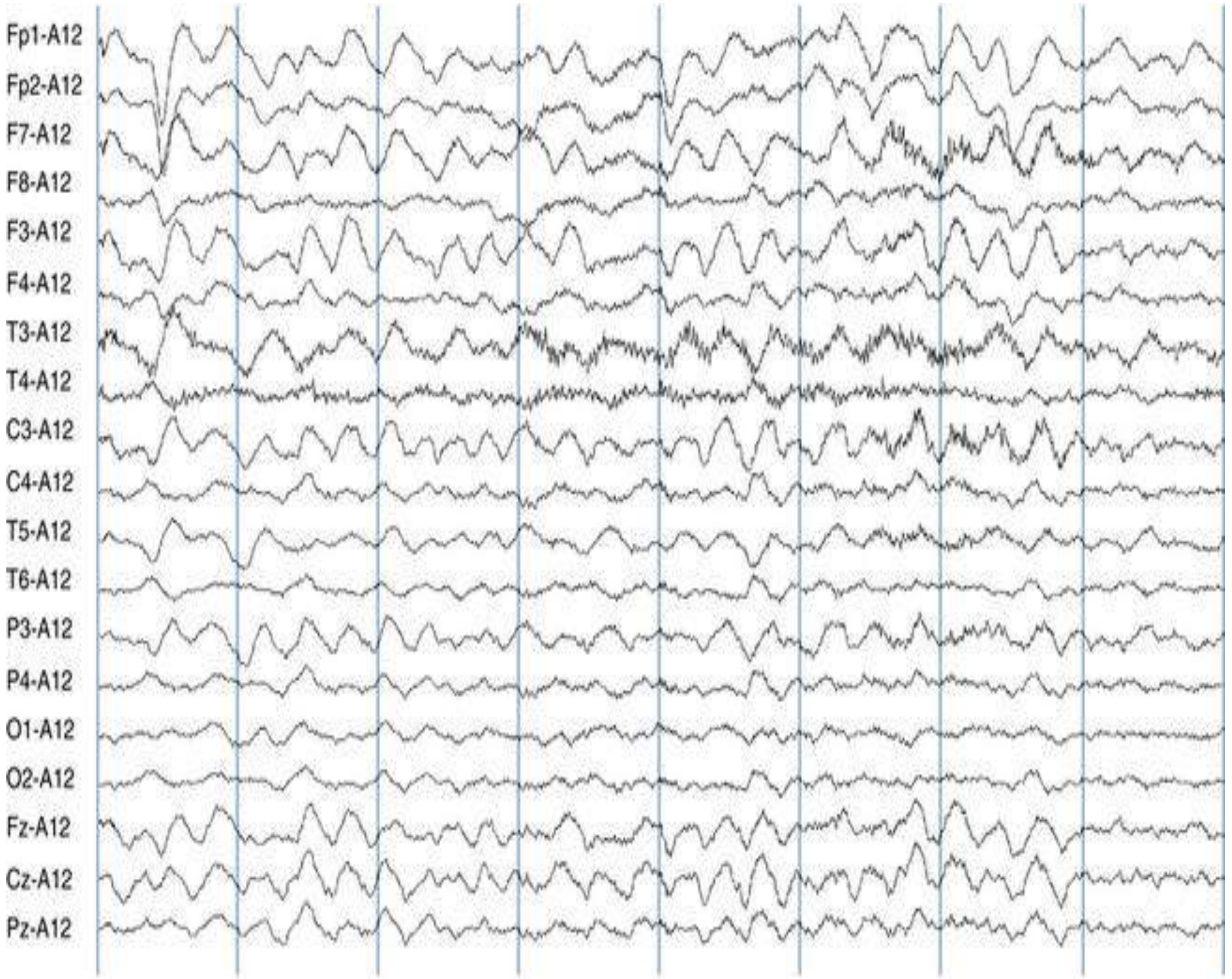
The representation of the EEG channels (i.e., waveform) is referred to as a **montage**.

- **Sequential montage**: Each channel represents the difference between two adjacent electrodes. The entire montage consists of a series of these channels. For example, the channel "Fp1-F3" represents the difference in voltage between the Fp1 electrode and the F3 electrode. The next channel in the montage, "F3-C3," represents the voltage difference between F3 and C3, and so on through the entire array of electrodes.



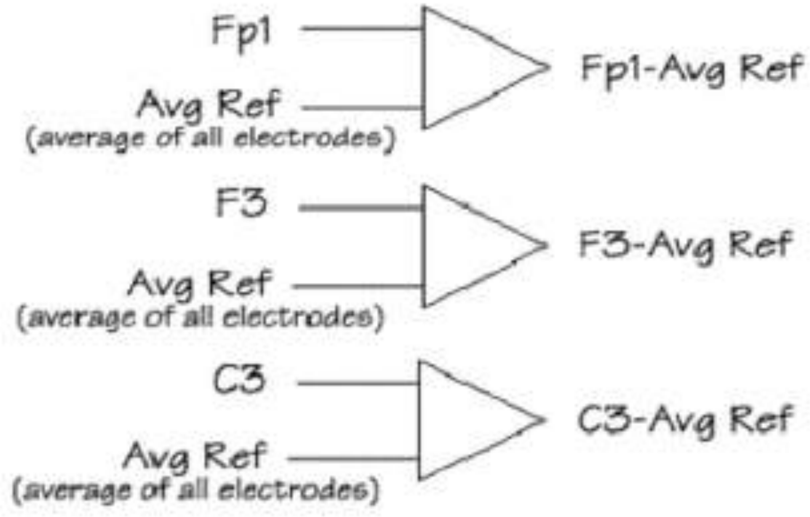
Representation of EEG channels:

- **Referential montage**: Each channel represents the difference between a certain electrode and a designated reference electrode. There is no standard position for this reference; it is, however, at a different position than the "recording" electrodes. Midline positions are often used because they do not amplify the signal in one hemisphere vs. the other. Another popular reference is "linked ears," which is a physical or mathematical average of electrodes attached to both earlobes or mastoids.

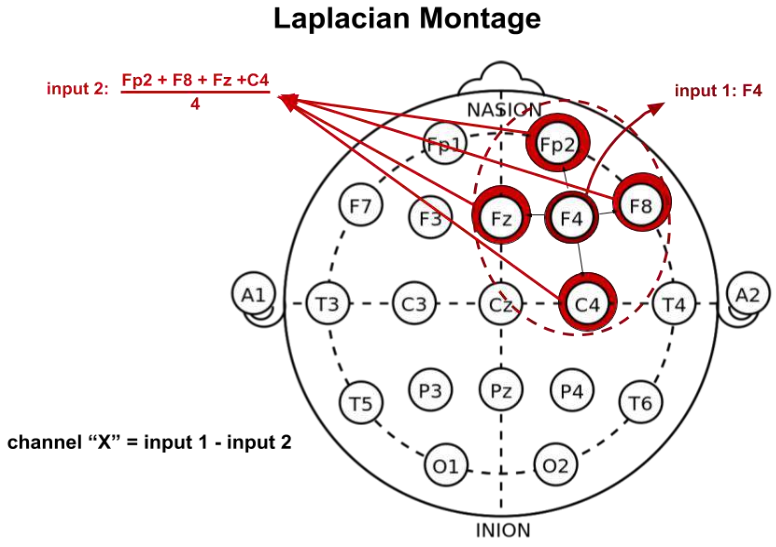


Representation of EEG channels:

- **Average reference montage:** The outputs of all of the amplifiers are summed and averaged, and this averaged signal is used as the common reference for each channel.



- **Laplacian montage:** Each channel represents the difference between an electrode and a weighted average of the surrounding electrodes.



EEG Rhythms

- Generally grouped by frequency: (amplitudes are about 100μV max)

Type	**Frequency**	**Location**	**Use**
Delta	<4 Hz	everywhere	occur during sleep, coma
Theta	4-7 Hz	temporal and parietal	correlated with emotional stress (frustration & disappointment)
Alpha	8-15 Hz	occipital and parietal	reduce amplitude with sensory stimulation or **mental imagery**
Beta	16-30 Hz	parietal and frontal	can increase amplitude during intense **mental activity**
Gamma	>30 Hz	Somatosensory cortex	A decrease in gamma-band activity is associated with **cognitive decline**
Mu	8-12 Hz	frontal (motor cortex)	diminishes with movement or **intention of movement**
Lambda	sharp, jagged	occipital	correlated with visual attention
Vertex			higher incidence in patients with epilepsy or encephalopathy

Alpha Rhythm

Frequency: 8 – 15 Hz

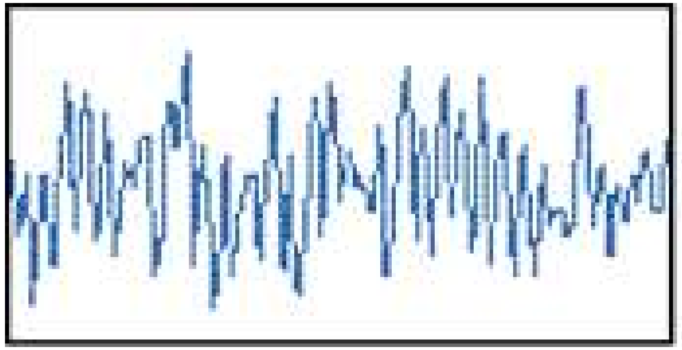
Amplitude: 5 – 100 microVolt

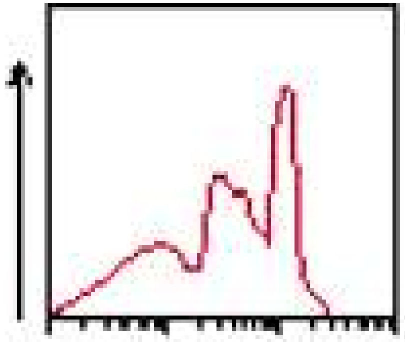
Location: Occipital, Parietal

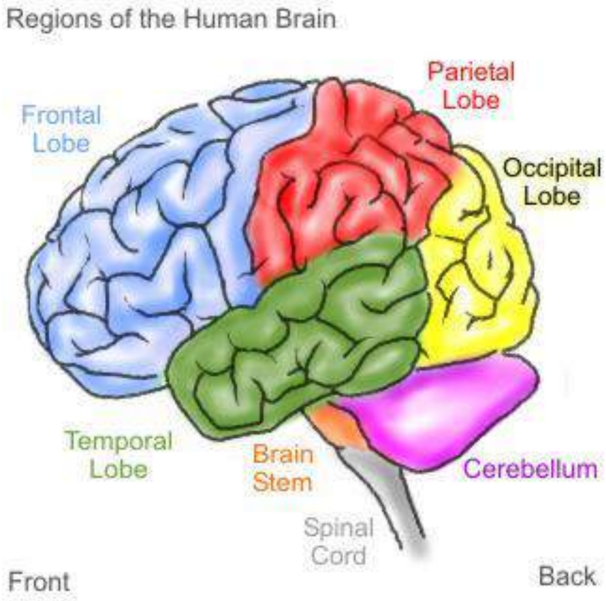
State of Mind: Alert Restfulness

Source: Oscillating thalamic pacemaker neurons

Alpha blockade occurs when new stimulus is processed







Beta Rhythm

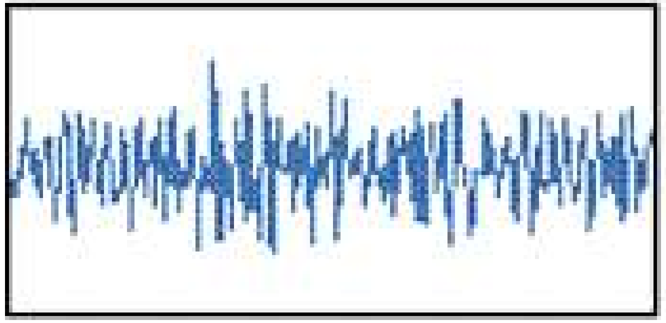
Frequency: 16 – 30 Hz

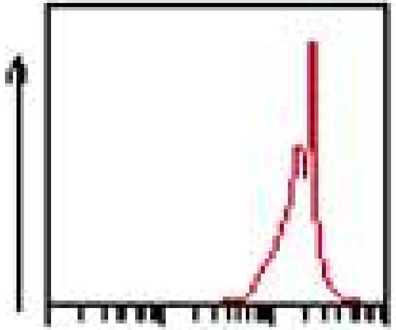
Amplitude: 2 – 20 microVolt

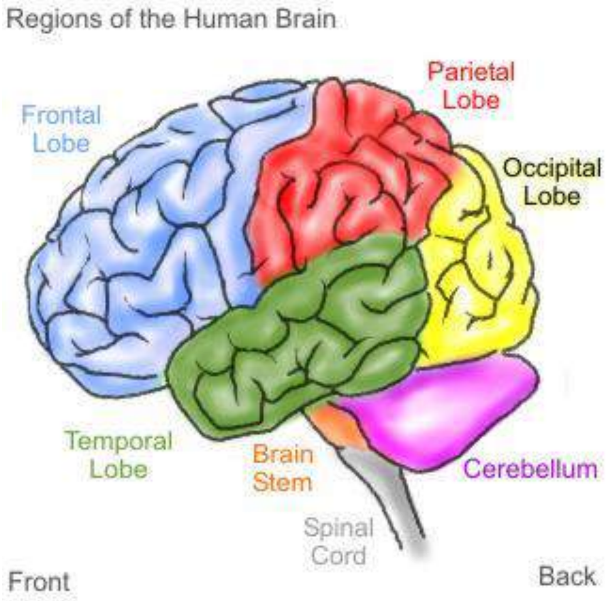
Location: Frontal

State of Mind: Mental Activity

Reflects specific information processing between cortex and thalamus







Delta Rhythm

Frequency: 1 – 4 Hz

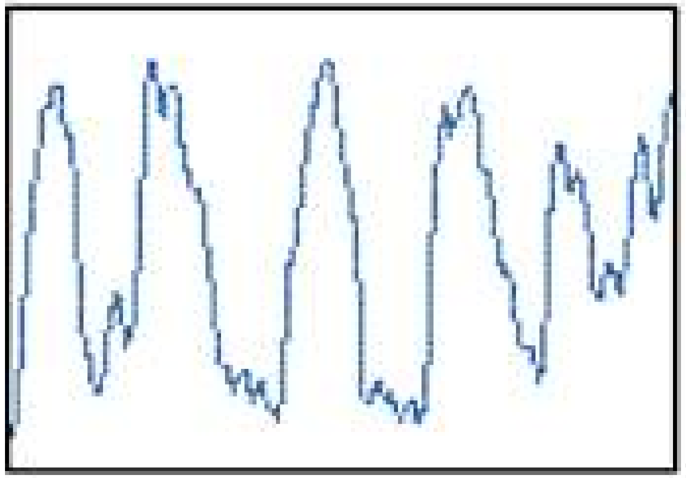
Amplitude: 20 – 200 microVolt

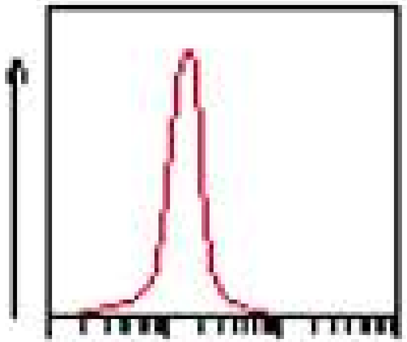
Location: Variable

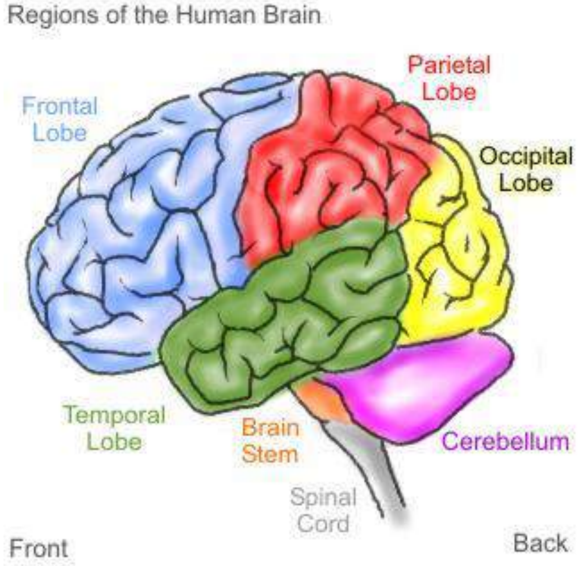
State of Mind: Deep sleep

Oscillations in Thalamus and deep cortical layers

Usually inibited by ARAS (Ascending Reticular Activation System)

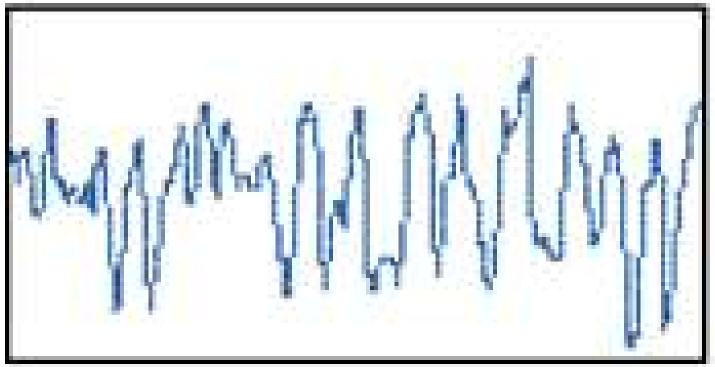


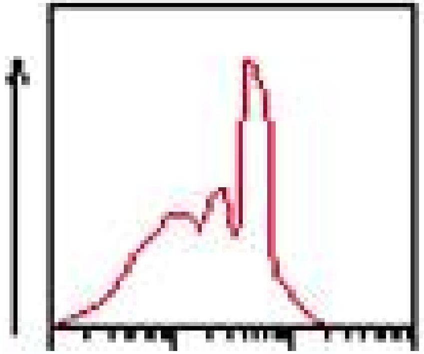


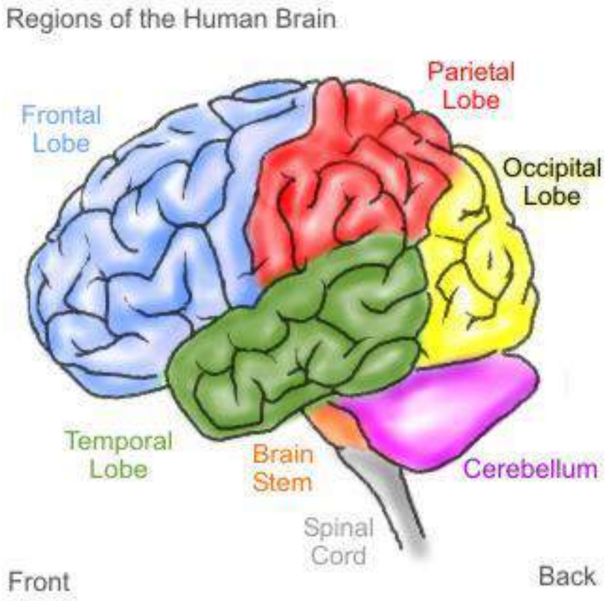


Theta Rhythm

Frequency:	4 – 7 Hz
Amplitude:	5 – 100 microVolt
Location:	Frontal, Temporal
State of Mind:	Sleepiness







Mu Waves

- Studied since 1930s
- Found in Motor Cortex
- Amplitude suppressed by Physical Movements, or *intent to* move physically
- (Wolpaw, et al 1991) trained subjects to control the mu rhythm by visualizing motor tasks to move a cursor up and down (1D)
- (Wolpaw and McFarland 2004) used a linear combination of Mu and Beta waves to control a 2D cursor.
- Weights were learned from the users in real time.
- Cursor moved every 50ms (20 Hz)
- 92% “hit rate” in average 1.9 sec

Alpha and Beta Waves

- Studied since 1920s
- Found in Parietal and Frontal Cortex
- Relaxed - Alpha has high amplitude
- Excited - Beta has high amplitude
- So, Relaxed -> Excited
  means Alpha -> Beta

Variables used in EEG measurement:

Frequency:

- Frequency refers to rhythmic repetitive activity (in Hz). The frequency of EEG activity can have different properties including:
- **Rhythmic**. EEG activity consisting in waves of approximately constant frequency.
- **Arrhythmic**. EEG activity in which no stable rhythms are present.
- **Dysrhythmic**. Rhythms and/or patterns of EEG activity that characteristically appear in patient groups or rarely or seen in healthy subjects.

Variables used in EEG measurement:

Voltage: Voltage refers to the average voltage or peak voltage of EEG activity.

- **Attenuation** (synonyms: suppression, depression). Reduction of amplitude of EEG activity resulting from decreased voltage.
- **Hypersynchrony**. Seen as an increase in voltage and regularity of rhythmic activity, or within the alpha, beta, or theta range. The term implies an increase in the number of neural elements contributing to the rhythm.
- **Paroxysmal**. Activity that reaching (usually) quite high voltage and ending with an abrupt return to lower voltage activity. Though the term does not directly imply abnormality, much abnormal activity is paroxysmal.

Variables used in EEG measurement:

Morphology: Morphology refers to the shape of the waveform. The shape of a wave or an EEG pattern is determined by the frequencies that combine to make up the waveform and by their phase and voltage relationships. Wave patterns can be described as being:

- **Monomorphic**. Distinct EEG activity appearing to be composed of one dominant activity
- **Polymorphic**. Distinct EEG activity composed of multiple frequencies that combine to form a complex waveform.
- **Sinusoidal**. Waves resembling sine waves. Monomorphic activity usually is sinusoidal.
- **Transient**. An isolated wave or pattern that is distinctly different from background activity.
    - Spike: a transient with a pointed peak and duration from 20 to less than 70 msec.
- Sharp wave: a transient with a pointed peak and duration of 70-200 msec.

Variables used in EEG measurement:

Synchrony:

- Synchrony refers to the simultaneous appearance of rhythmic or morphologically distinct patterns over different regions of the head, either on the same side (unilateral) or both sides (bilateral).

Periodicity:

- Periodicity refers to the distribution of patterns or elements in time (e.g., the appearance of a particular EEG activity at more or less regular intervals). The activity may be generalized, focal or lateralized.

Thank You!