Brain Signal Acquisition

Non Invasive Approaches

Electroencephalography (EEG)

- 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.

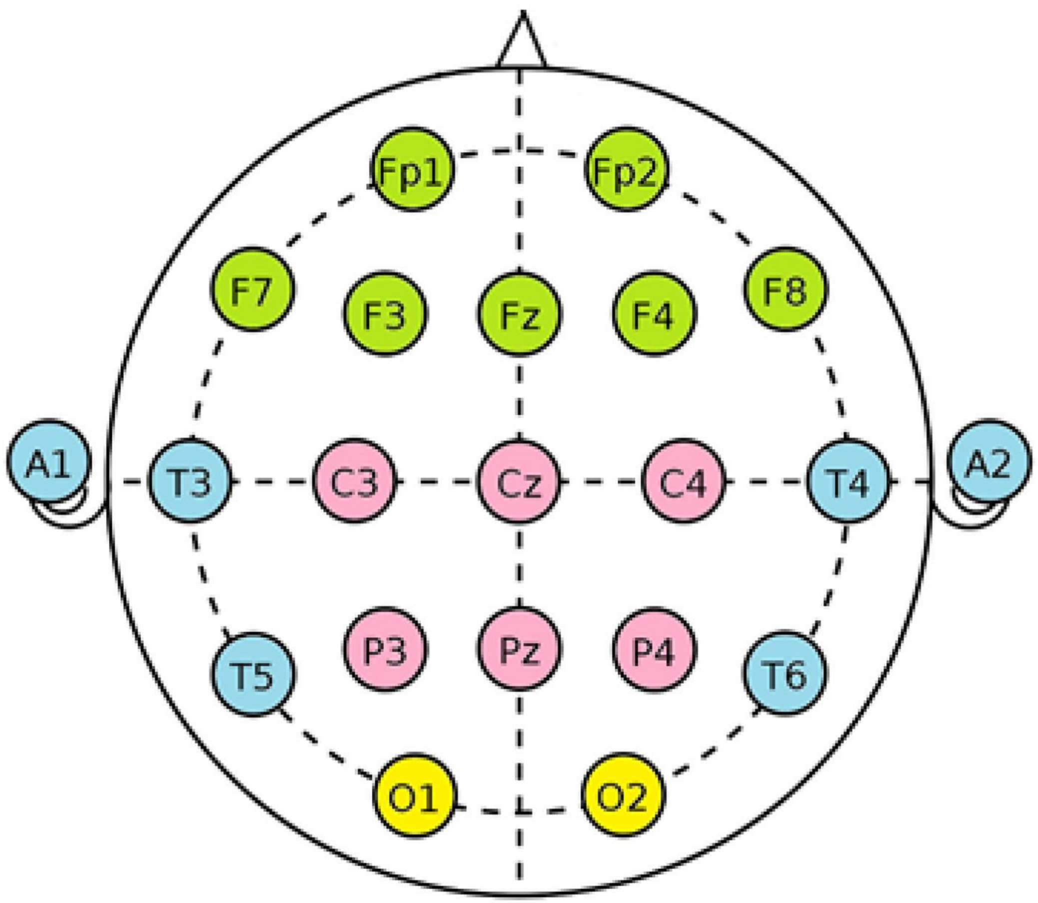
Disadvantages of water electrodes

- 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.

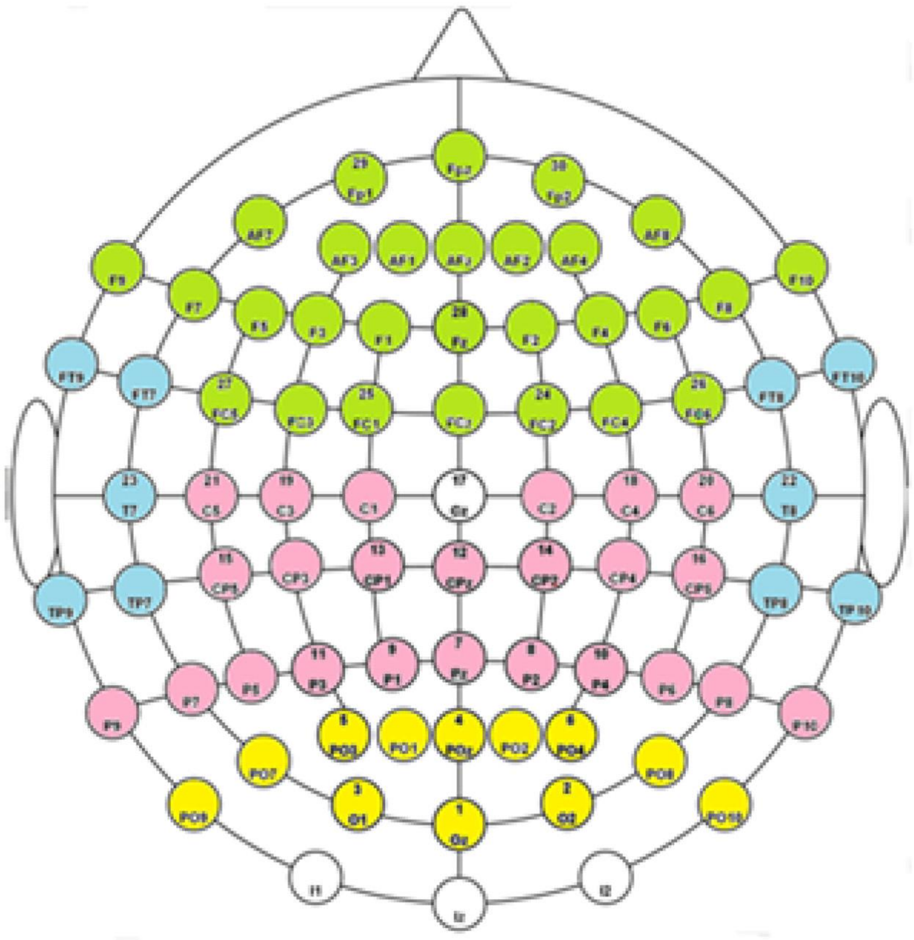
Water electrodes:

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



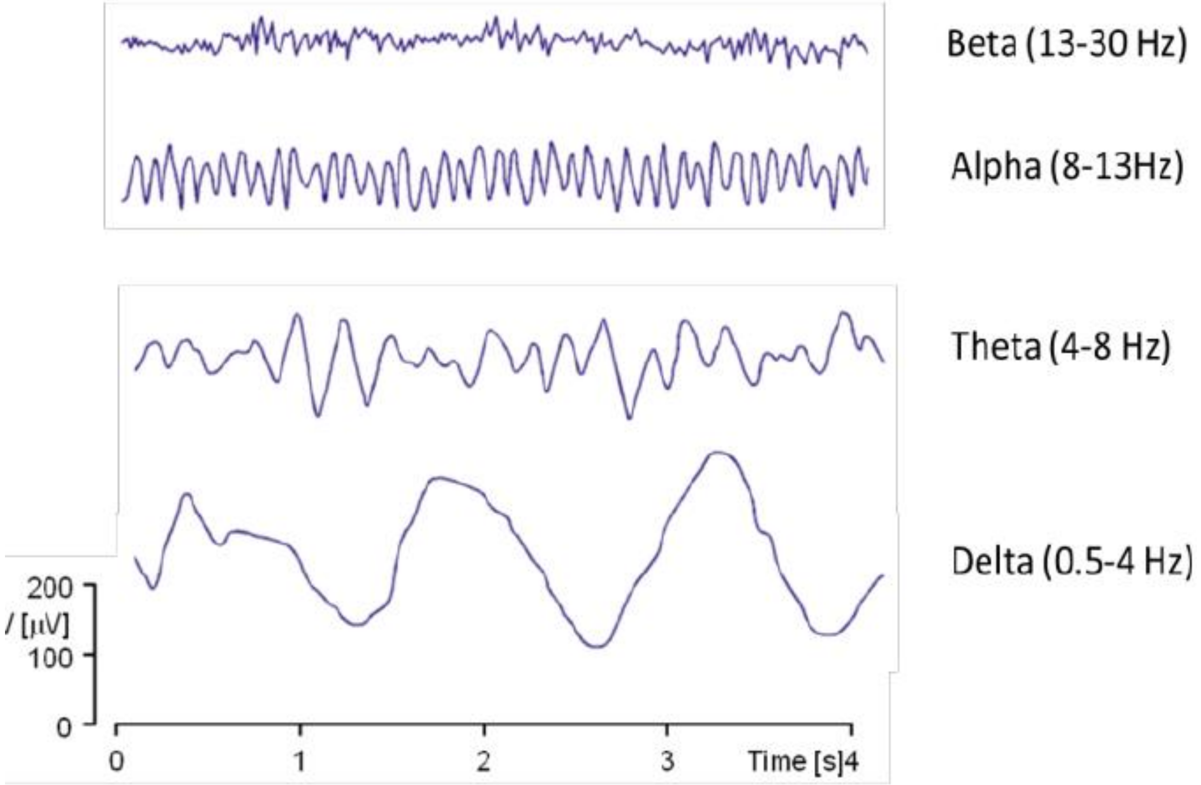
10-10 Electrode System

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.

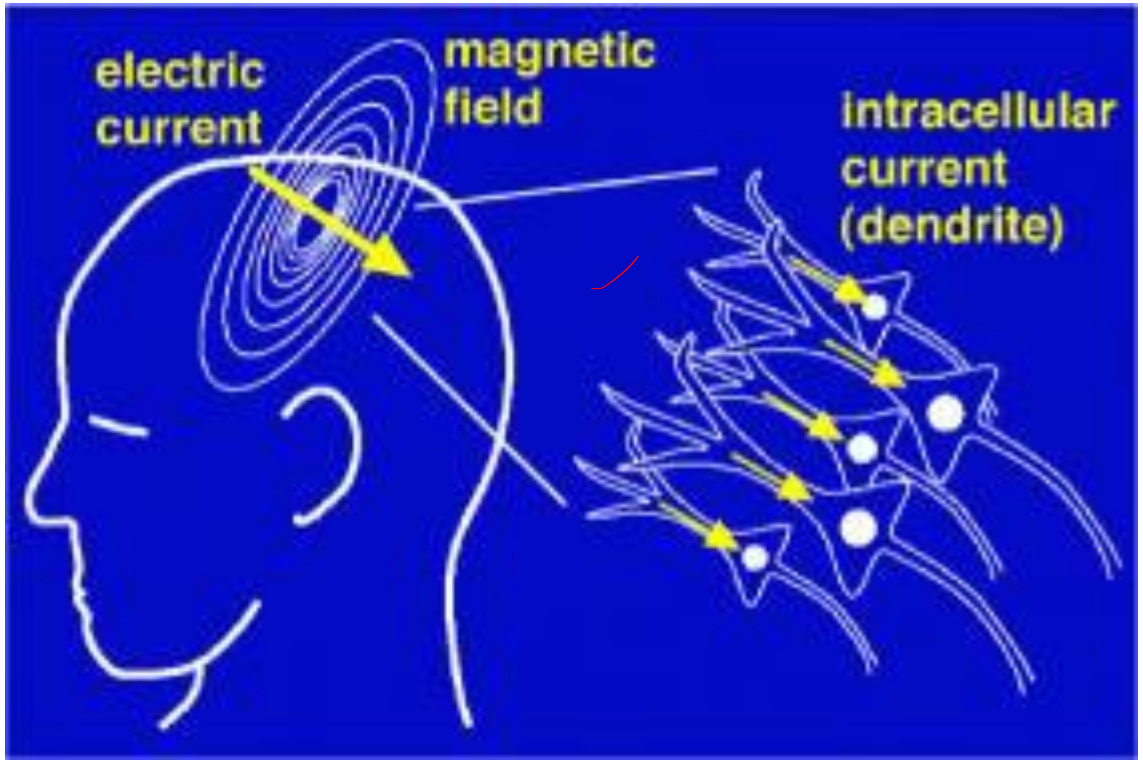
- EEG recordings are well-suited to capturing oscillatory brain activity or "brain waves" at a variety of frequencies
  - Alpha waves (8 to 13 Hz)
  - Beta waves (13 to 30 Hz)
  - Delta waves (0.5-4 Hz)
  - Theta waves (4-8 Hz)
  - Gamma waves (30-100 Hz or more)



Non Invasive Approaches

Magnetoencephalography (MEG):

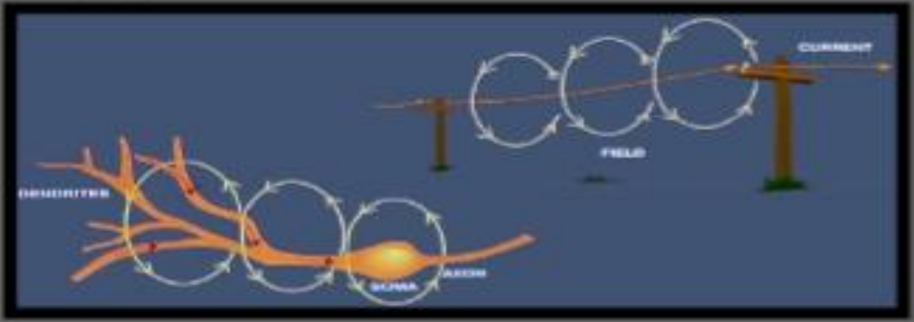
- Measures magnetic fields produced by activity of thousands of cortical neurons oriented perpendicular to the cortical surface
- Magnetic fields not distorted by skull and scalp
- Better spatial resolution than EEG
- Expensive and bulky
- Magnetically shielded rooms



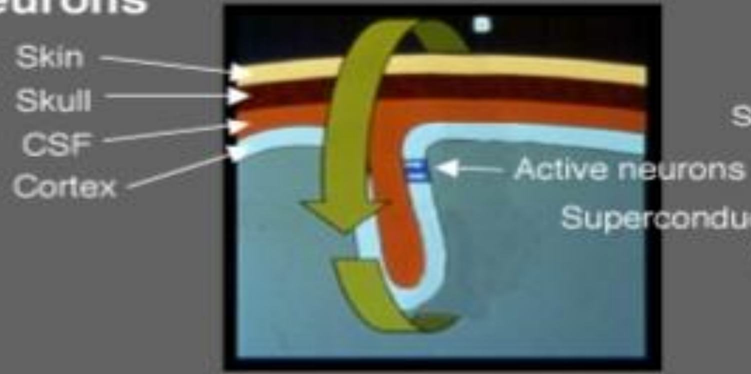
(image A: Wikimedia Commons;
image B: http://dateline.ucdavis.edu/photos_images/dateline_images/040309/DondersMEGOle_W2.jpg).

Basic Principles of MEG

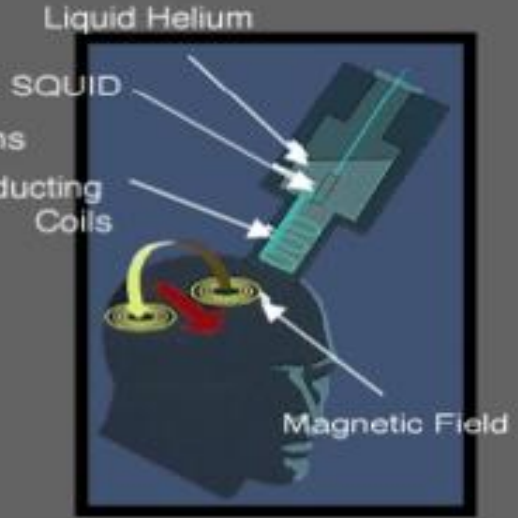
Sources of Magnetic Fields



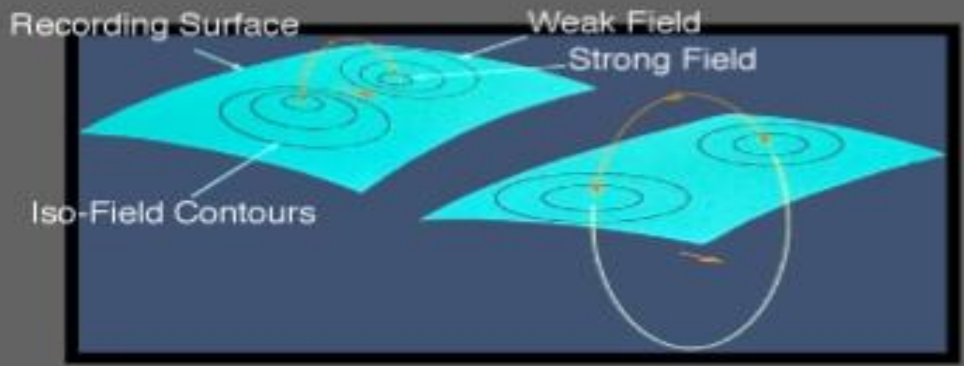
Orientation of Neurons



Detection Device

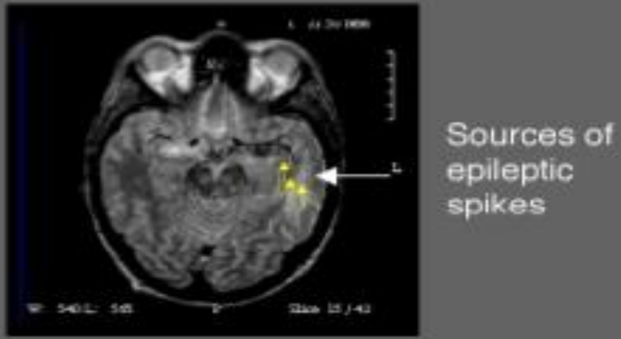


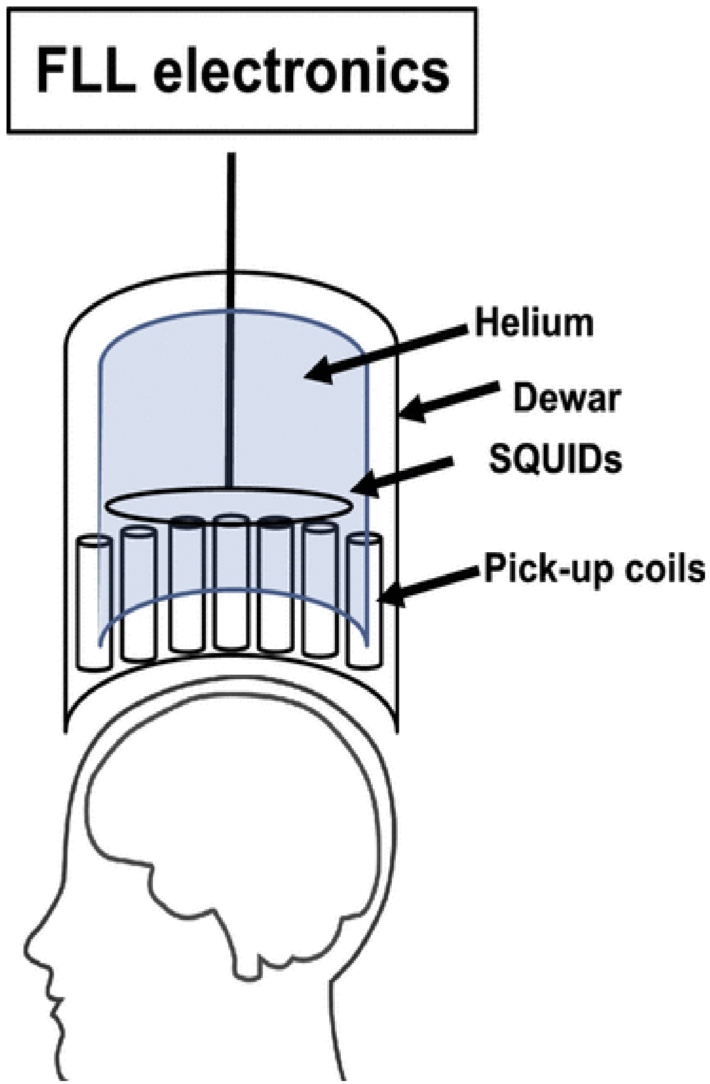
Magnetic Field Pattern



Model

Result





- 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

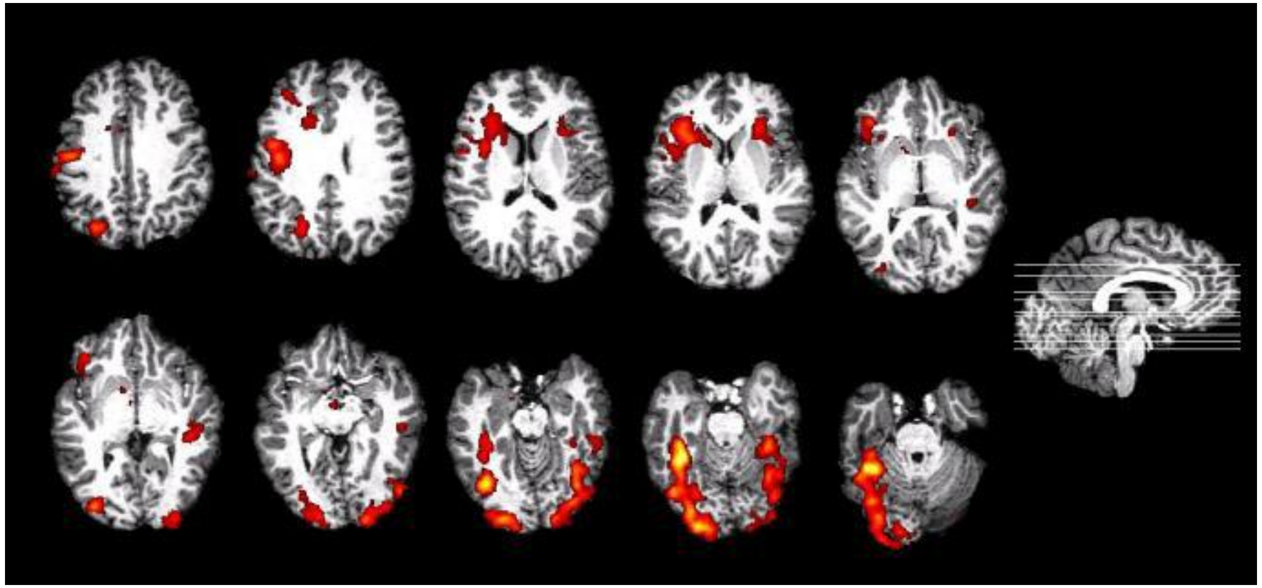
Non Invasive Approaches

<u>Functional Magnetic Resonance Imaging (fMRI) :</u>

- 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).

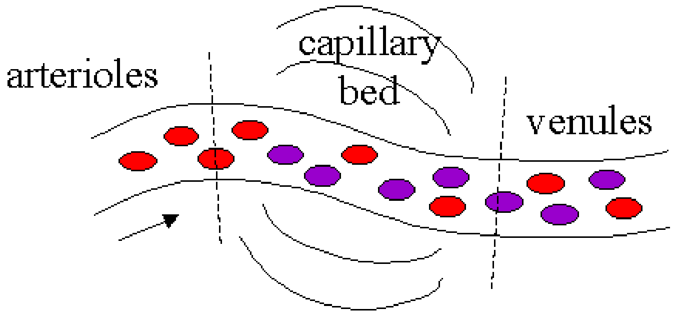


Example fMRI Images (word reading task)

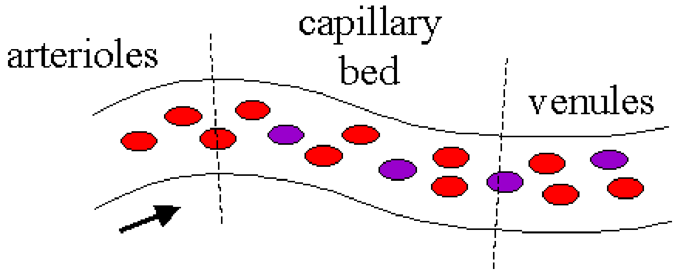
Blood Oxygen Level Dependent (BOLD) Signal

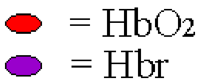
↑neural activity ➔ ↑ blood flow ➔ ↓ deoxyhemoglobin ➔ ↑ MR signal

Basal state



Activated state





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

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

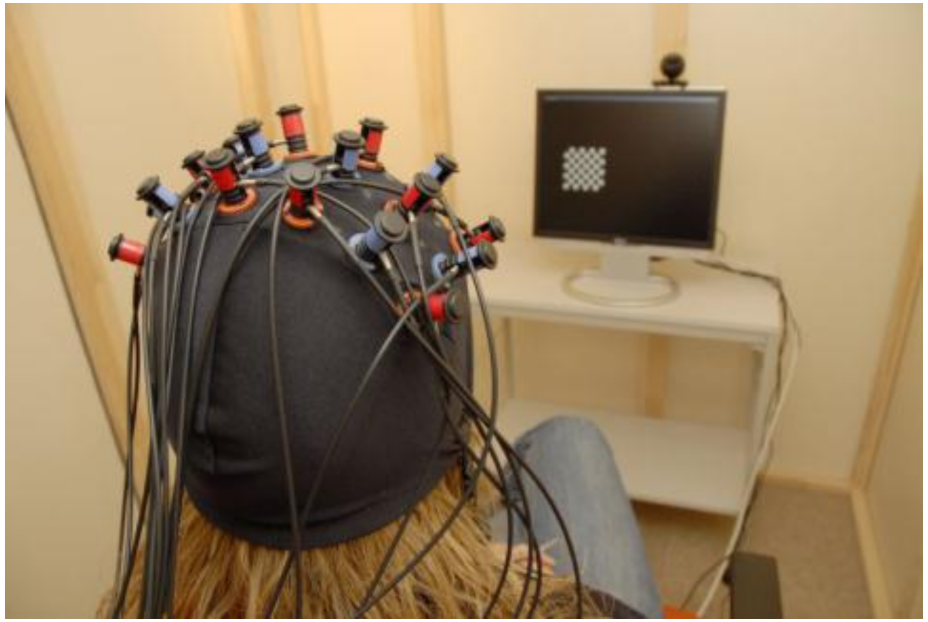
- **CBV:** Cerebral Blood Volume
- **CBF:** Cerebral Blood Flow
- **HBr:** Deoxy- Hemoglobin

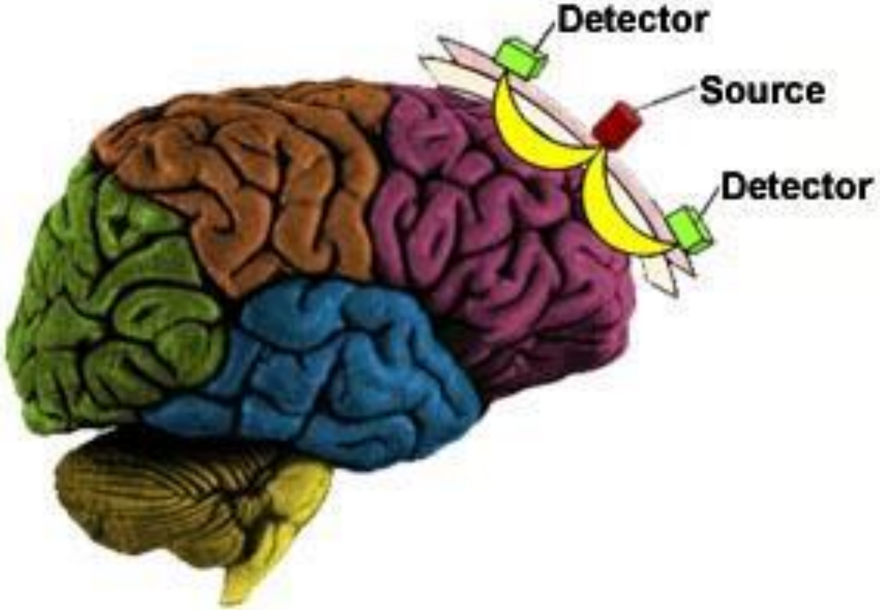
Source: Jorge Jovicich

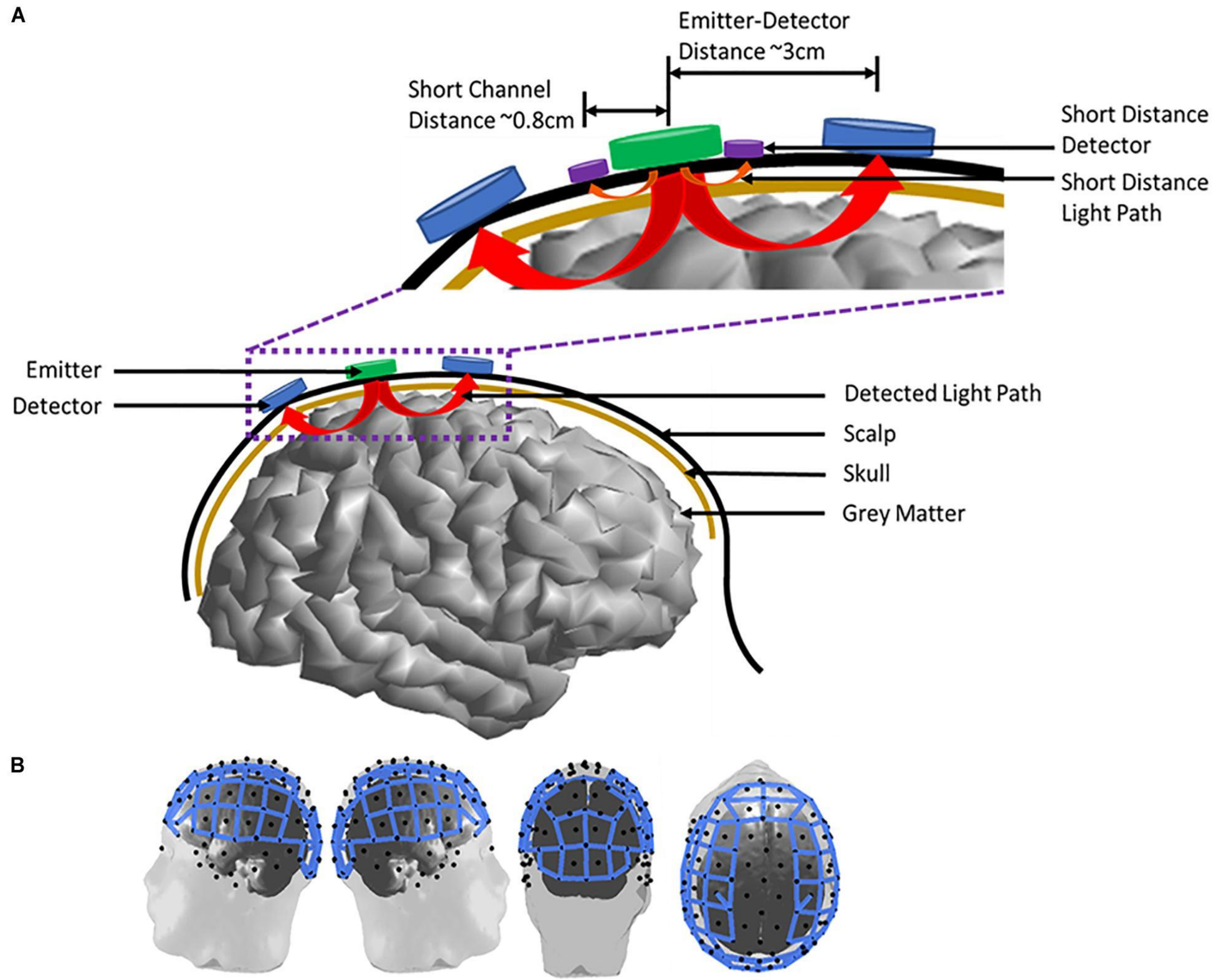
Non Invasive Approaches

Functional Near-Infrared Spectroscopy (fNIRS)

- 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.

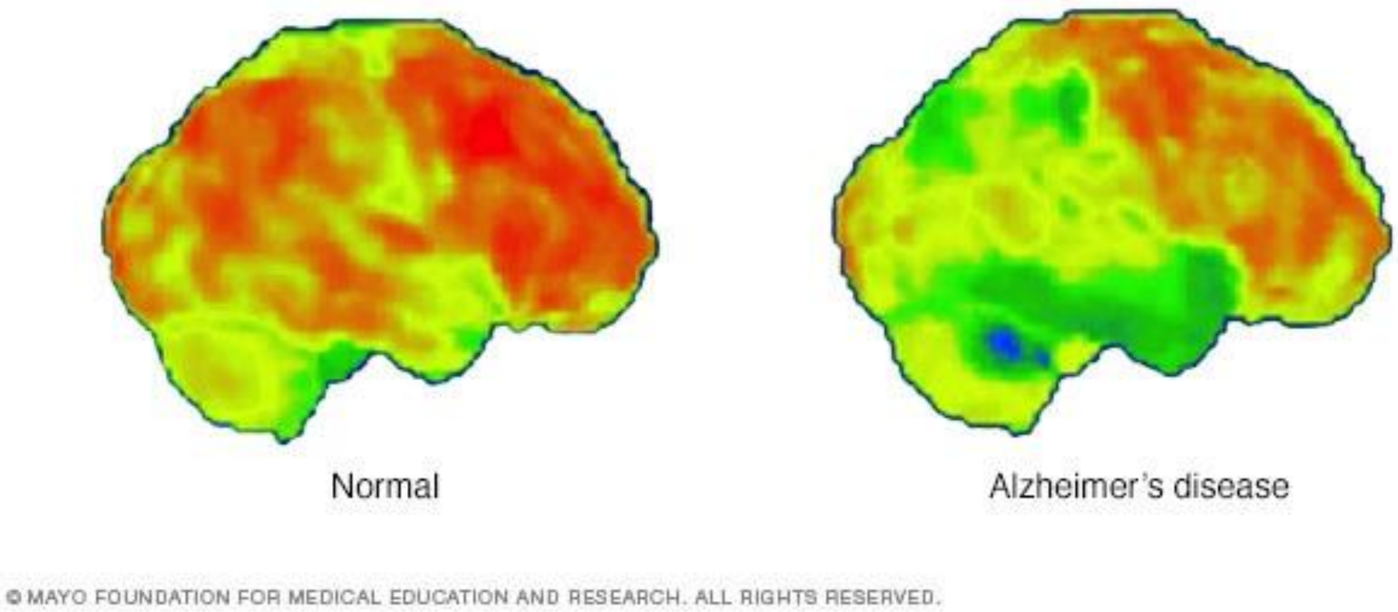
Non-Invasive Approaches

- **Positron Emission Tomography (PET):**

What does a PET scan check for?

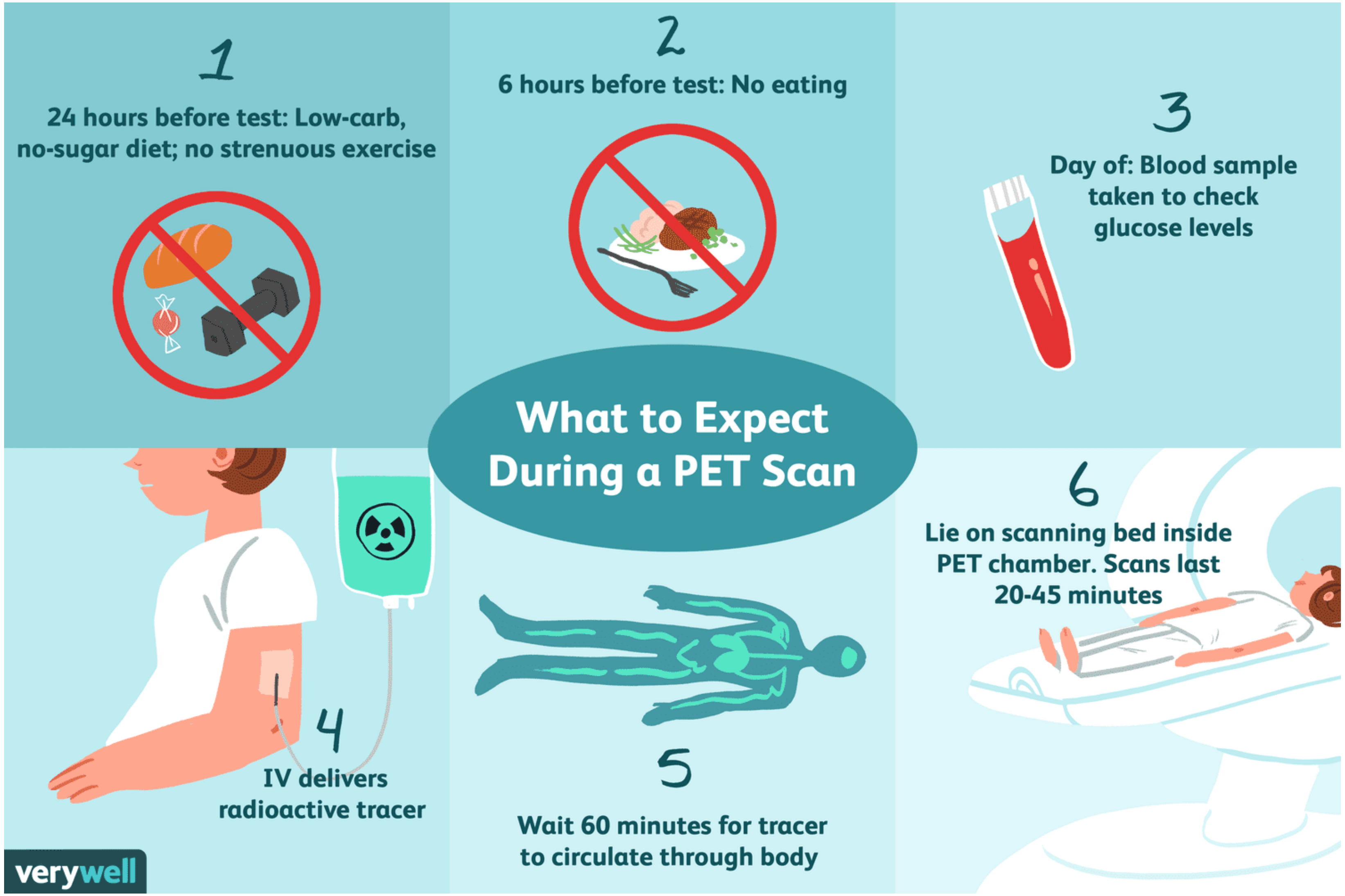
- Cancer, including breast cancer, lung cancer and thyroid cancer.
- Coronary artery disease, heart attack or other heart problems.
- Brain disorders, such as brain tumors, epilepsy, dementia and Alzheimer’s disease.

Positron Emission Tomography (PET):



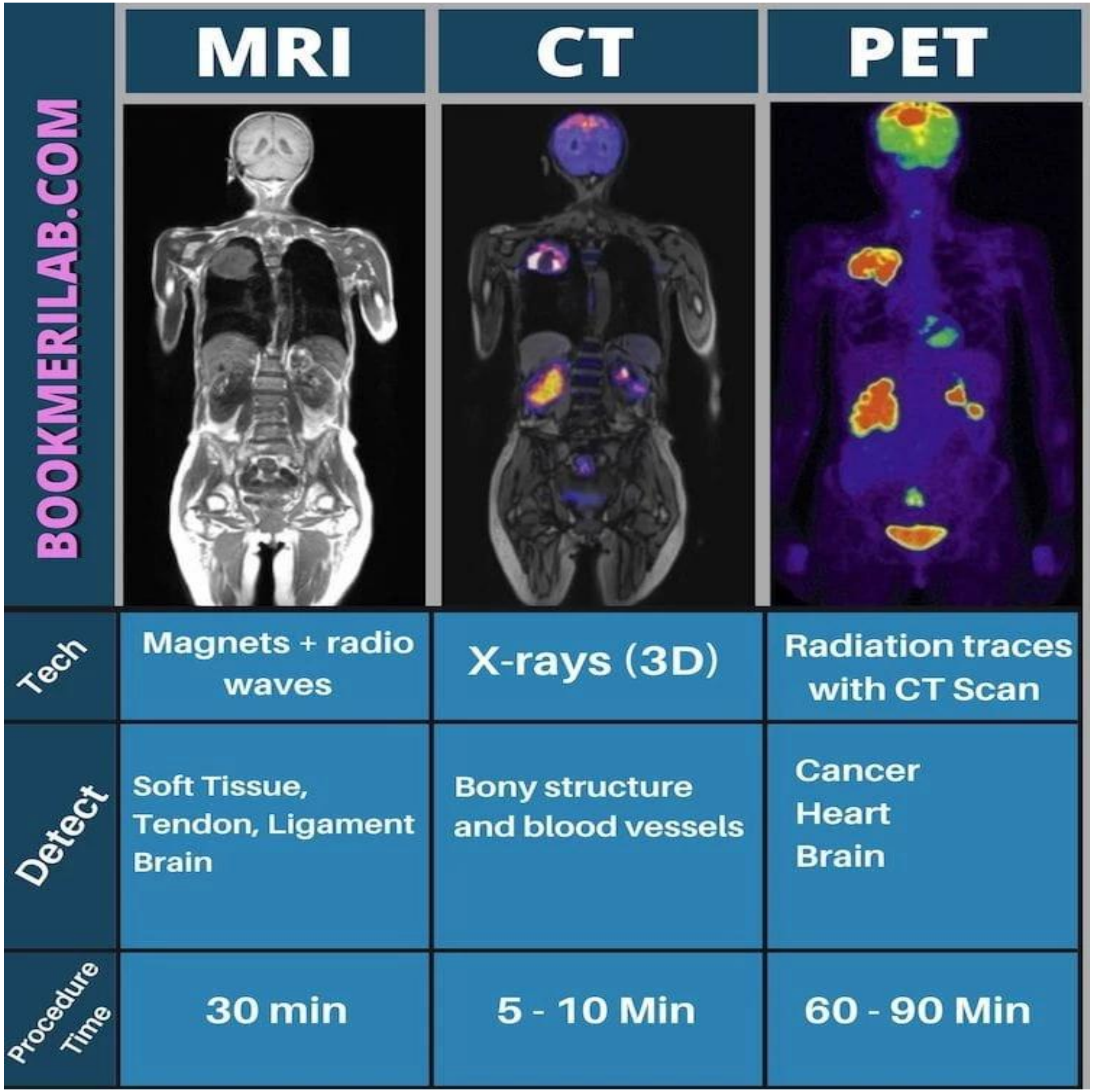
A PET scan can compare a normal brain (left) with one affected by Alzheimer's disease (right). An increase in blue and green colors shows decreased brain metabolic activity due to Alzheimer's disease.

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



Source: Internet

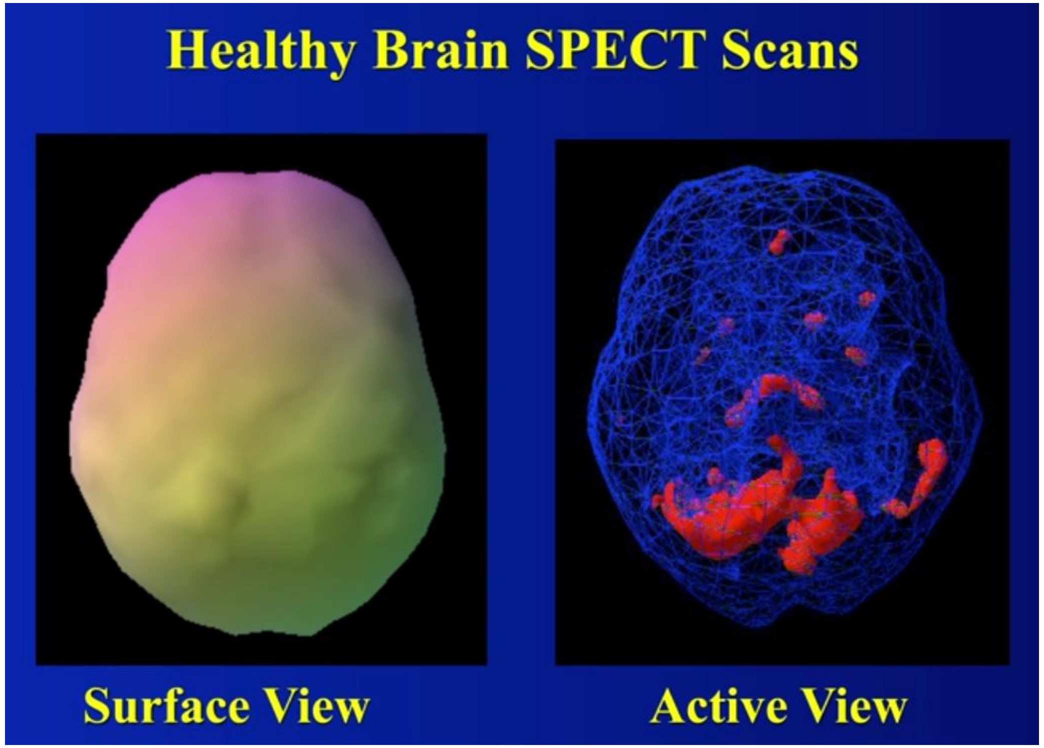
<u>Comparison between MRI, CT and PET Scan</u>



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.



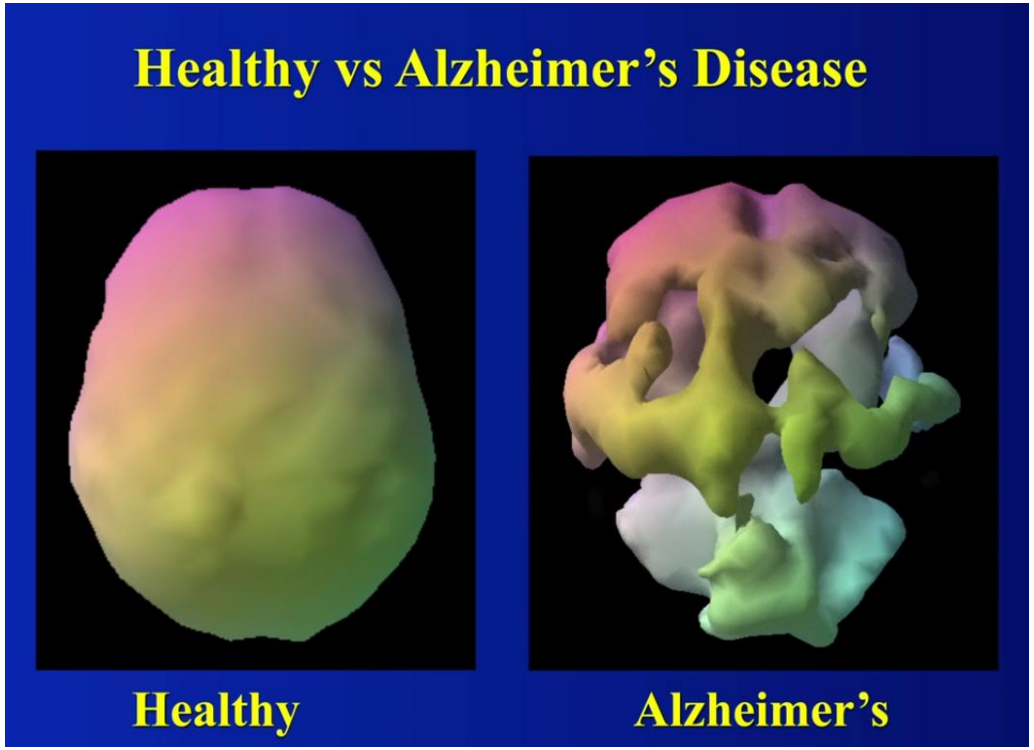


Image credit: https://hamnaqasim.medium.com/brain-scans-a-lesson-to-learn-9dfe67abd841

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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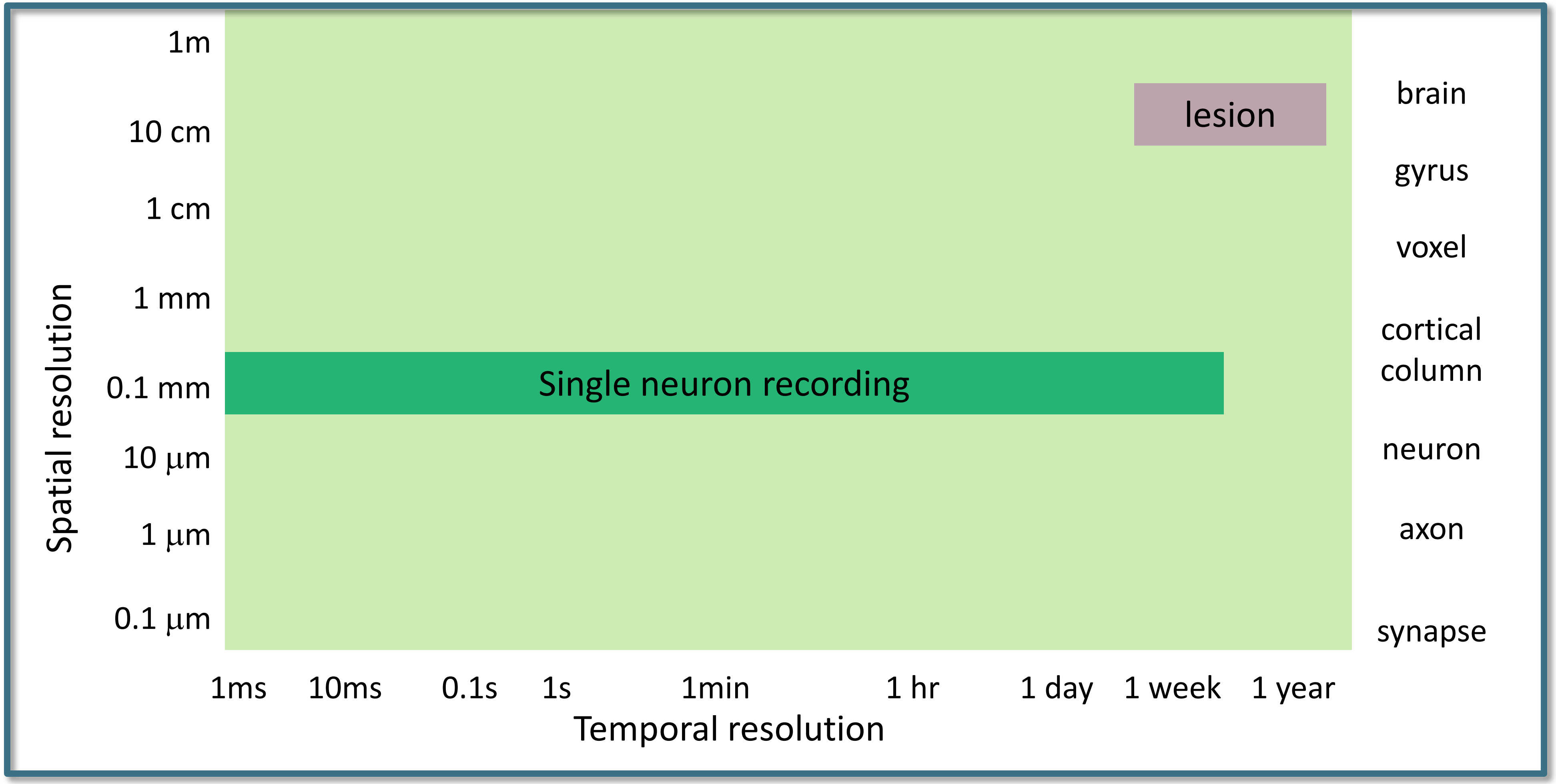

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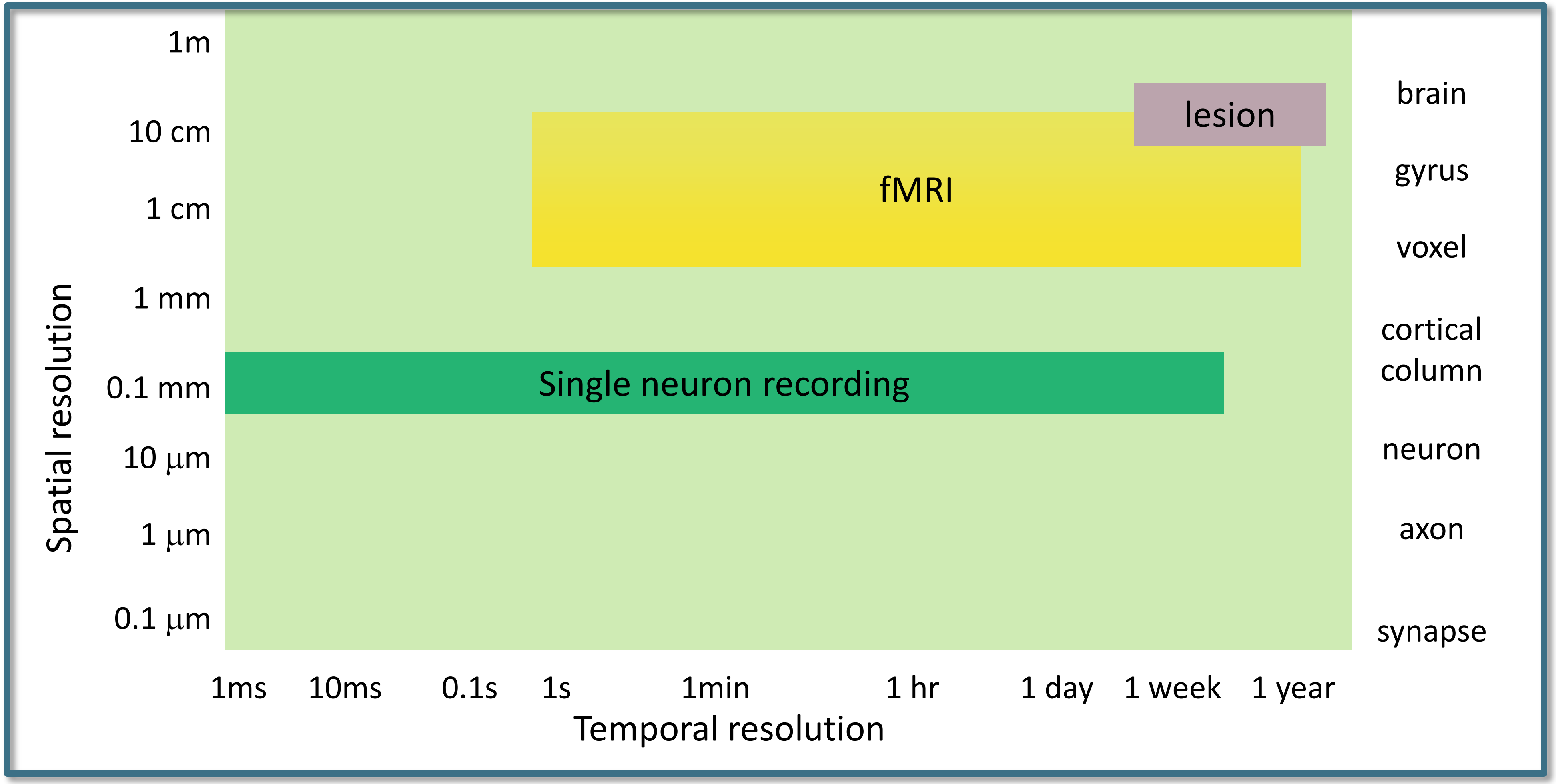

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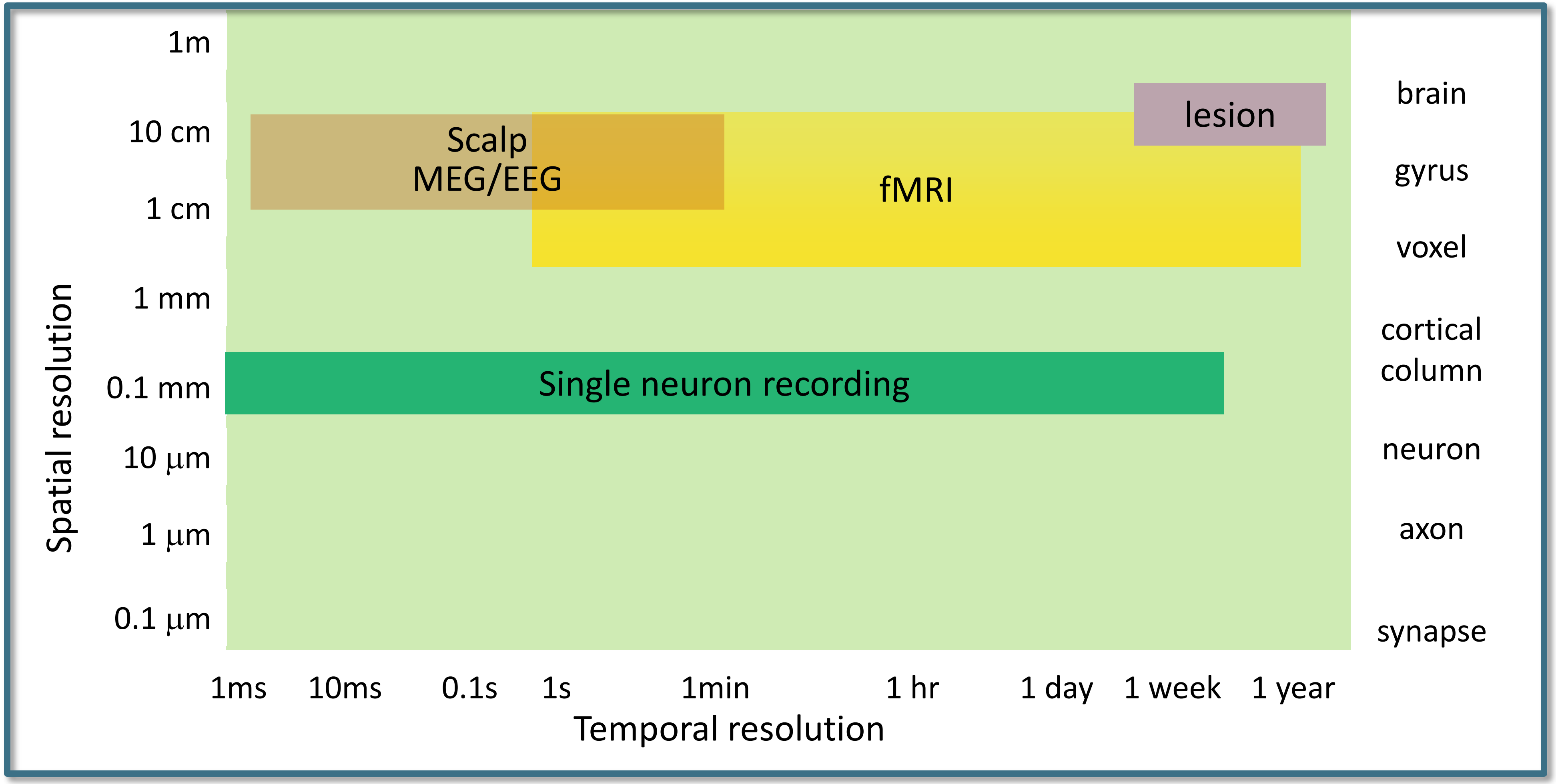

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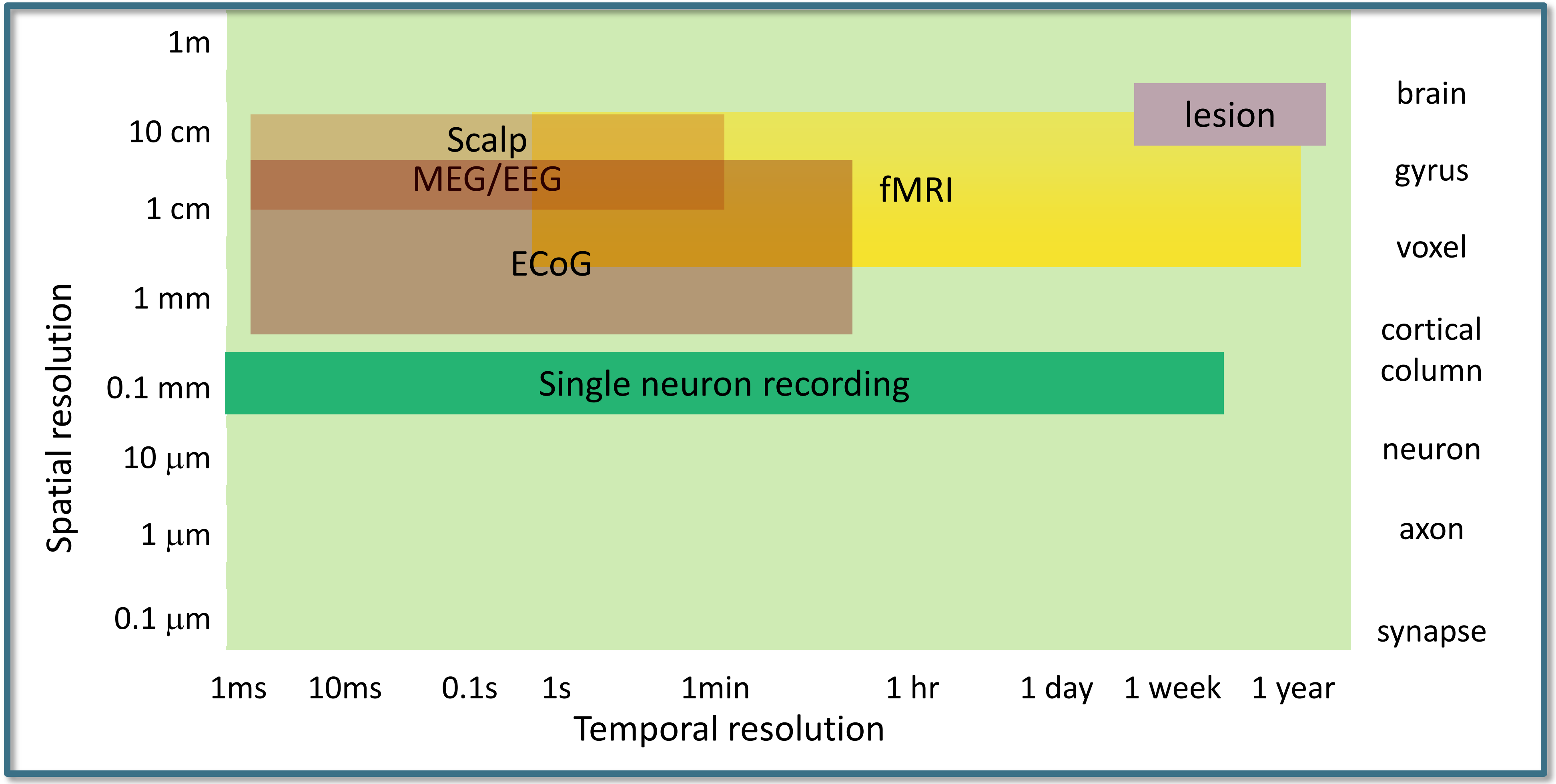

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