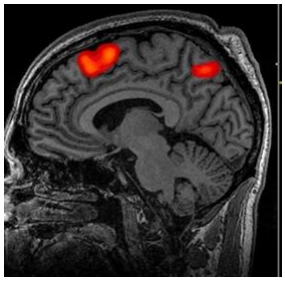
Module 1

How do we measure neural activity?

- Direct vs indirect methods
  - Brain activity can be measured using direct or indirect methods
  - **Direct methods** directly measure electrical activity generated by neurons in real time (with ms precision)
    - Direct measures include
      - Action potentials
      - Electrical changes, and
      - Extracranial voltage
  - Indirect measures track changes that happen because active neurons require oxygen and energy. By tracking their use in different parts of the brain, we obtain an *indirect* measurement of brain activity
    - Indirect measures include tracking
      - Blood flow
      - ATP
      - Blood oxygenation
- fMRI
  - fMRI provides structural and functional data by measuring localized haemodynamic changes
    - It is non-invasive, unlike PET scans, and allows for human-centric studies
    - It offers high *spatial resolution* compared to EEG
- How does fMRI work?
  - How MRI process work?
    - The setup requires a high-strength magnet (usually 1.5-3 Tesla), a radiofrequency coil, and a head coil
      - Images are produced by mapping white and grey matter based on water content



    - The physics relies on hydrogen ions, which have a single proton spinning on a random axis
      - When placed in a magnetic field, these protons align either parallel or anti-parallel
      - A radiofrequency pulse shifts this axis of orientation; when the pulse is turned off, the protons return to their original orientation and release energy
    - Areas with higher energy signify more H ions and more water, which indicates increased blood flow
      - Tissues need more oxygen to power the Na+/K+ pump to maintain ion concentrations in the ICF and ECF

The BOLD Response

- Magnetic properties of blood + MRI signal
    - fMRI relies on the fact that oxygenated and deoxygenated blood have *different magnetic properties*
        - **Oxygenated blood** is weakly diamagnetic, and therefore, causes *minimal distortion* of the local magnetic field
        - **Deoxygenated blood** is *paramagnetic*, and therefore, it *distorts the surrounding field*
            - These distortions change the MRI signal (especially the T2-weighted signal), causing *faster signal decay*
- Inferring neural activity from haemodynamic changes
    - Active neurons use more energy, since ATP must be 'spent' to restore the electrochemical gradient after action potentials are fired
    - Because energy use increases, the heart must send more oxygenated blood to active parts of the brain
        - Thus, *cerebral blood flow* increases
    - However, there is an *oversupply* of oxygenated blood; the active neurons are supplied with more blood than they actually require
        - More oxygenated blood = less signal distortion of the magnetic field → this results in a *stronger BOLD signal*
- The BOLD signal
    - This BOLD signal reflects changes in the balance of oxygenated (weakly diamagnetic) and deoxygenated (paramagnetic) haemoglobin
    - fMRI is particularly sensitive to changes in *deoxyhaemoglobin* because it disrupts the magnetic signal more strongly
        - In fMRI, *activation* refers to a *significant increase in the BOLD signal*, and indicates *increased neural activity*
- Spatial smoothing
    - **Spatial smoothing** = where signals from neighbouring voxels are *averaged out*, in order to improve the *signal/noise ratio*
    - This helps to reveal *consistent activation patterns*, especially when comparing brain activity across different subjects

What are the limitations of fMRI?

- fMRI is *not a direct measure of neural activity*
    - Changes in blood flow can be *mislocalised* For example, signals may appear *downstream* from the actual site of activity due to blood flow through vessels
    - Vascular responses reflect multiple changes (eg blood velocity, volume fraction or red blood cells) which all influence the BOLD signal
    - This makes interpretation *imperfect*