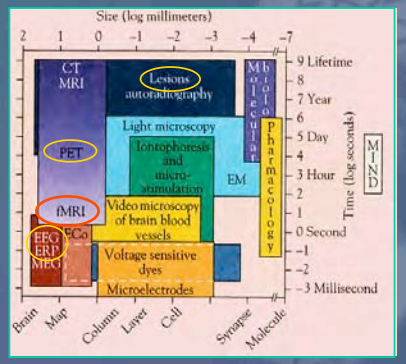
How to study the neural basis of human vision?

What should the ideal technique be like?

- High Temporal Resolution
- High Spatial Resolution
- Should cover a large extent of the brain
- Sensitive
- Safe

What techniques are available?

- Neuropsychology (Brain lesions)
- EEG, MEG
- PET
- fMRI



Brain Lesions

As a result of traumas, surgery, infarcts, or diseases

-Case of <u>prosopagnosia</u>

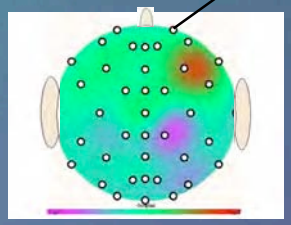
<u>Main advantage:</u> causality

<u>Disadvantages</u>

- Necessity, but not sufficiency
- Specificity (multiple/extensive lesions may lead to more than one deficit)
- Plasticity (neural reorganization complicates interpretation)
- Rarity (only very few cases may exist)

EEG

(Electro-EncephaloGraphy)



MEG

(Magneto-Encephalography)

EEG and MEG have great temporal resolution, but...

- **Poor spatial localization/resolution**
  (restricted mostly to cortex, issue of the inverse problem)
- **Weak signal (need hundreds of trials)**

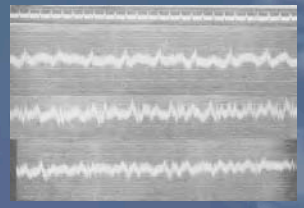
Neuroimaging (PET, fMRI)

Provide an indirect link between neural activity and behavior:

The indirect link is Vascular response to neural activity

Your brain is like a muscle

Dr. Fulton's case (1920s)

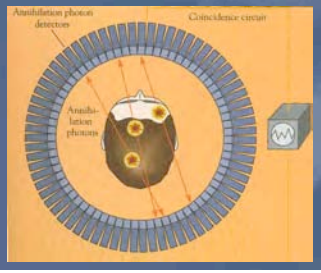


PET

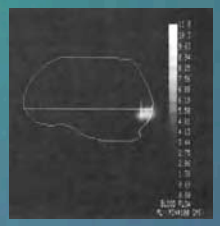
(Positron Emission Tomography)

Radio-isotope: O^{15}

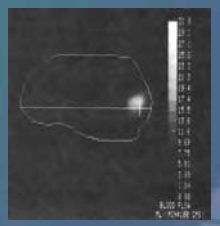
(Bolus Injection of H_2O^{15})



Results



Foveal stimulation



Peripheral stimulation

Fox et al (1986)

Advantage: has relatively good spatial resolution (order of cms)

Disadvantages

- Injection of Radioactive Isotopes
  - Cannot use same subject repeatedly
  - Needs to combine results from several subjects
  - No developmental studies
- Poor temporal resolution (40secs)!
- Expensive! (cyclotron)

fMRI

(functional magnetic resonance imaging)

Advantages

- Harmless
  - Can use same subject repeatedly
  - Can look at single subject data (Individuality!)
    or can combine subjects together (population analysis)
  - Developmental studies allowed!
- Much better temporal resolution (about 1sec)
- Better spatial resolution (less than 1 cm)
- Much more accessible, affordable.
- Can get both anatomical and functional data in the same session

Some disadvantages

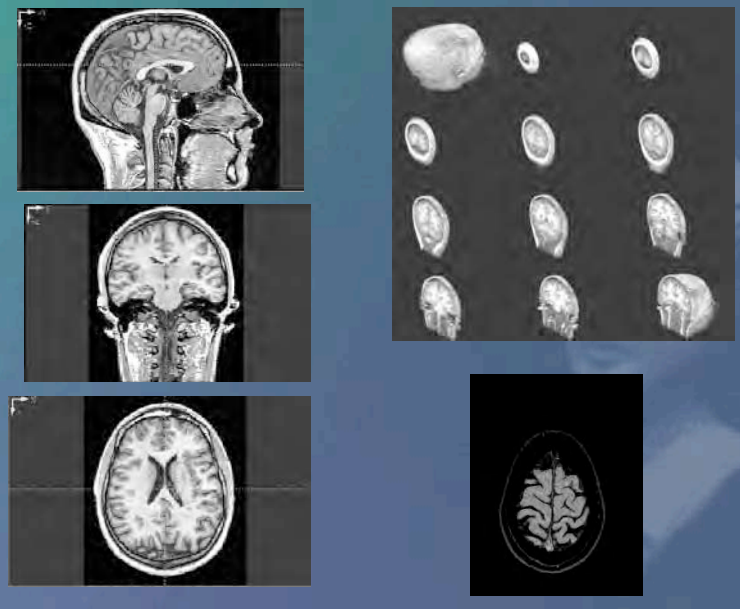
MRI is noisy...

…and magnetic!...

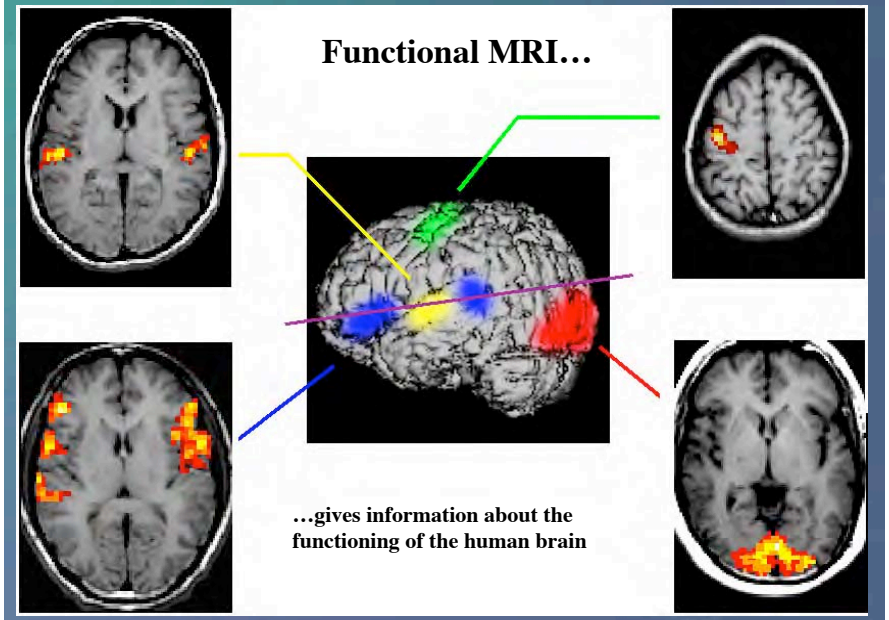
...and can be claustrophobic

MRI can give images of both the anatomy and the physiology of the human brain

MRI gives great images of the anatomy of the human brain



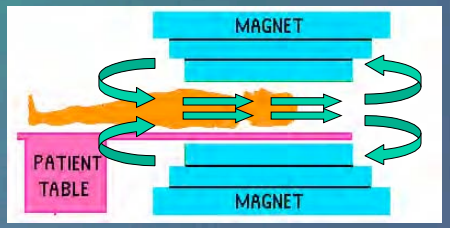
Functional MRI…



…gives information about the functioning of the human brain

How does MRI work?

The scanner is essentially a large magnet

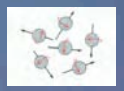


x 30,000 times that of the earth (for 1.5T)

The scanner and its associated hardware is responsible for both generating the magnetic field and detecting how it is affected by brain tissue.

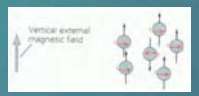
Without an external magnetic field:

Atoms (mostly H protons) in water normally spin and precess (wobble) in all directions in the body



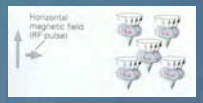
With an external magnetic field (provided by the scanner):

H atoms in water align their axis of precession (provided by the scanner)



Just like iron fillings around a bar magnet

An electromagnetic pulse (RF) emitted by the scanner creates a transient magnetic field that is transverse to the basal magnetic field. This RF pulse flips the angle of precession of the H atoms.



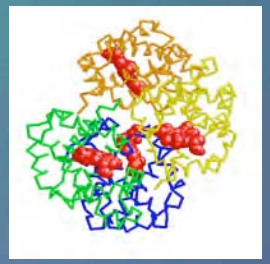
The scanner measures the strength of the electromagnetic signal produced by the flipped atoms as they return to their basal state.

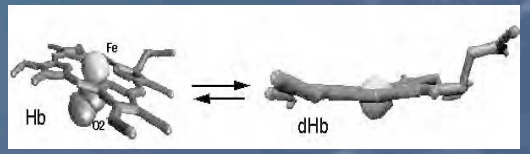
Various concentrations of different atoms in brain tissues affect the magnitude of the magnetic field differently

This leads to different signal intensities in different brain tissues.

How does fMRI work?

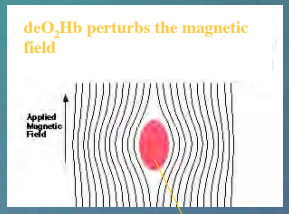
Alignment of the subject's H atoms in the magnetic field are affected by the relative concentration of deoxyhemoglobin/oxyhemoglobin in the brain.





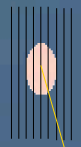
DeO_2Hb, relative to O_2Hb, perturbs the magnetic field, making it less homogeneous.

deO_2Hb perturbs the magnetic field



deO_2Hb

O_2Hb does not affect the magnetic field

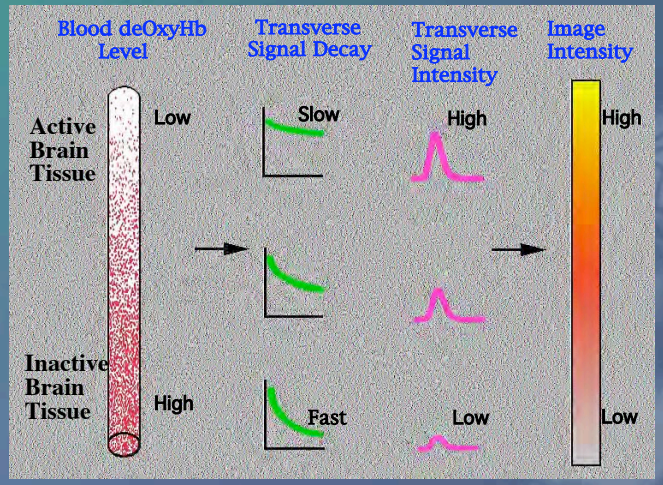


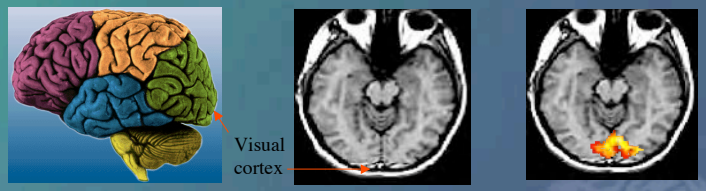
O_2Hb

The strength of the transverse (flipped) signal depends on the homogeneity of the magnetic field

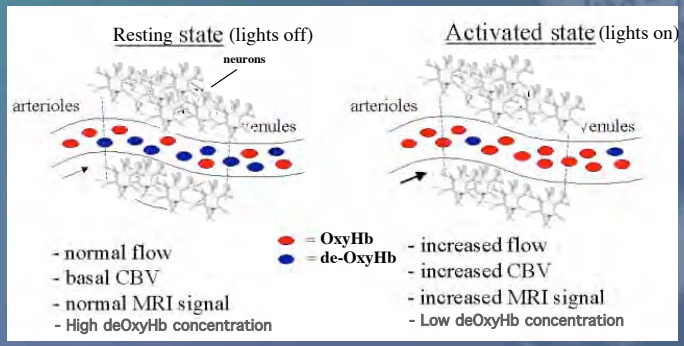
Heterogeneity in the magnetic field decreases the transverse (flipped) signal

Hence, the transverse signal is smaller when the concentration of deOHB is high.





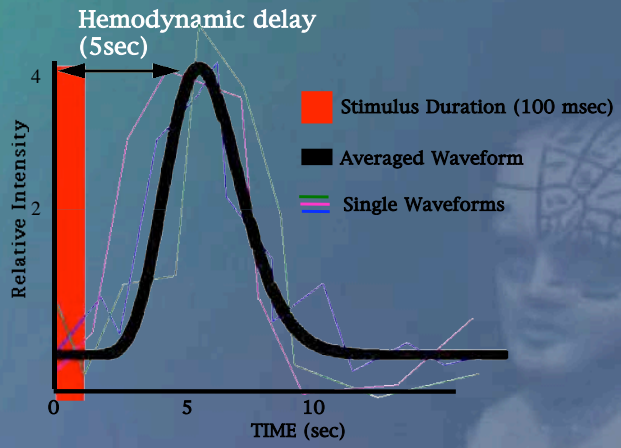
Looking at the physiological response to visual stimulation



The wash-out of deOxyHb from activated brain regions leads to greater magnetic field signal intensity

Spatial and Temporal Characteristics of the fMRI signal

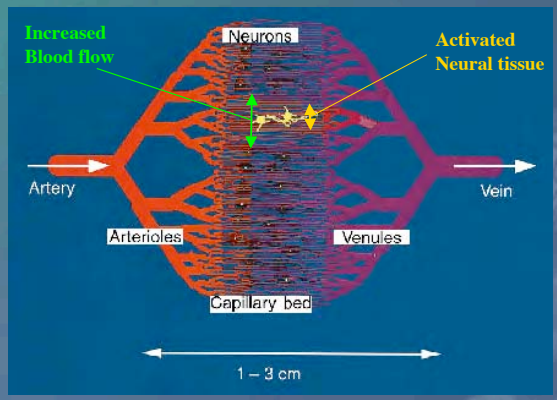
Temporal Characteristic (Hemodynamic Response)



Temporal resolution of fMRI signal is mostly limited by the sluggishness in the hemodynamic response to the stimulus presentation.

Using some clever experimental tricks, temporal resolution may be less than 1 second

Spatial Characteristics

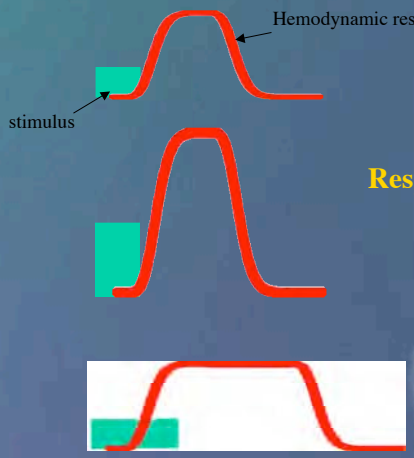


Spatial Resolution of fMRI is mostly limited by the hemodynamic spread of activation.

'Watering the whole garden for the sake of one thirsty flower'.

Spatial resolution is in the mm range

What is the coupling between neural activity and BOLD signal?



Response linearity

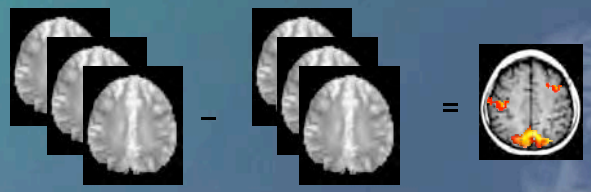
Most significant limitation of fMRI:

signal is small (about 1 %)

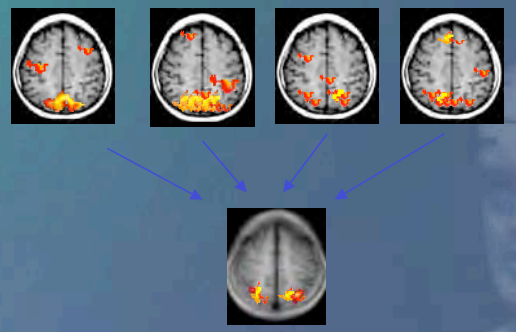
Why?
- Indirect measure of activation
- Physical and physiological Noise
  - Fluctuations in hardware (magnetic field, signal drift, etc…)
  - Random motion of ions in body tissues
  - Head Motion (accidental, response-related)
  - Cardiac Cycle
  - Respiratory Cycle
  - Subject Variability

Solution: To increase signal, take several pictures of the brain

Single subject Data



Group Average Data



Why combining subjects?

1) to increase statistical power
2) to make population-wide inferences

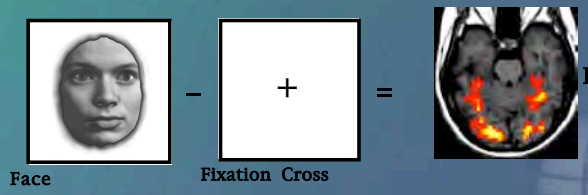
Important Experimental Design Issue

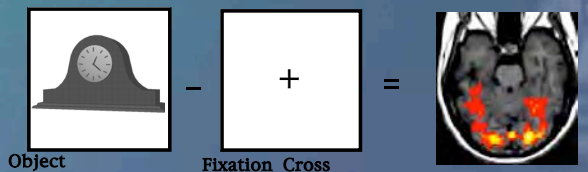
How to isolate brain areas involved in specific functions ?

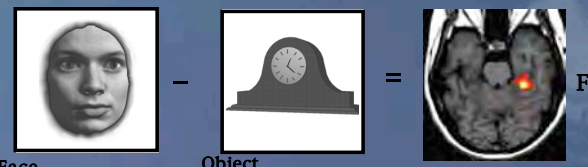
Subtraction

Compare two or more tasks to each other.

Example: How to find out if there is a place in the brain that preferentially responds to faces?



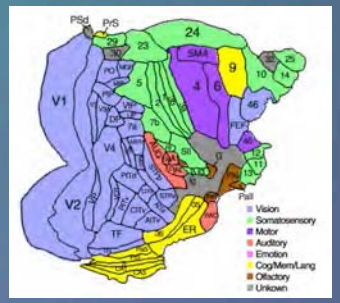




What can you study about the visual system with fMRI?

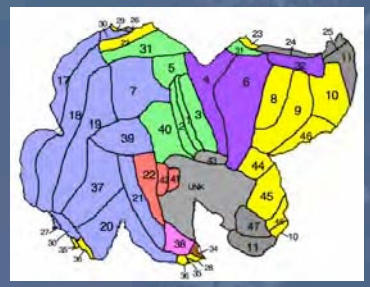
Visual areas

A large portion of the primate brain is devoted to vision

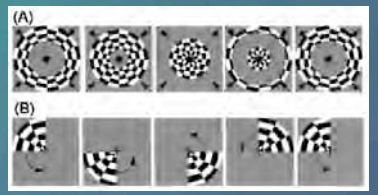


About 30 visual cortical regions

So it appears in humans



The topographic(retinotopic) organization of several human visual cortical areas can be mapped with fMRI

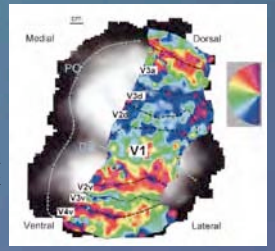


Eccentricity representation

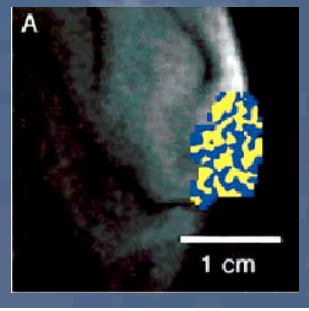
Angular representation

Even the columnar structure of visual cortex?

Flattened cortex

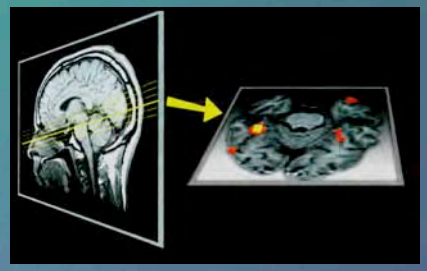


> 8 regions

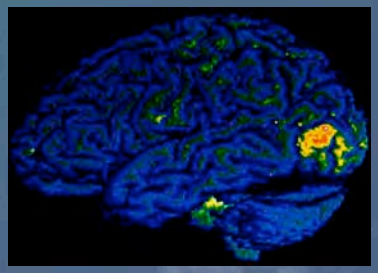


We can look also at higher-level visual areas

Faces

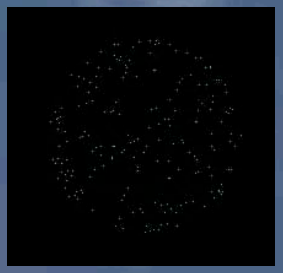


Motion



And even higher-level stuff….

e.g. spatial attention



Future Developments

1) Stronger magnets
2) Improving Temporal Resolution (EEG + fMRI)

fMRI is very powerful, but it is not the end all and be all technique.

It is primarily a correlational technique: it does not reveal causal relationship between brain and behavior.