Outline for Today

fMRI Contrast Mechanisms and pulse sequences

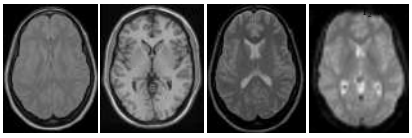
- BOLD contrast
- Fast Imaging sequences for fMRI Image Acquisition
- Motion-weighted contrast:
  - Flow weighted Contrast
  - Perfusion Weighted Contrast
  - Diffusion Weighted Contrast

Functional Magnetic Resonance Imaging, Huettel, Chapter 5

Dr Sue Francis, SPMMRC,
email: susan.francis@nottingham.ac.uk

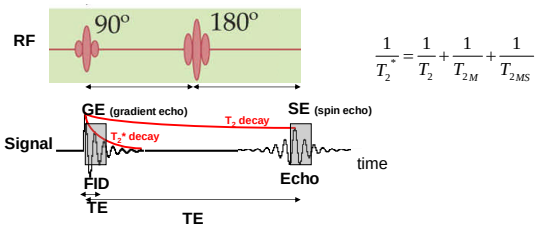
MRI Review

- based on the NMR phenomenon
- large magnetic field and radio waves
- image water distribution
- can select contrast weighting based on water content (PD) and relaxation mechanisms (T_1, T_2, T_2*)



PD T_1 T_2 T_2*

T_2 vs T_2*



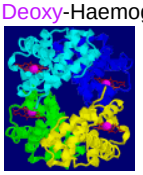
$$\frac{1}{T_2^*} = \frac{1}{T_2} + \frac{1}{T_{2M}} + \frac{1}{T_{2MS}}$$

- Pure T_2 dephasing is intrinsic to sample (e.g. different for CSF and fat).
- T_2* dephasing includes true T_2 as well as field inhomogeneity (T_{2M}) and tissue susceptibility (T_{2MS}) and leads to rapid loss of signal.
- Susceptibility refers to the dephasing caused by the magnetic field-distorting effects of paramagnetic substances → **BOLD**

Red blood cells and Magnetism

- The Hemoglobin (Hb) Molecule
  - Haemoglobin is the oxygen-transport metalloprotein in the red cells.
  - An organic molecule containing four heme groups (with iron in each) and globular protein (globin).
- Oxygen Characteristics
  - No oxygen bound - deoxyhemoglobin (**dHb**)
  - Oxygen bound - oxyhemoglobin (**HbO_2**)
- Magnetic Properties

Deoxy-Haemoglobin

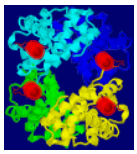


paramagnetic

different to tissue

$\Delta\chi$=0.08ppm

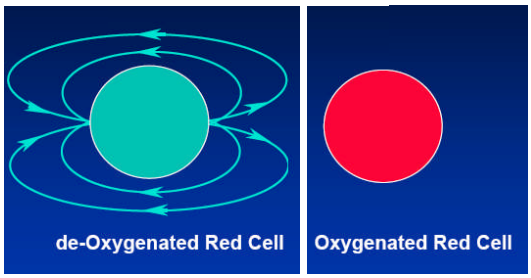
Oxy-Haemoglobin



diamagnetic

same as tissue

Magnetism and oxygenation state



An object with differing magnetic properties distorts the field

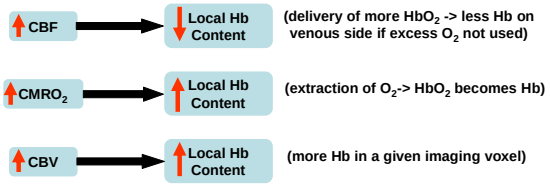
T_2* Contrast

- T_2* weighted images are sensitive to the amount of deoxygenated haemoglobin present.
- Brain regions become oxygen rich after neurons are active.
- This is termed the 'Blood Oxygenation Level Dependent' measure (**BOLD**) effect.

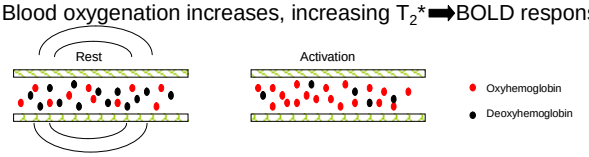
BOLD Physiology - Lecture next week

BOLD Effect

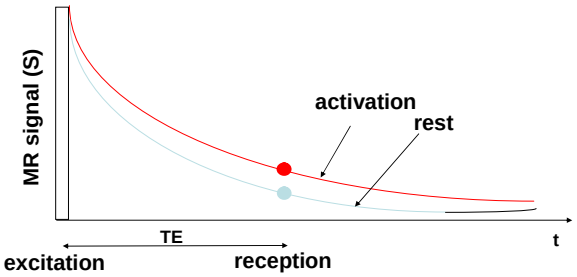
- Blood Flow (CBF), Blood Volume (CBV), and oxygen consumption ($CMRO_2$) have different effects on HbO_2 concentration:



- Blood oxygenation increases, increasing T_2* ➡BOLD response

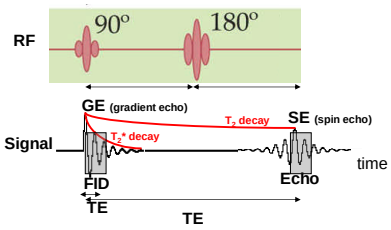


T_2* Effect = BOLD Effect

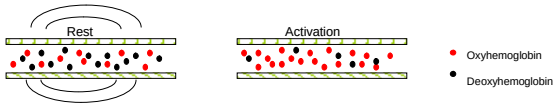


For optimal BOLD sensitivity use TE ~ T_2* grey matter

T_2 vs T_2*



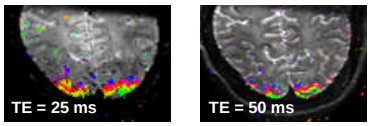
- On activation blood oxygenation increases leading to:
  - increasing T_2* - increasing BOLD response (diffuse signal change)
  - increasing T_2 – increasing BOLD response (localised signal change)



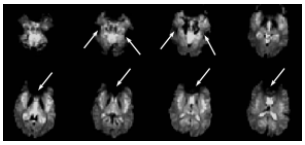
Gradient Echo vs Spin Echo BOLD

• Spin Echo eliminates effect of magnetic field inhomogeneities around large blood vessels, minimizing contaminating effect in fMRI images, but signal change is lower so GE BOLD typically used.

gradient echo (T_2)* *spin echo (T_2)*



• SE reduces susceptibility artifacts caused by magnetic field inhomogeneities near air-tissue interfaces in the brain, e.g. frontal and temporal lobes.



Fast Imaging sequences for fMRI Image Acquisition

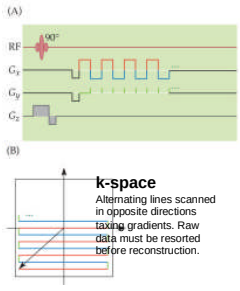
Echo Planar Imaging (EPI)

(Mansfield, University of Nottingham, 1977)

- Fast imaging technique
  - typically acquire image in a single shot (20-100ms)
  - trade off SNR and resolution for speed

• Entire k-space is filled using rapid gradient switching following a single excitation – therefore data must be acquired before significant T_2* or T_2 decay.

• EPI now most common fast imaging method for fMRI but requires a very strong gradient system - gradient technology was not common until late 1980s and early 1990s.

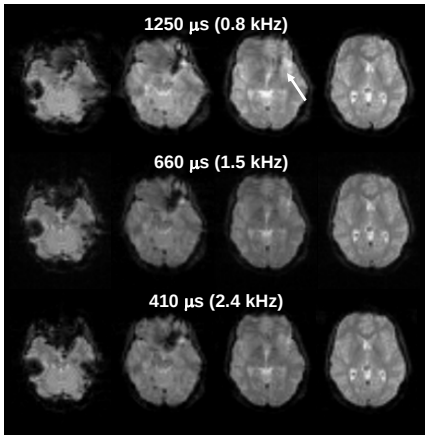


Echo Planar Imaging (EPI)

(Mansfield, University of Nottingham)

- GE-EPI is most common BOLD sequence – T_2*-weighted
- Artifacts:
  - geometric distortion in areas of magnetic field non-uniformity
  - signal loss in areas of magnetic field non-uniformity
  - EPI geometry effects distortion and signal loss

fMRI EPI Bandwidth

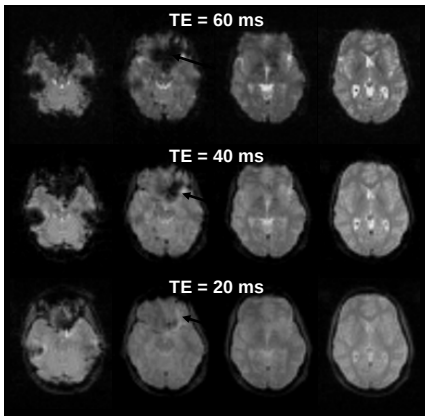


Decreasing EPI acquisition times (increasing bandwidth)

GE-EPI
4x4x4mm voxels
64x64 matrix
TE = 40 ms

•data must be acquired before significant T_2* or T_2 decay.

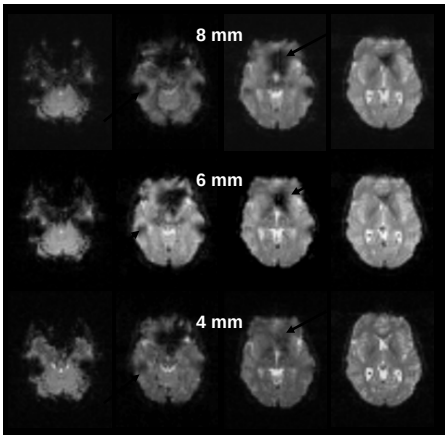
fMRI GE-EPI Echo Time



decreasing TE (*decreasing BOLD sensitivity*)

GE-EPI
4x4x4mm voxels
64x64 matrix
410 μs (2.4 kHz BW)

fMRI Slice Thickness

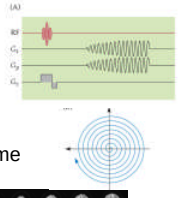


decreasing slice thickness

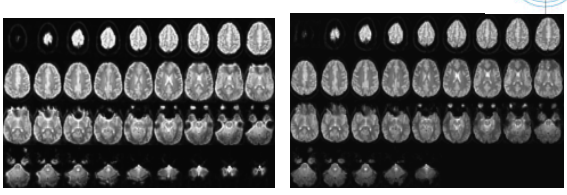
GE-EPI
4x4 mm voxels
64x64 matrix
410 μs (2.4 kHz BW)

Ultra-Fast Spiral Scanning

A new family of fast imaging sequences



An image (64x64) can be acquired in ~ 20 ms
Reduce head motion
Increase number of images collected per unit time



Spiral scanning **EPI scanning**

Motion Contrast Imaging Methods

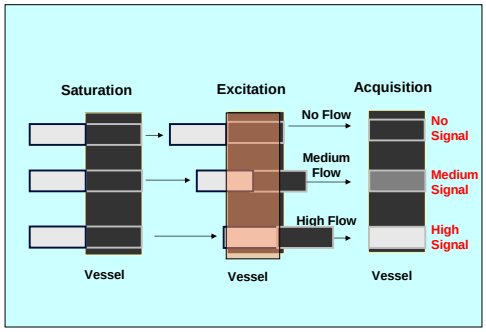
Prepare magnetization to make signal sensitive to different motion properties

- Flow weighting (bulk movement of blood)
- Diffusion weighting (water - random motion)
- Perfusion weighting (blood flow into capillaries)

Flow Weighting: MR Angiogram

- Time-of-Flight Contrast
- Phase Contrast

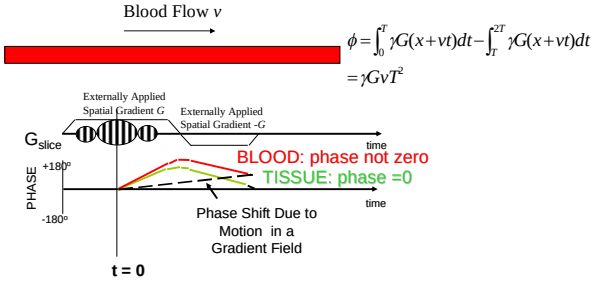
Time-of-Flight Contrast



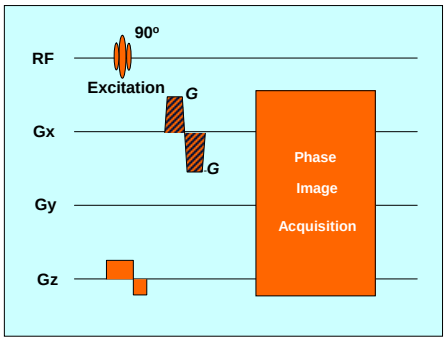
Signal from 'flight' of un-saturated blood into image

Phase Contrast (Velocity Encoding)

- Analogous to Doppler ultrasound
- Phase shifts in moving spins (blood) are measured
- Phase is proportional to velocity.



Pulse Sequence: Phase Contrast



MR Angiogram

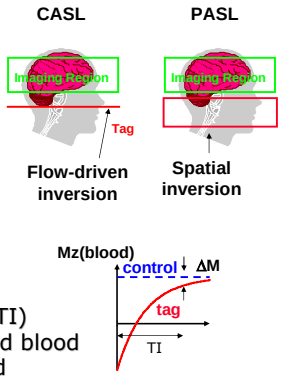
Perfusion Weighting: Arterial Spin Labeling (ASL)

- Naturally occuring water in arterial blood is used as an endogenous contrast agent.
- Magnetically 'label' (tag) blood flowing into a tissue of interest, acquire a second image with no 'label' (control), subtract images to form a perfusion weighted image.
- Two main ASL variants of labeling:
  Continuous ASL (**CASL**) and Pulsed ASL (**PASL**)

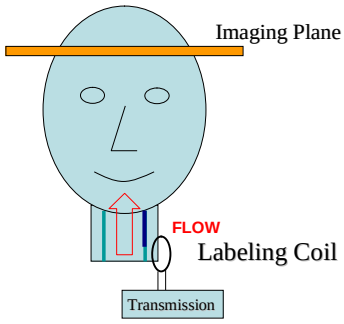
CASL vs. PASL

- CASL
  - Long pulse applied to neck arteries to invert inflowing blood
- PASL
  - A slab is labeled (usually inverted) surrounding slices of interest

After post-labeling delay (TI) (~1 – 2s) (allowing labelled blood to enter) image is acquired



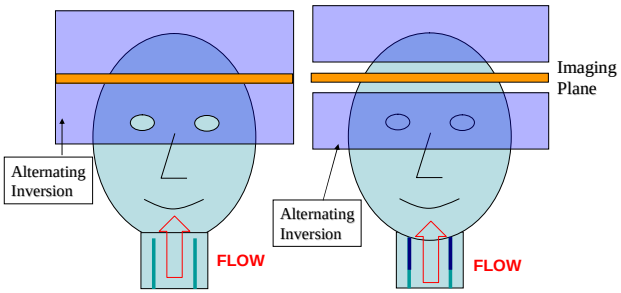
CASL



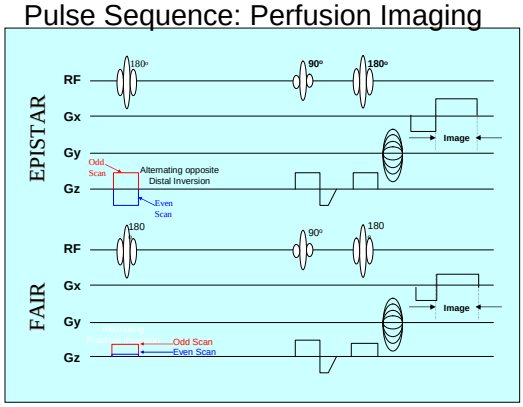
Uses separate coil to tag in the neck

PASL

• Use a single coil for labeling and imaging



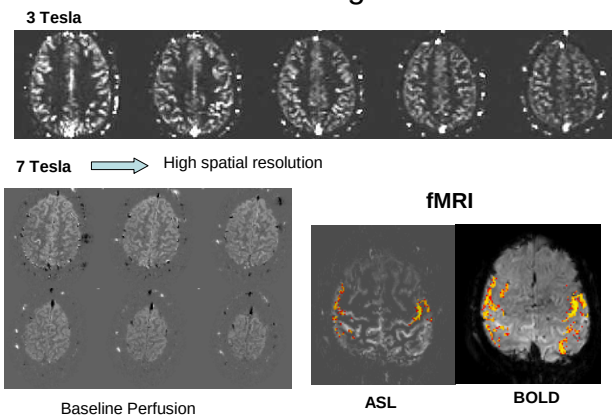
Pulse Sequence: Perfusion Imaging



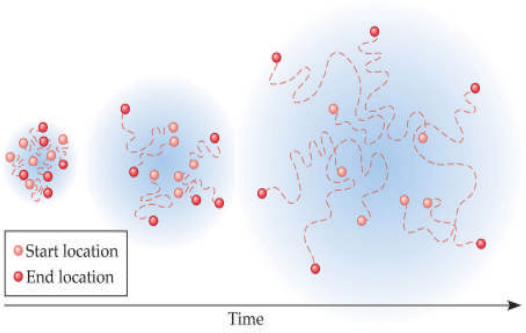
Advantages of ASL Perfusion Imaging

1. It is non-invasive – repeated measures
2. Quantitative measurement of capillary perfusion
3. Can use for functional imaging for improved spatial localisation of activated regions.

ASL Images



Diffusion

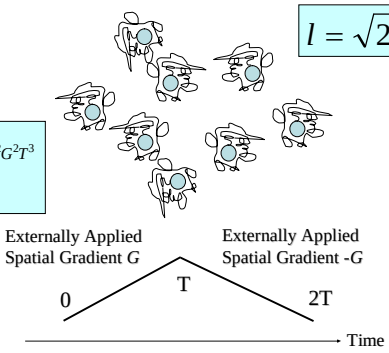


Diffusion is the random motion of water molecules

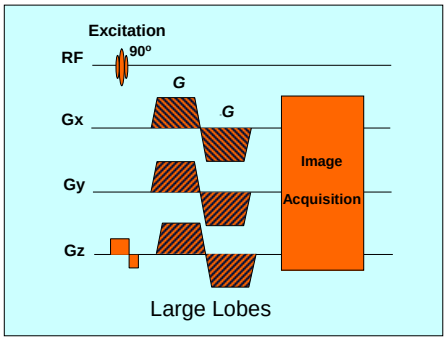
Diffusion Weighting

$$l = \sqrt{2Dt}$$

$$S = S_o e^{-\frac{2}{3}D\gamma^2G^2T^3}$$

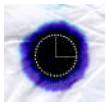


Pulse Sequence: Gradient-Echo Diffusion Weighting

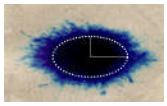


Diffusion Anisotropy

- Motion of water through tissue
- Faster in some directions than others



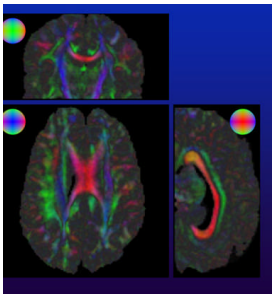
Kleenex



Newspaper

Anisotropy: diffusion rate depends on direction

Diffusion Tensor Imaging



- White matter of the brain contains many, many neuronal axons which are long tubes.
- Neurons cause water diffusion in the brain to be anisotropic.
- Using diffusion MRI we can measure the direction of neuronal tracts in the brain.

DTI and fMRI