EL5823/BE6203 --- Medical Imaging - I

Functional MRI

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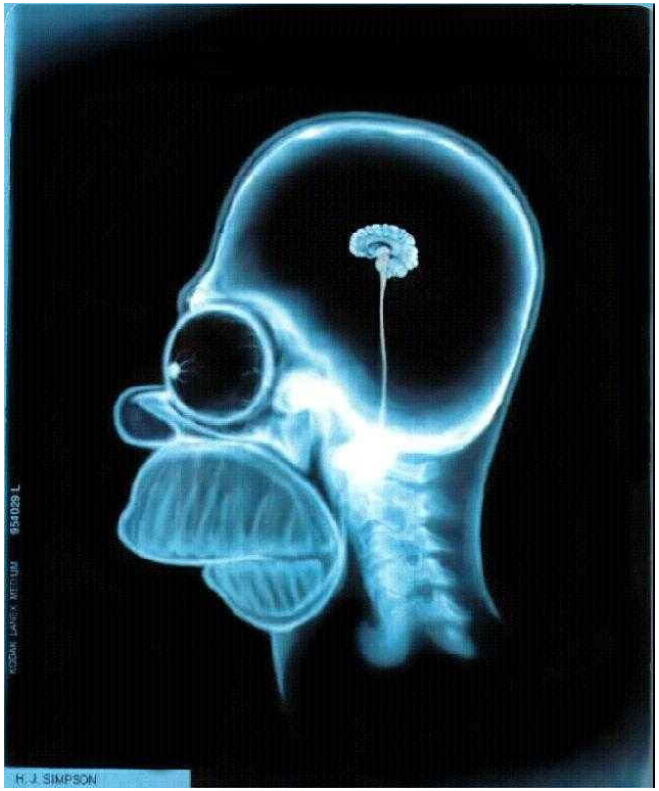
Overview

- Used to determine which area of brain is responsible for a given cognitive task
- The oxygenation status of the blood stream changes after the onset of a neuron activity
- fMRI: Taking a time series of MRI images of the brain after the subject is given a cognitive task
  - At each voxel, plot the MRI signal in time
  - Neuron activity at a voxel usually leads to a special MRI signal pattern
  - Detect such patterns
  - Voxels with detected patterns are considered to be responsible for the cognitive task

MRI vs. fMRI

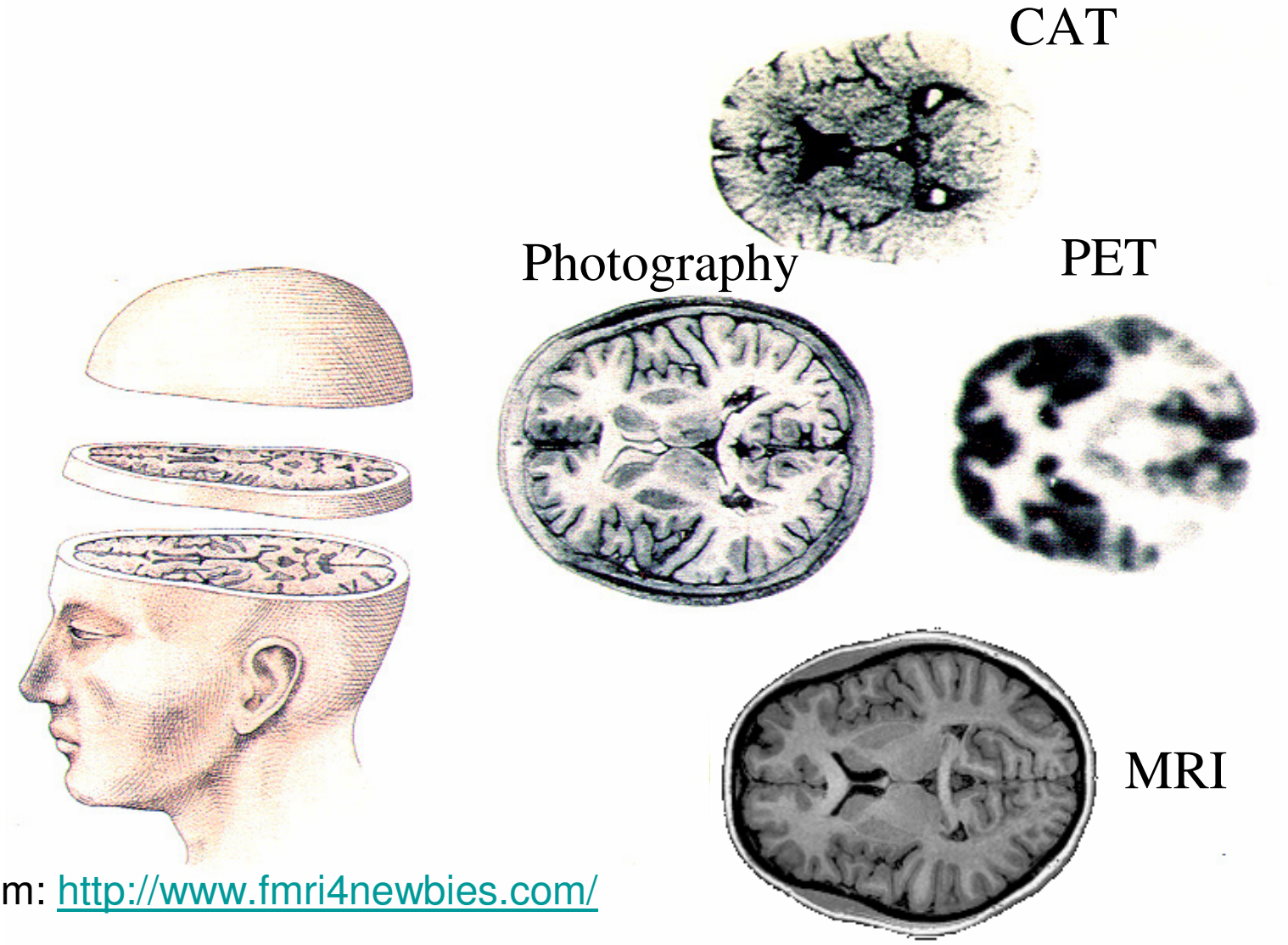
MRI studies brain anatomy.



Functional MRI (fMRI) studies brain function.

http://www.fmri4newbies.com/

Brain Imaging: Anatomy



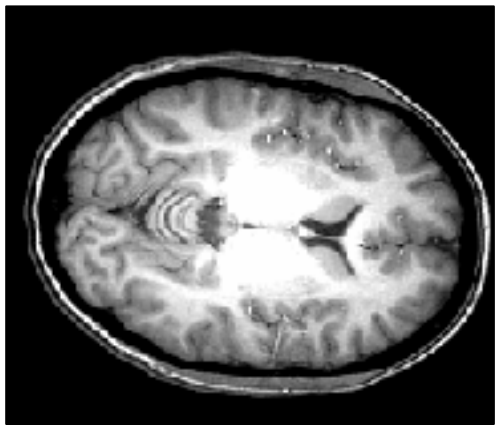
From: http://www.fmri4newbies.com/

Source: modified from Posner & Raichle, Images of Mind

MRI vs. fMRI

MRI

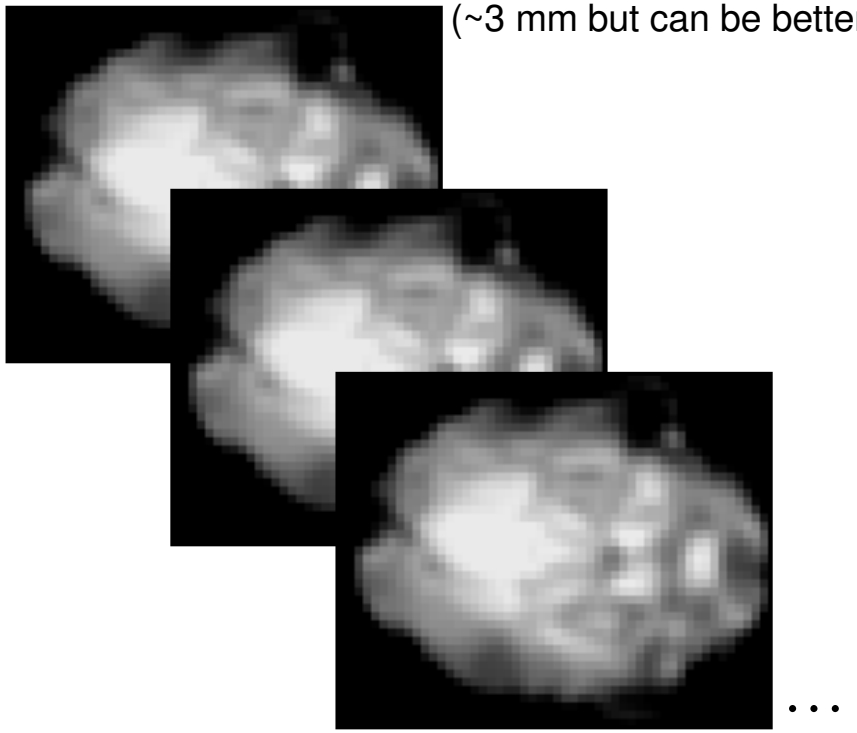
high resolution
(1 mm)



one image

fMRI

low resolution
(~3 mm but can be better)



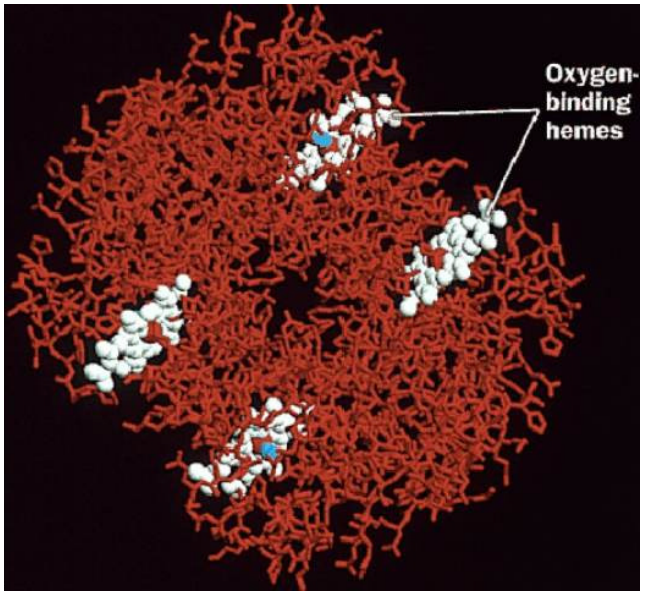
...

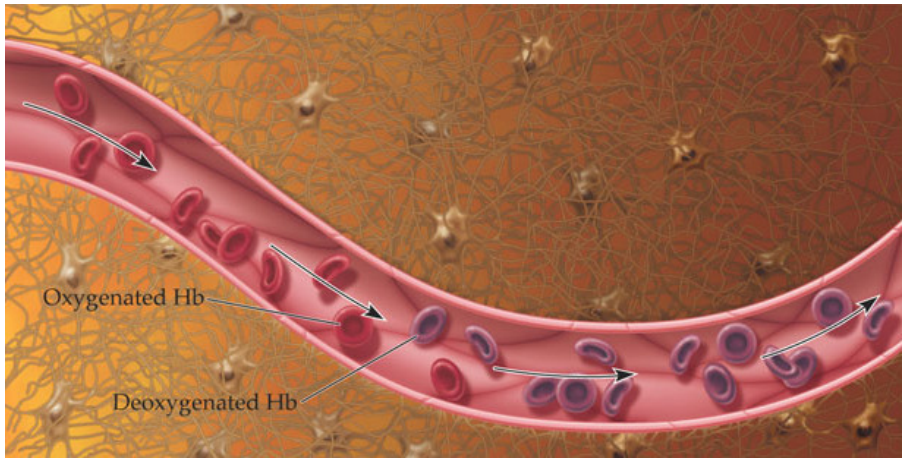
many images
(e.g., every 2 sec for 5 mins)

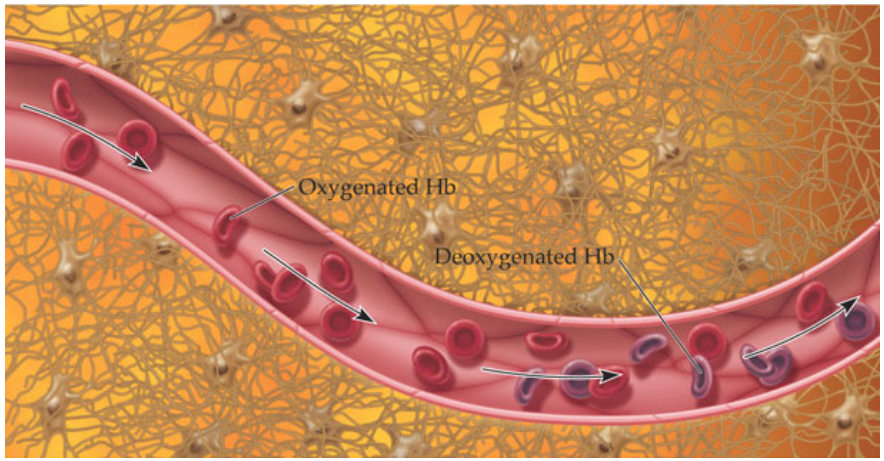
http://www.fmri4newbies.com/

↑ neural activity ➔ ↑ blood oxygen ➔ ↑ fMRI signal

Hemoglobin







From: http://www.fmri4newbies.com/

Figure Source, Huettel, Song & McCarthy, *2004, Functional Magnetic Resonance Imaging*

Properties of Hemoglobin

- Two types of hemoglobin:
  - Oxyhaemoglobin (a haemoglobin protein contained within the red blood cells with an oxygen molecule attached to it)
  - Deoxyhaemoglobin (a haemoglobin protein contained within the red blood cells without an oxygen molecule attached to it)
- Oxygenated Hb do not have magnetic responses
- Deoxygenated Hb have magnetic responses. Increase in deoxygenated Hb increases inhomogeneity of the local magnetic field (spins are more out of phase), leading to lower T2*, hence decreased FID
- When a neuron is activated, it draws oxygen from blood stream, leading to more concentration of deoxygenated Hb in the blood
- The BOLD fMRI technique basically measures changes in the inhomogeneity of the magnetic field
- BOLD: Blood Oxygenation Level Dependent

Impact of Field Inhomogeneity to the FID Signal

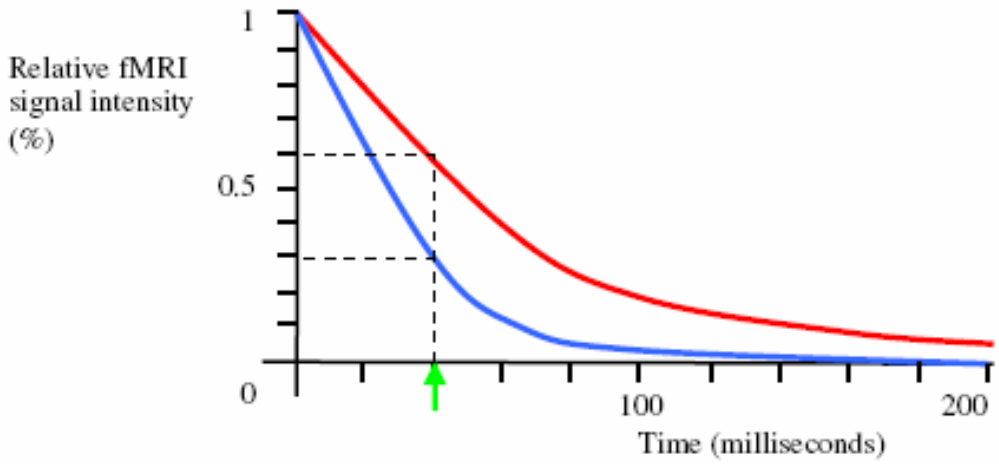


Figure 1.2a: Decay of the fMRI signal over time after termination of the RF-pulse. The blue curve represents the decay in fMRI signal in a magnetic field with a larger inhomogeneity. The red curve represents the decay in fMRI signal in a magnetic field with a smaller inhomogeneity. Therefore, the blue curve decays faster than the red curve. The green arrow indicates the point in time at which the signal intensity is measured. It can be seen that when the fMRI signal decays faster (the blue curve), the signal intensity at the moment of measurement is lower than when the fMRI signal decays slower (the red curve).

From: http://www.sph.sc.edu/comd/rorden/fmri_guide/fmri_guide.pdf

Changes of the BOLD fMRI Signal

- The function of the BOLD fMRI signal against time in response to a temporary increase in neuronal activity is known as the hemodynamic response function (HRF)
- After the onset of a neuron activity, the active neurons use oxygen thereby increasing the relative level of deoxyhaemoglobin in the blood, which leads to the decrease of the BOLD fMRI signal initially.
- Following this initial increase in deoxyhaemoglobin, there is a massive oversupply of oxygen-rich blood (reaching maximum at ~6s), leading to a large decrease in deoxyhaemoglobin, and hence increase in the BOLD fMRI signal.
- Finally, the level of deoxyhaemoglobin slowly returns to normal and the BOLD fMRI signal decays until it has reached its original baseline level (~24s).

Based on: http://www.sph.sc.edu/comd/rorden/fmri_guide/fmri_guide.pdf

Hemodynamic Response Function (HEF)

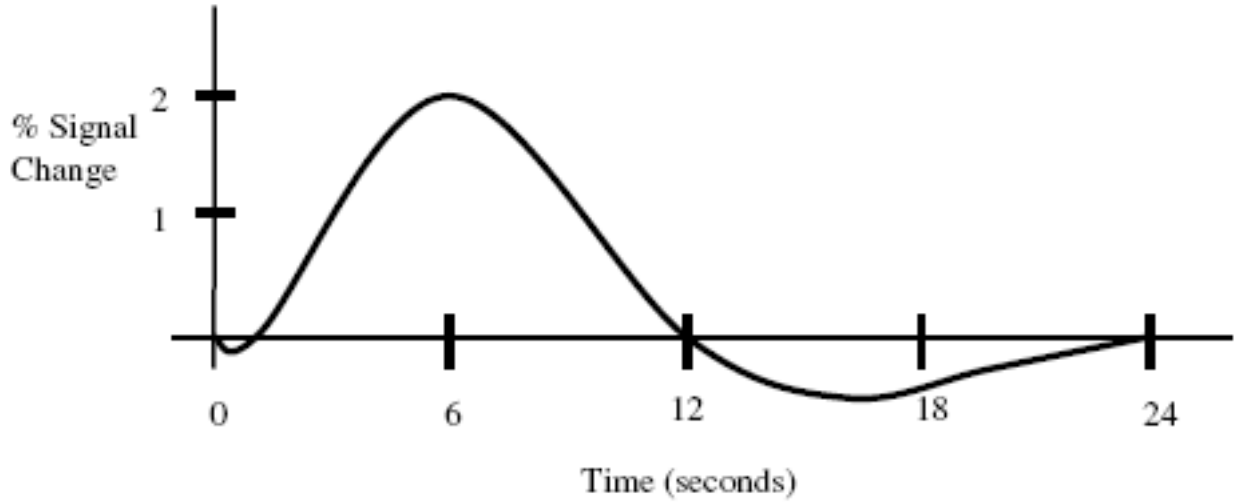
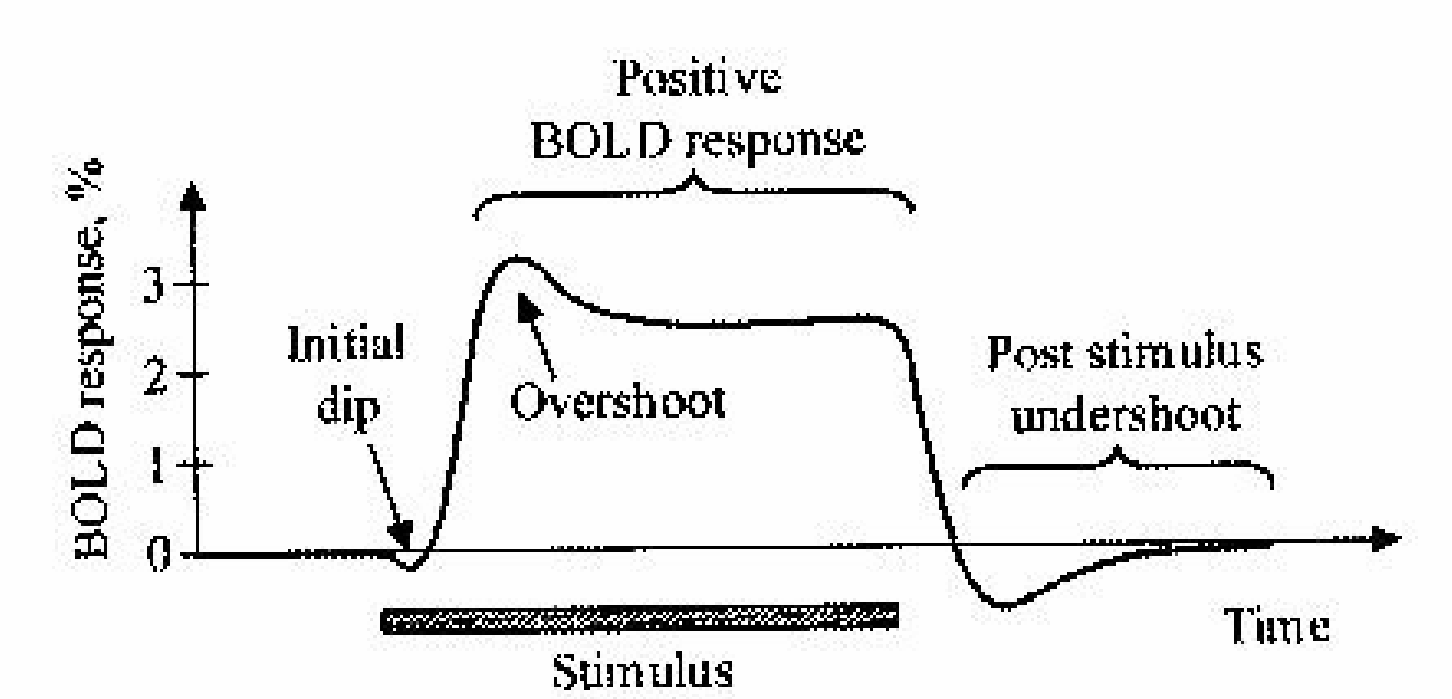


Figure 1.2b: Time course of the HRF in response to a short-lasting increase in neuronal activity at time = 0. Note that the signal shows a small dip immediately after the transient increase in neuronal activity (initially, the level of deoxyhaemoglobin increases). Following this initial dip, however, the signal becomes much stronger due to the increase in oxygenation (and therefore the decrease in the level of deoxygenation).

From: http://www.sph.sc.edu/comd/rorden/fmri_guide/fmri_guide.pdf

Another View of HEP

- HEF is also known as BOLD Time course



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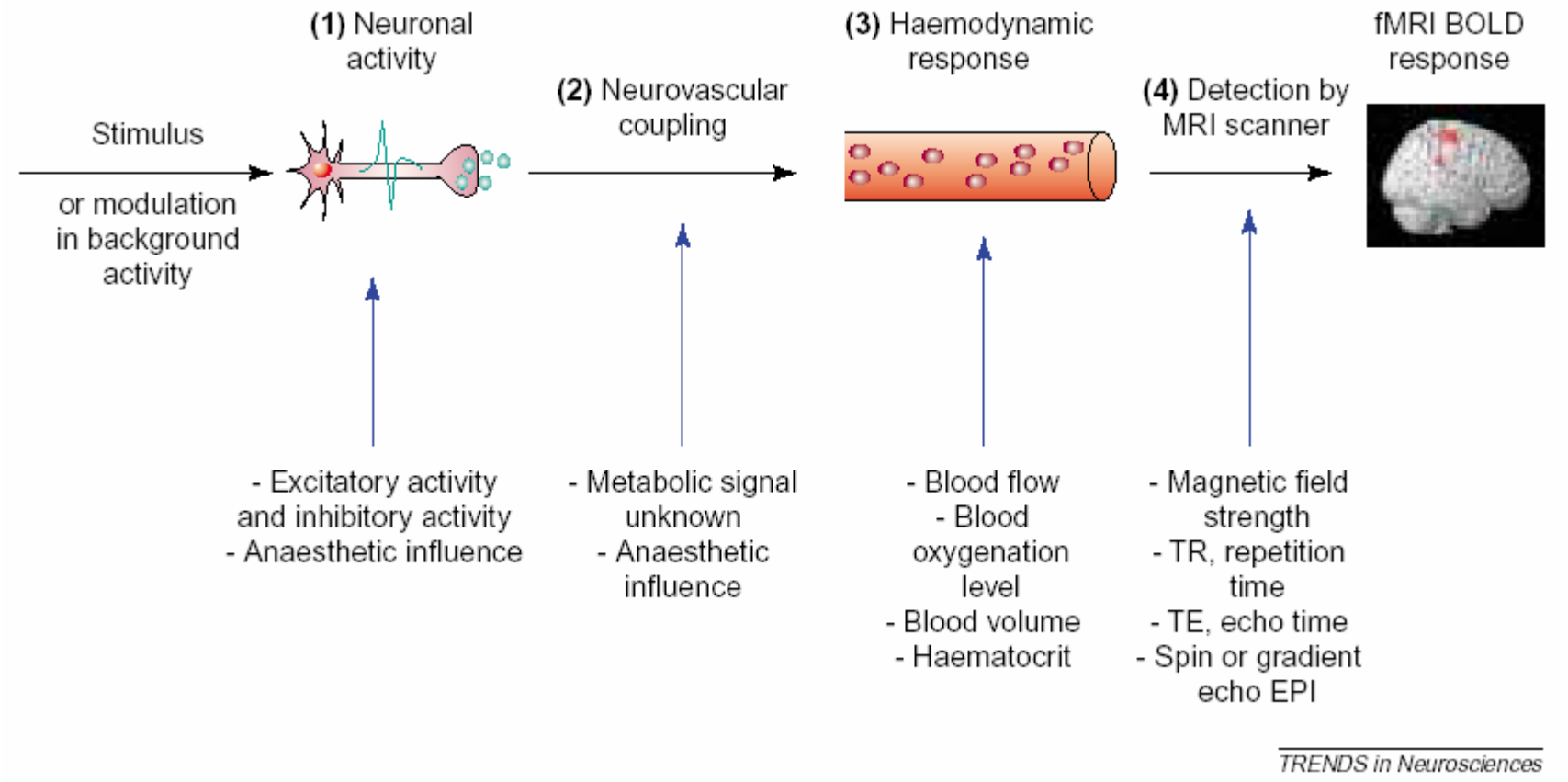
Stimulus to BOLD



Source: Arthurs & Boniface, 2002, *Trends in Neurosciences*

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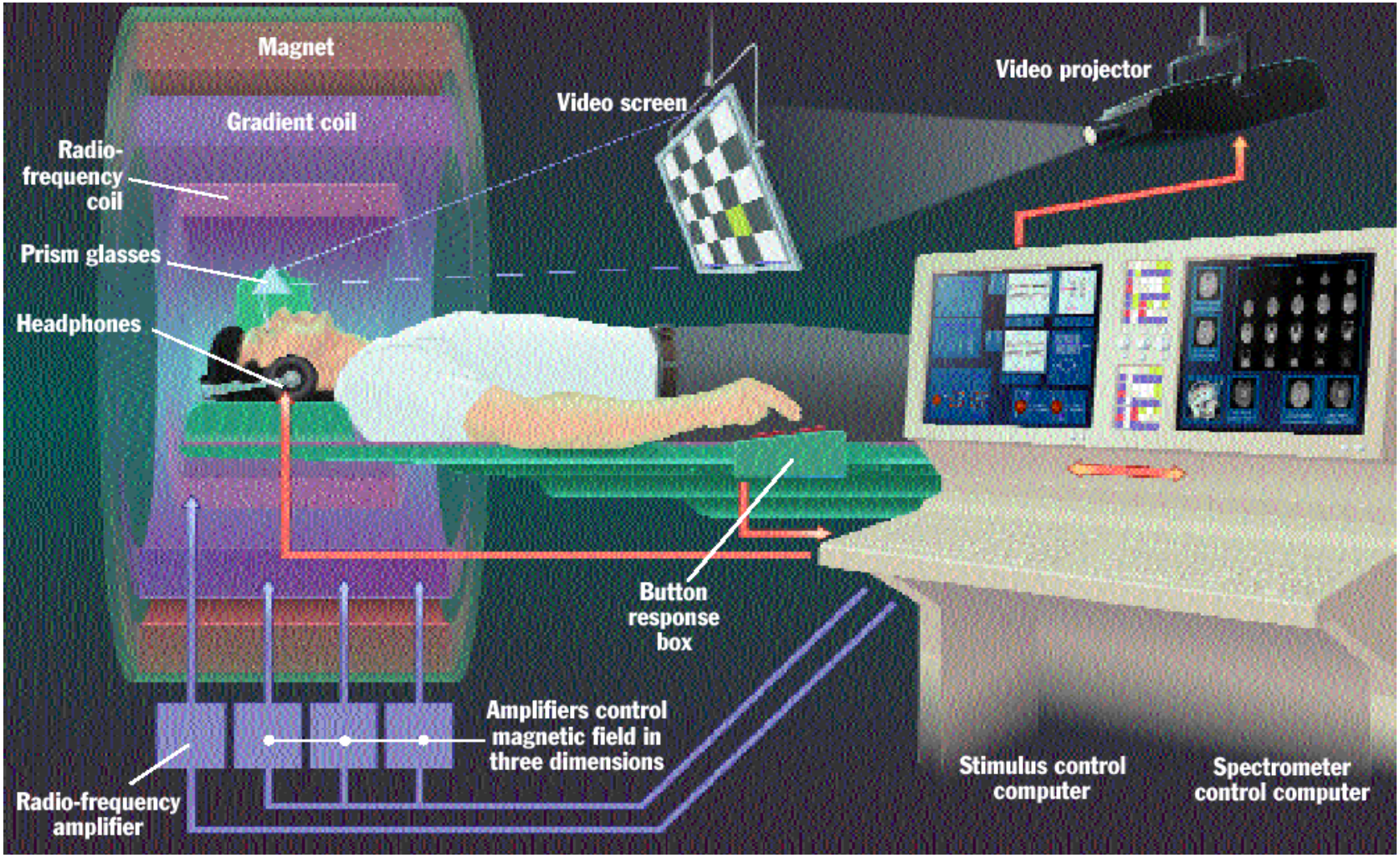
fMRI Set up



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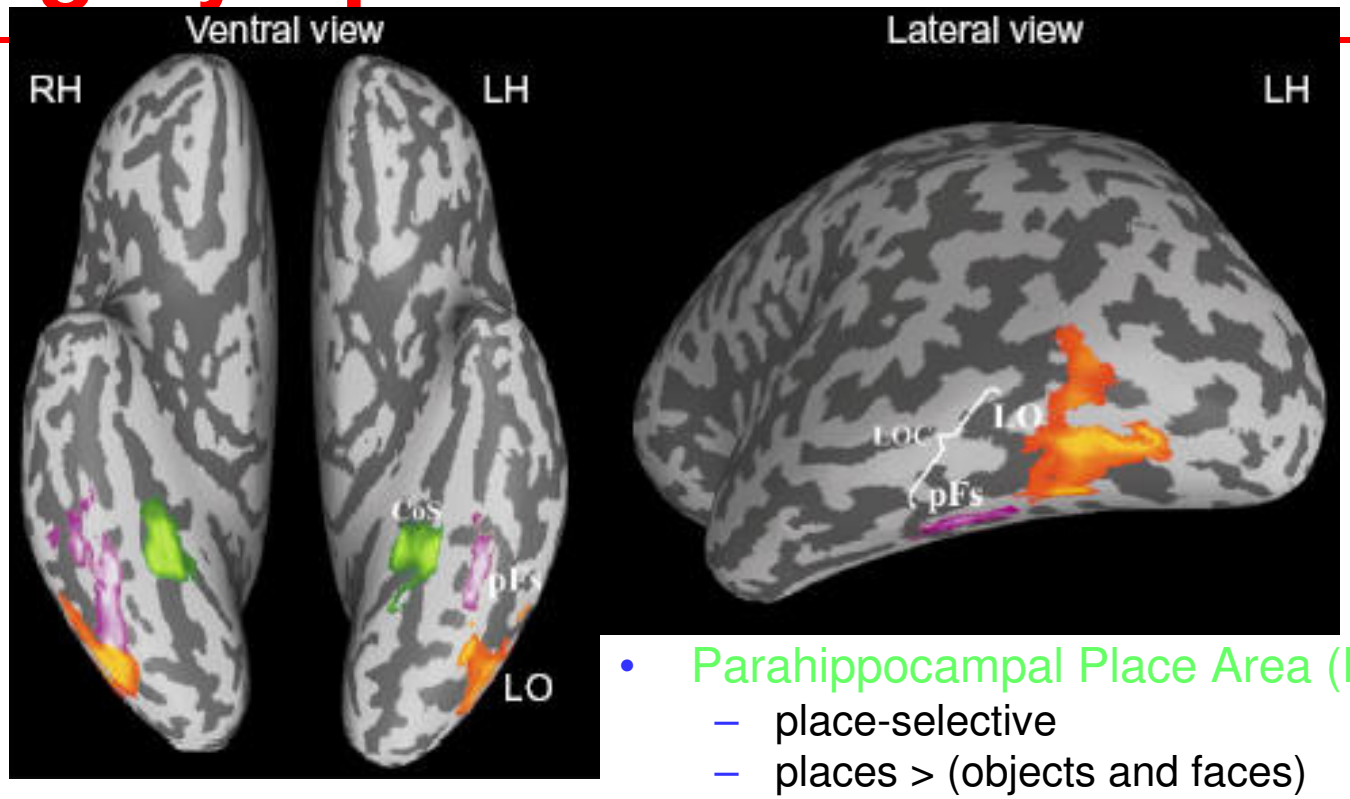
Category-Specific Visual Areas

objects

faces

places



- Lateral Occipital (LO)
  - object-selective
  - objects > (faces & scenes)
  - objects > scrambled images

- Parahippocampal Place Area (PPA)
  - place-selective
  - places > (objects and faces)
  - places > scrambled images

- Fusiform Face Area (FFA) or pFs
  - face-selective
  - faces > (objects & scenes)
  - faces > scrambled images
  - ~ posterior fusiform sulcus (pFs)

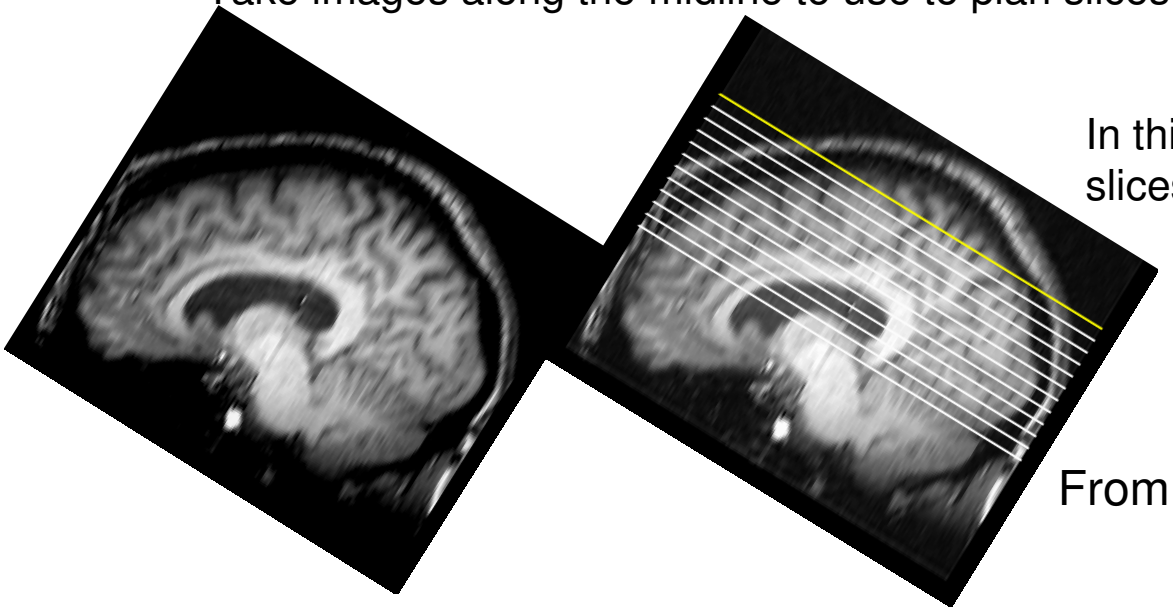
http://www.fmri4newbies.com/

fMRI Experiment Stages: Prep

1) Prepare subject
   - Consent form
   - Safety screening
   - Instructions and practice trials if appropriate
2) Shimming
   - putting body in magnetic field makes it non-uniform
   - adjust 3 orthogonal weak magnets to make magnetic field as homogenous as possible
3) Sagittals

Perhaps the most frequently misspelled word in fMRI: Should have one g, two t's

Take images along the midline to use to plan slices



In this example, these are the *functional* slices we want: 12 slices x 6 mm

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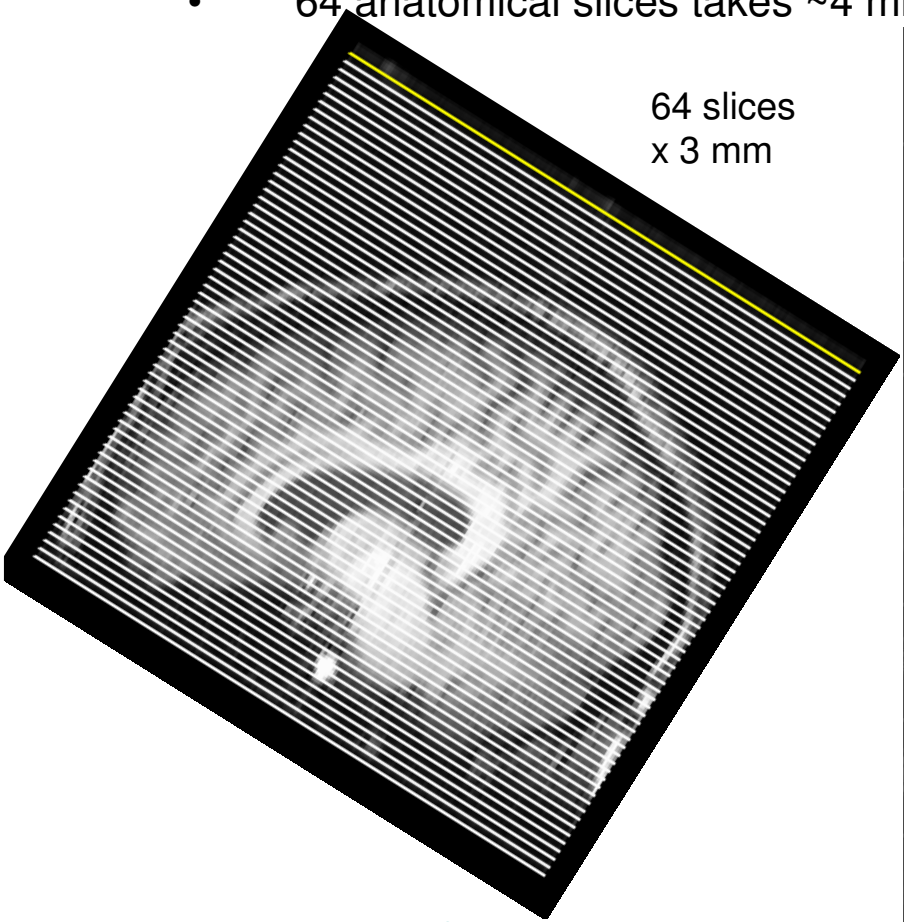
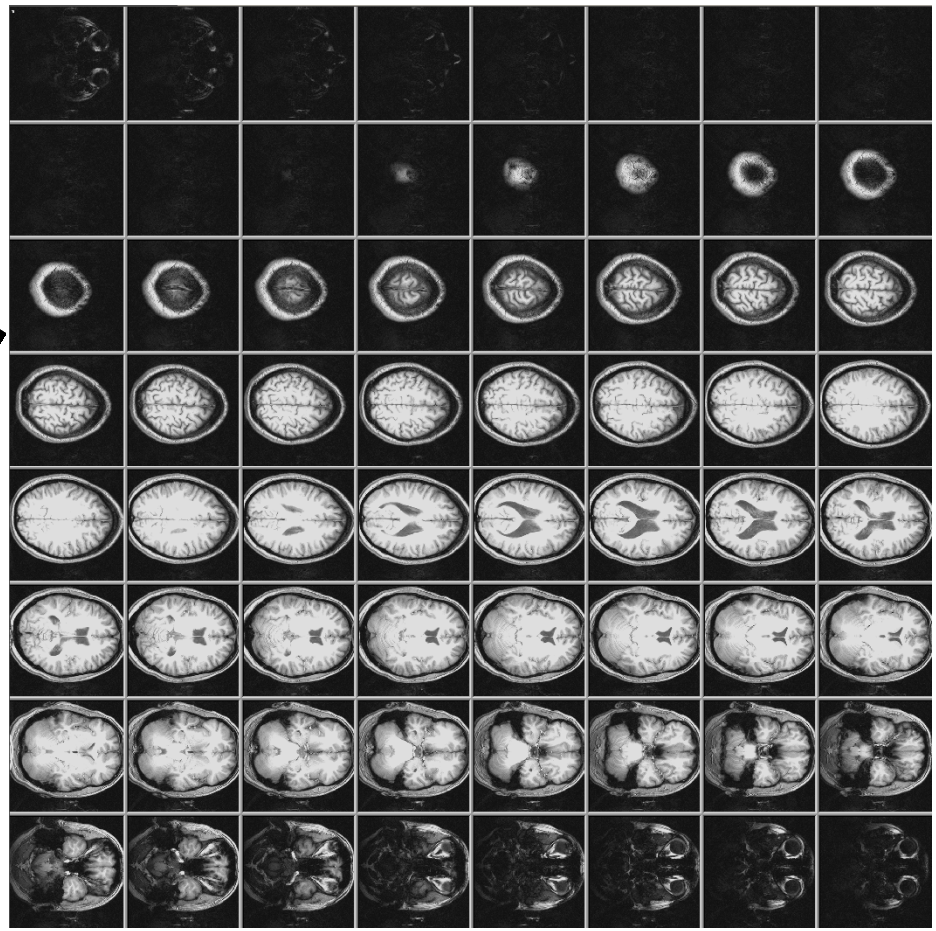
fMRI Experiment Stages: Anatomicals

4) Take anatomical (T1) images

- high-resolution images (e.g., 0.75 x 0.75 x 3.0 mm)
- 3D data: 3 spatial dimensions, sampled at one point in time
- 64 anatomical slices takes ~4 minutes





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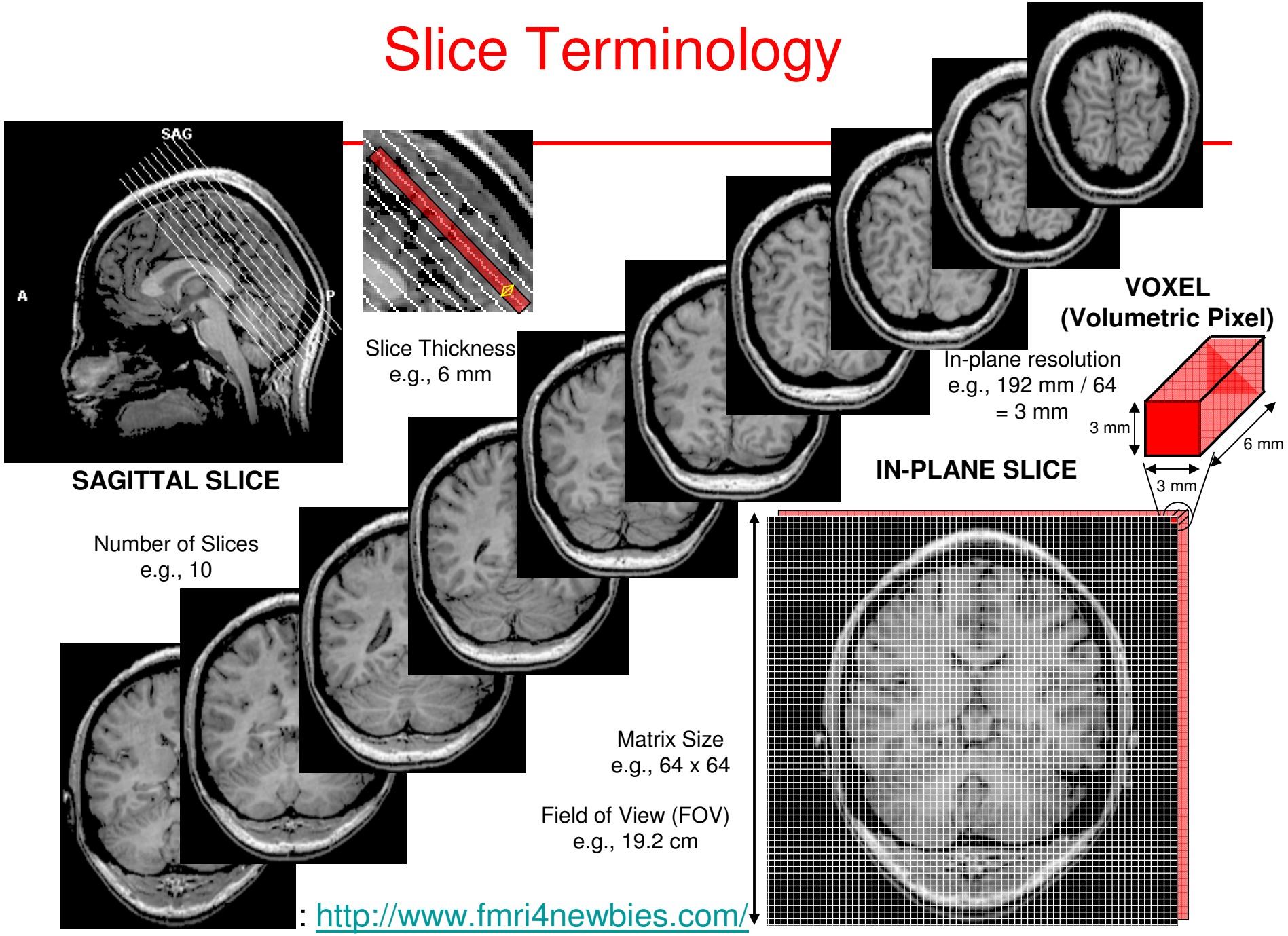
Slice Terminology

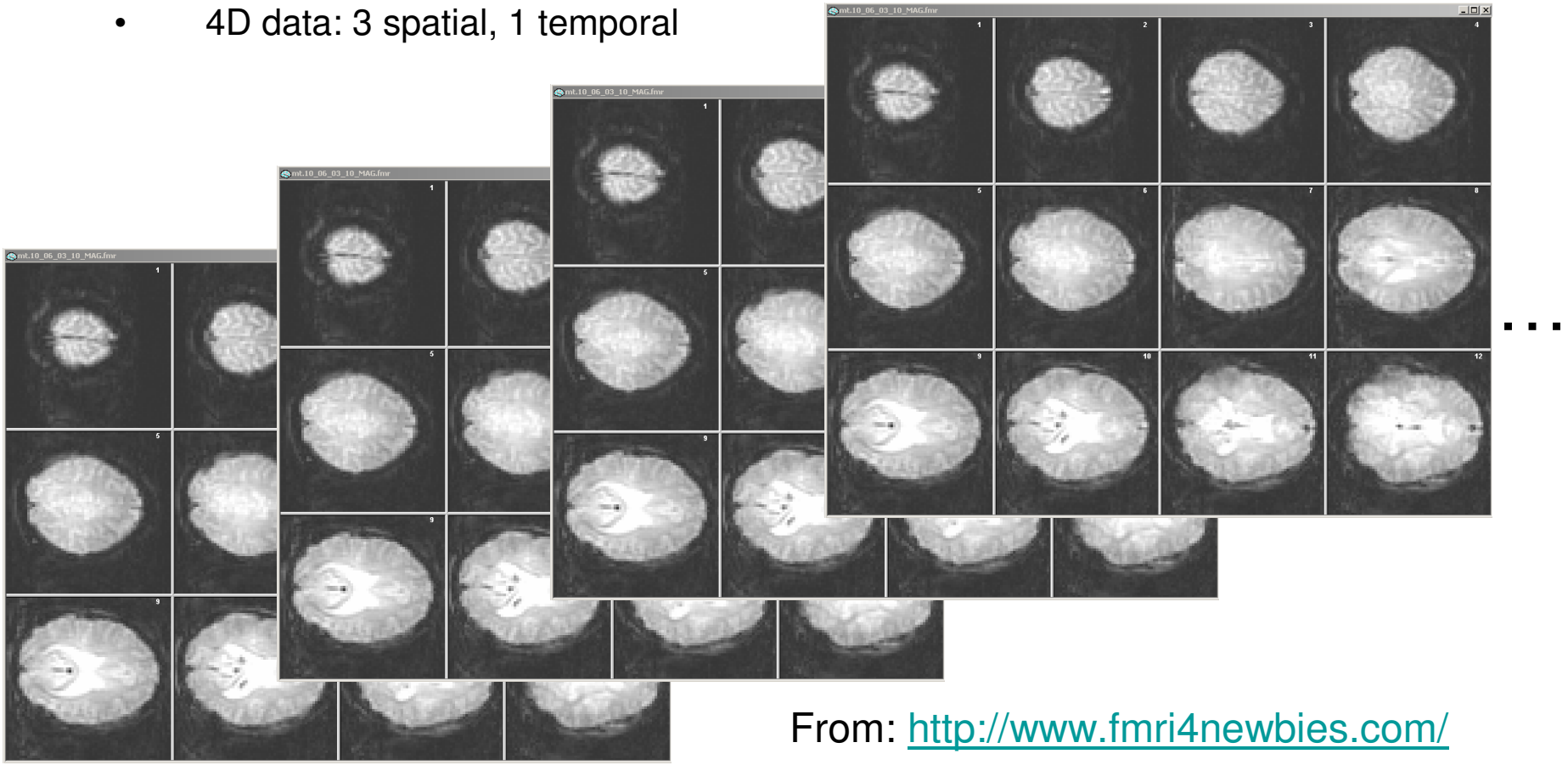


: http://www.fmri4newbies.com/

fMRI Experiment Stages: Functionals

5) Take functional (T2*) images

- images are indirectly related to neural activity
- usually low resolution images (3 x 3 x 6 mm)
- all slices at one time = a volume (sometimes also called an image)
- sample many volumes (time points) (e.g., 1 volume every 2 seconds for 136 volumes = 272 sec = 4:32)
- 4D data: 3 spatial, 1 temporal



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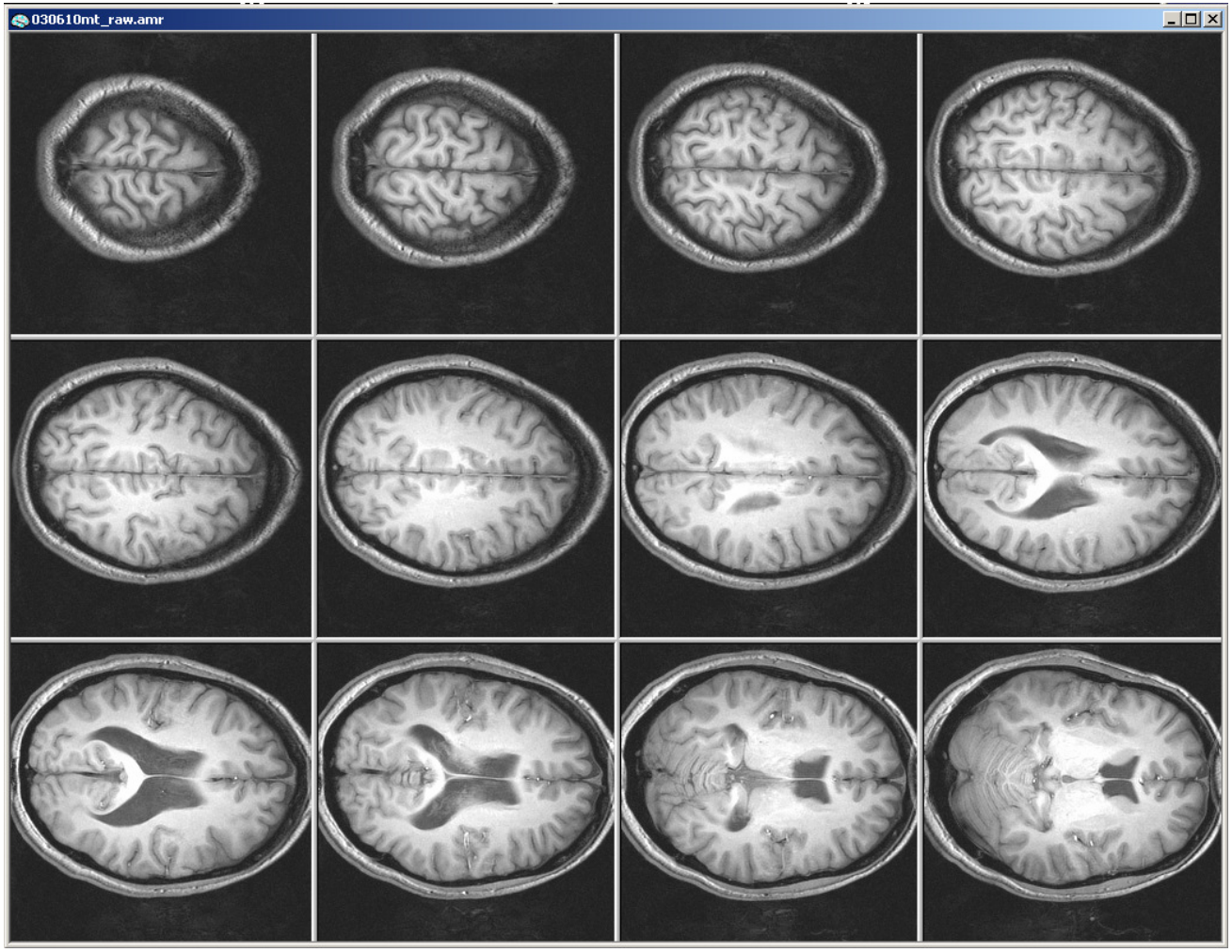
Anatomic Slices Corresponding to Functional Slices



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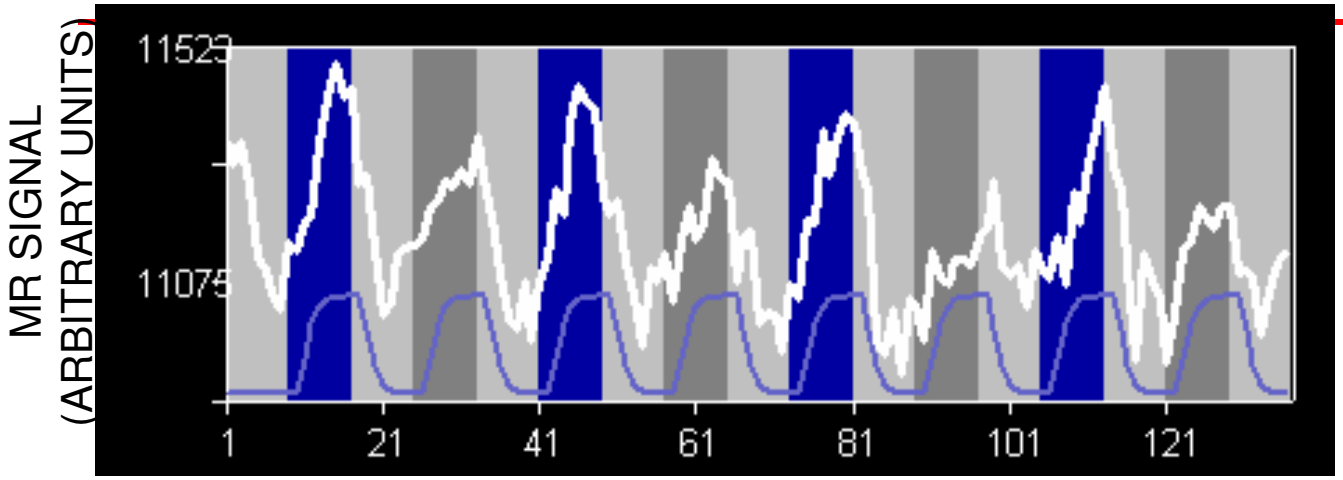
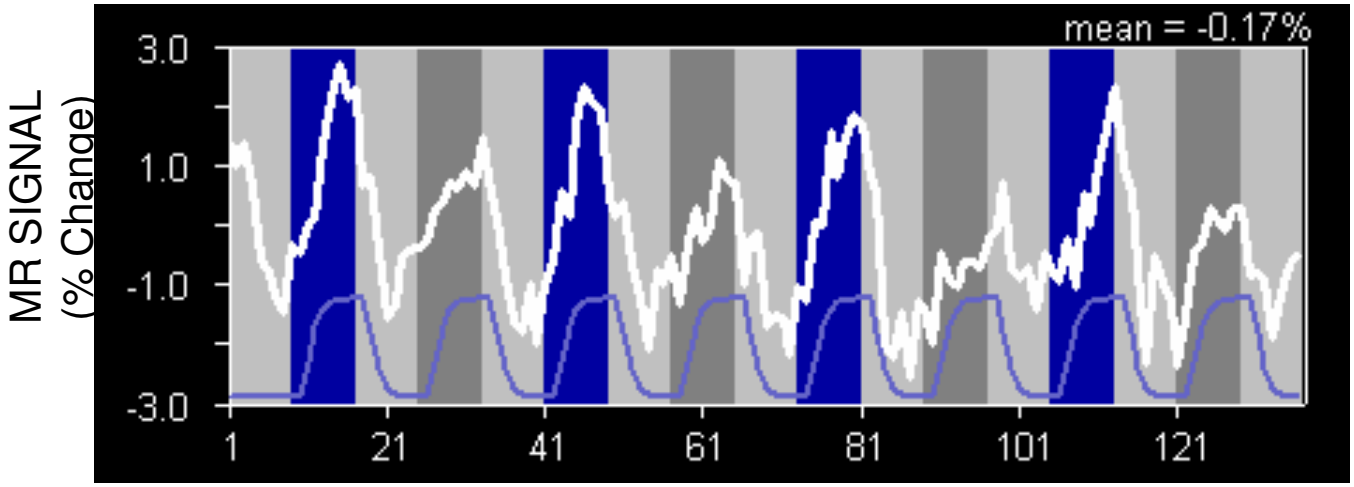
Time Courses



Arbitrary signal varies from coil to coil, voxel to voxel, day to day, subject to subject

TIME



To make the y-axis more meaningful, we usually convert the signal into units of % change:

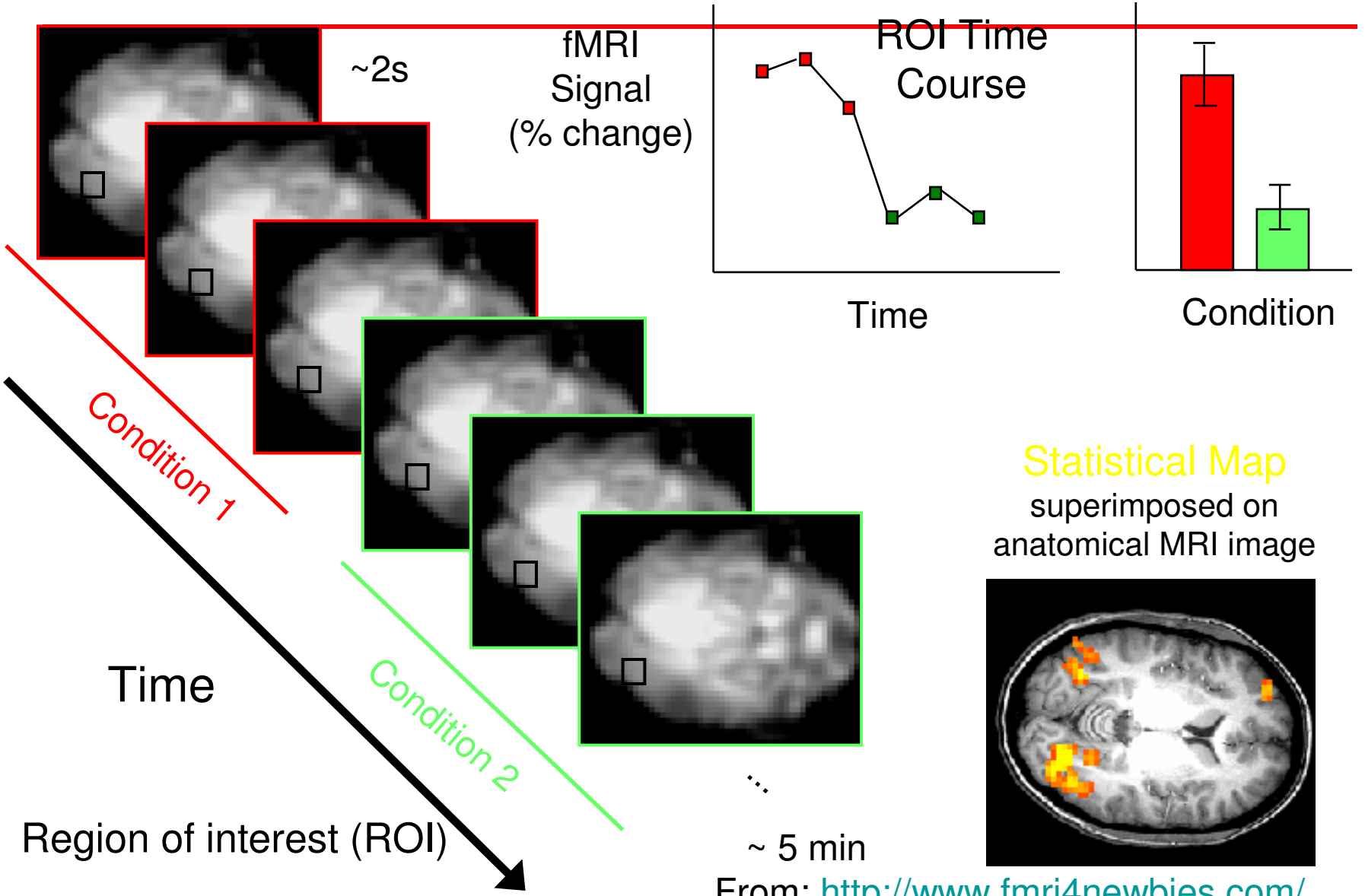
100*(x - baseline)/baseline

Changes are typically in the order of 0.5-4 %.

From: http://www.fmri4newbies.com/

Activation Statistics

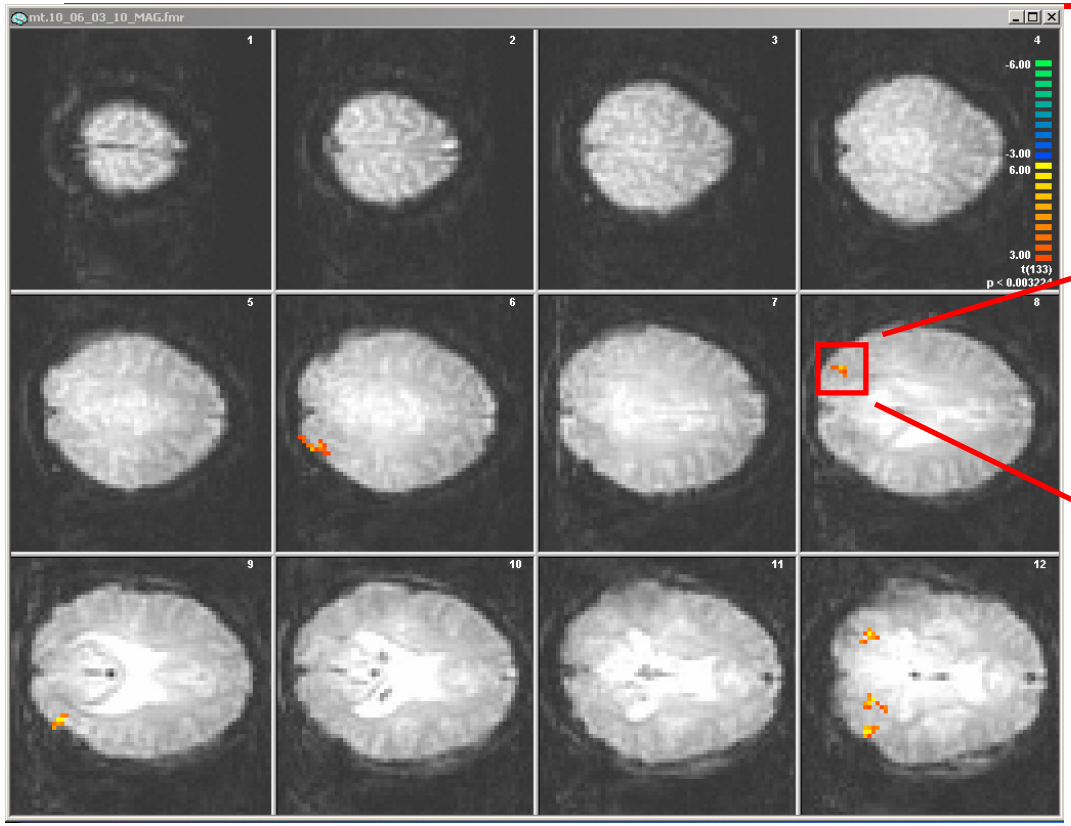
Functional images



Statistical Map
superimposed on anatomical MRI image

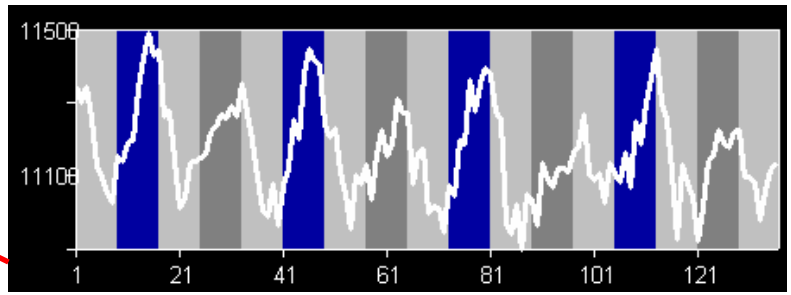
From: http://www.fmri4newbies.com/

Statistical Maps & Time Courses



Use stat maps to pick regions

Then extract the time course



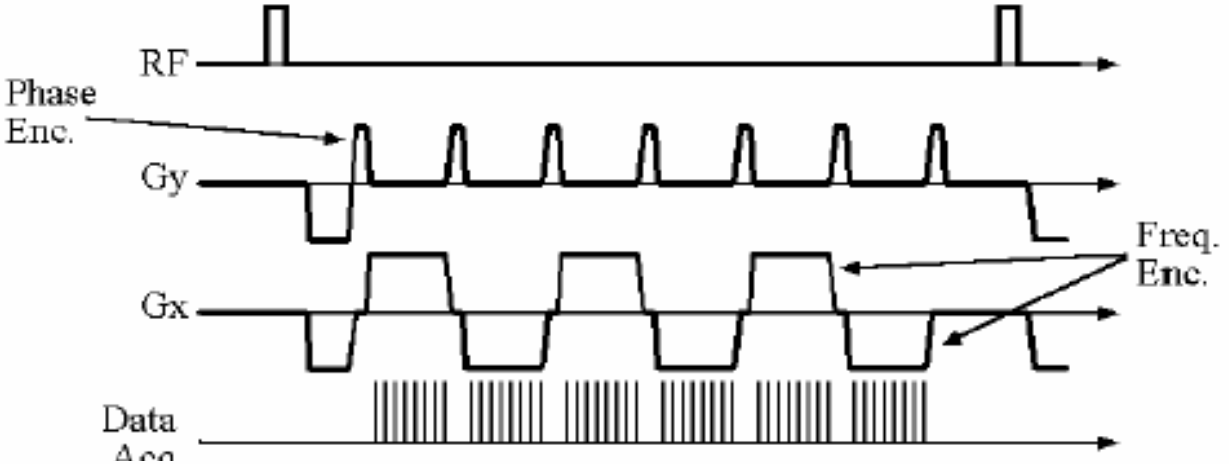
From: http://www.fmri4newbies.com/

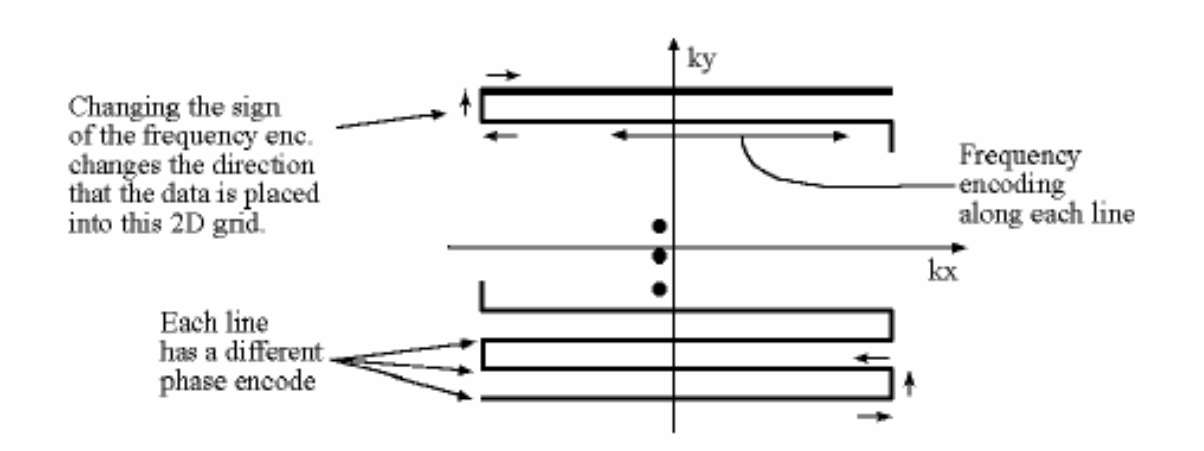
RF Sequences Used in fMRI

- Must image very fast
- Image the FID signal decrease due to T2*
- Typically use echo planar pulse sequence

Echo planar imaging

- Avoid going back to origin after each read-out
- "Single shot" imaging, popular in fMRI
- Spatial resolution limited by gradient switching time





Challenges of fMRI Image Analysis

- The same voxel in volumes taken at different times may correspond to different neurons, due to patient motion
  - Register the volumes taken at different times, to a reference volume (e.g. high resolution anatomical viewe taken with conventional MRI)
- Slices in the same volume are taken at different times, leading to shifts in the response
  - Time correction is needed

Reference

- N.M. van Strien, http://www.mri-tutorial.com/tutorial_fmri.html
- Bianca de Haan, fMRI guide, http://www.sph.sc.edu/comd/rorden/fmri_guide/index.html
- **Jody Cullham,** fMRI for newbies: http://www.fmri4newbies.com/

- A. Webb, Introduction to Biomedical Imaging, Chap. 4