UNIVERSITÀ
DEGLI STUDI DI TRIESTE

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Neuroimaging
functional MRI

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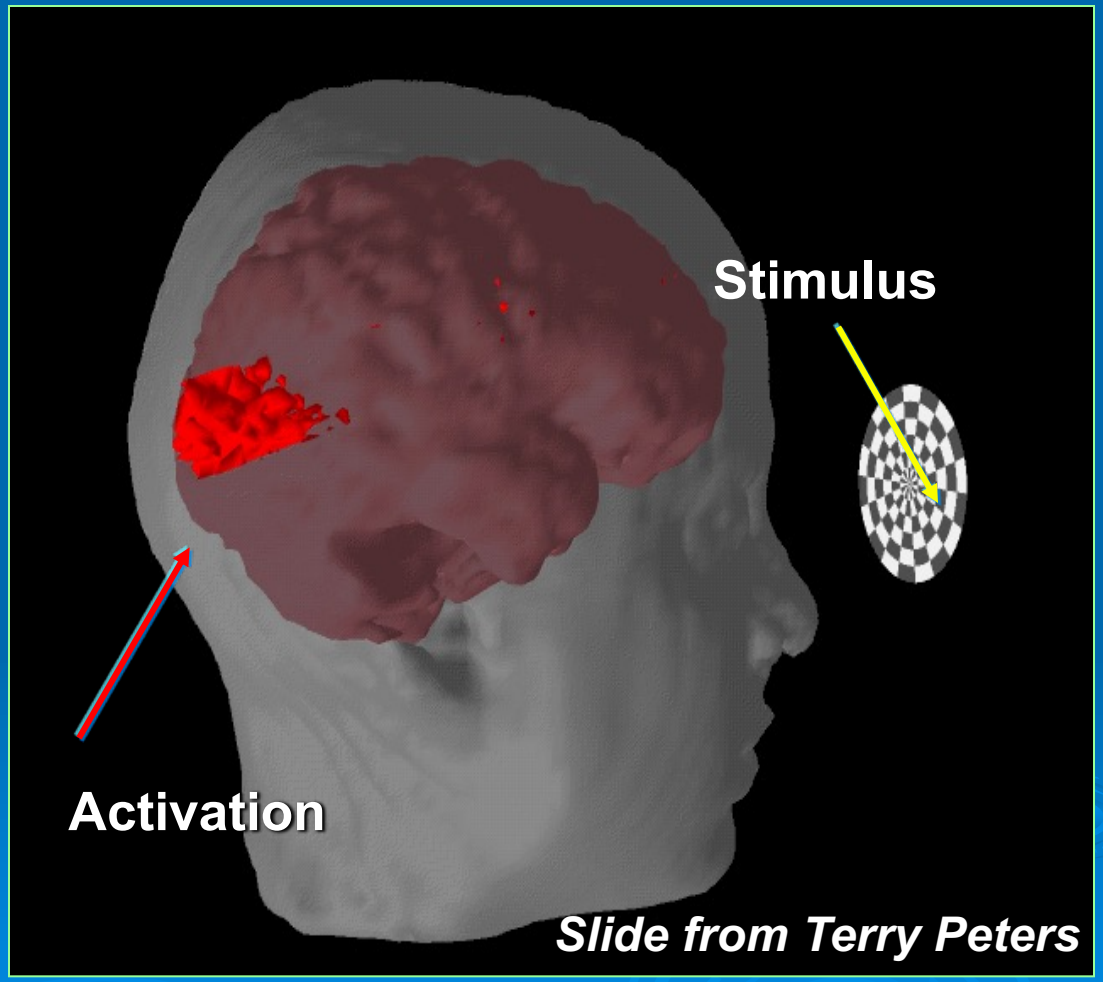
fMRI

Subject looks at flashing disk while being scanned "Activated" sites detected and merged with 3-D MR image



http://www.imaios.com/en/e-Courses/e-MRI/Functional-MRI/introduction

Outline

- What are we going to observe ?
  - Physics and physiological basis of brain activation and of the MRI contrast
- How to collect such information ?
  - Data acquisition
- Data analysis
  - Statistical criteria
- Examples

Functional MR Imaging (fMRI)

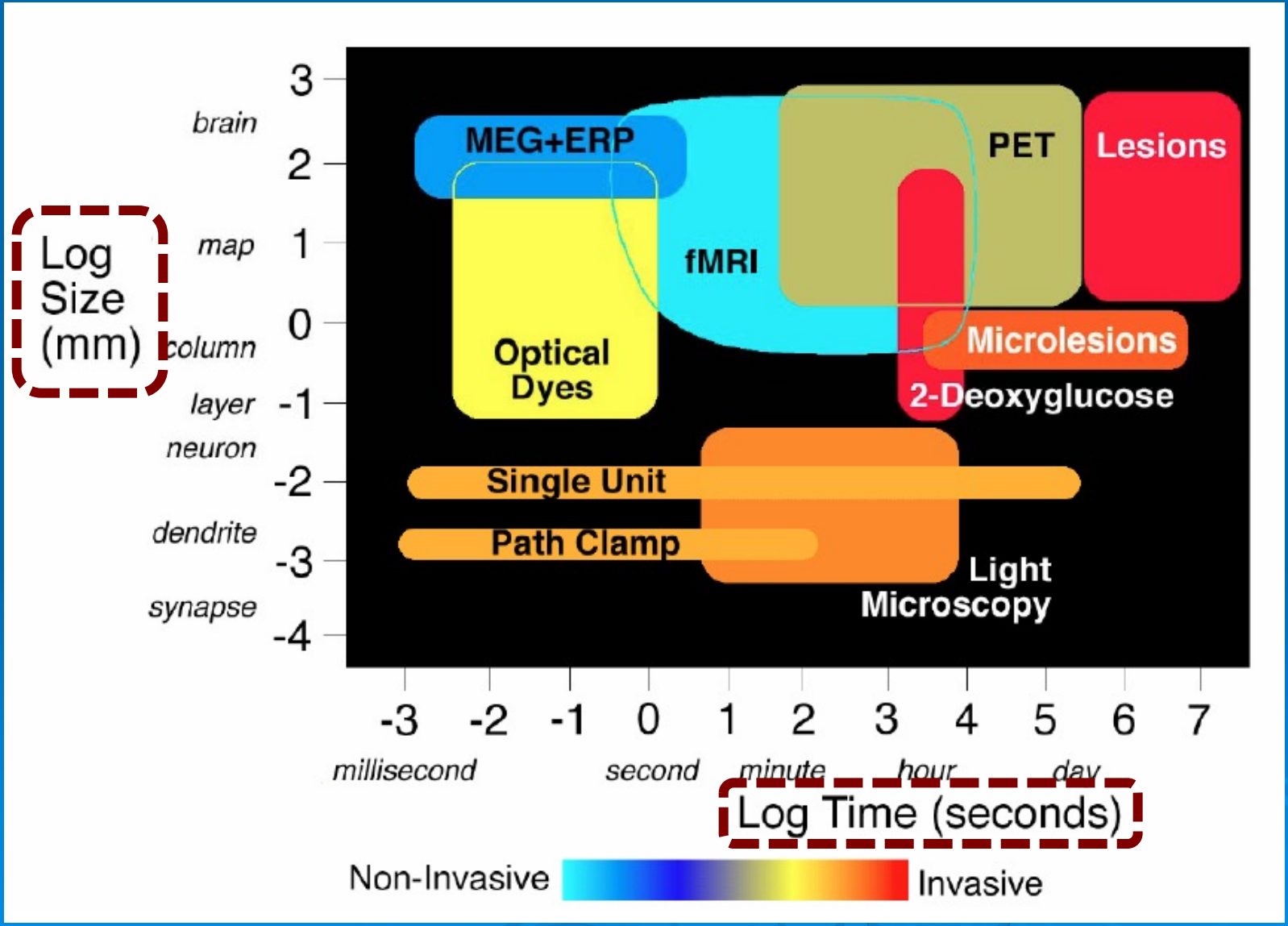
Peter Jezzard, PhD

FMRIB Centre, Oxford University,
John Radcliffe Hospital, Oxford, OX3 9DU

http://www.fmrib.ox.ac.uk/physics

Some slides from http://users.fmrib.ox.ac.uk/~peterj/lectures/miccai99/sld001.htm

Brain mapping techniques



Spatial resolution (log size), time resolution (log time)

The history of brain mapping

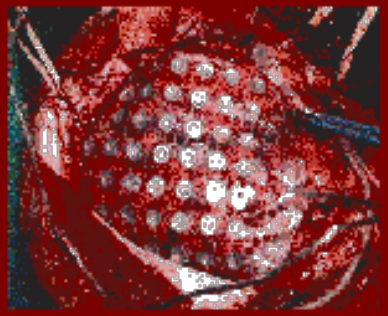
Functional Mapping Methods

Phrenology

EEG

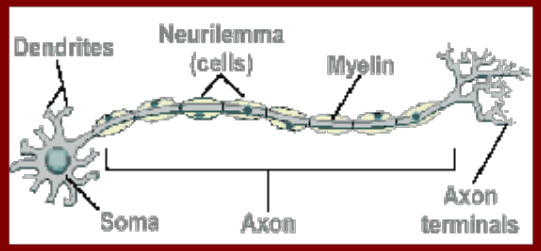
Positron Emission Tomography

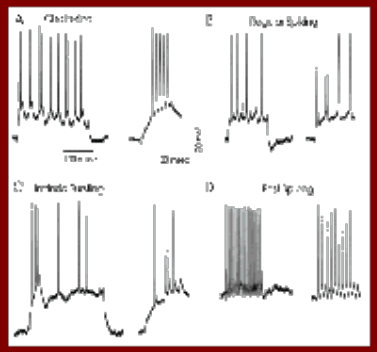
Implanted electrodes



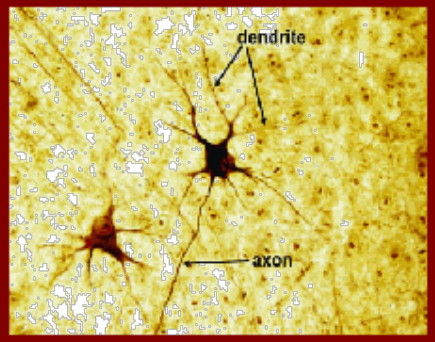
The physiology behind it

The Neuron



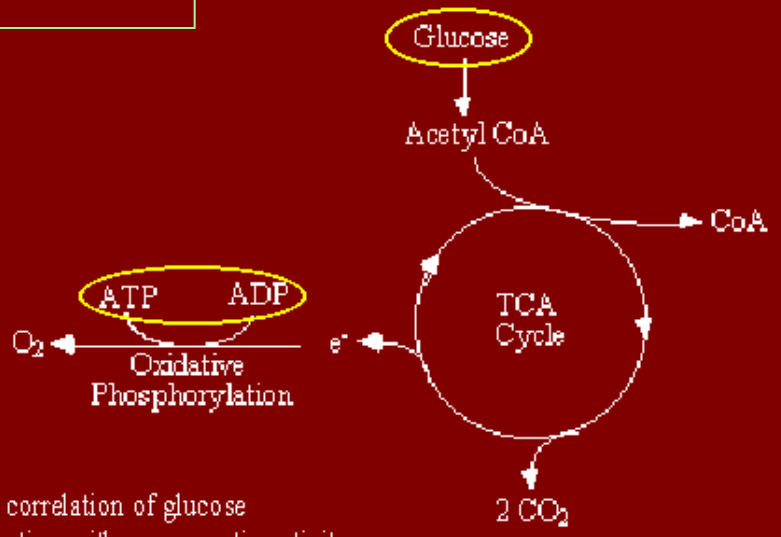


spiking activity



silver stain

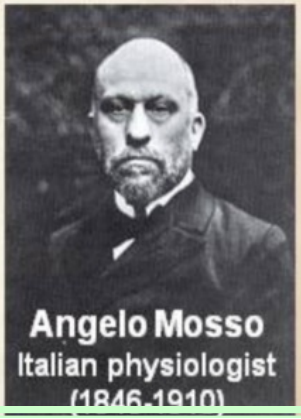
Brain Metabolism



high correlation of glucose utilization with pre-synaptic activity

How can we meassure brain activity?

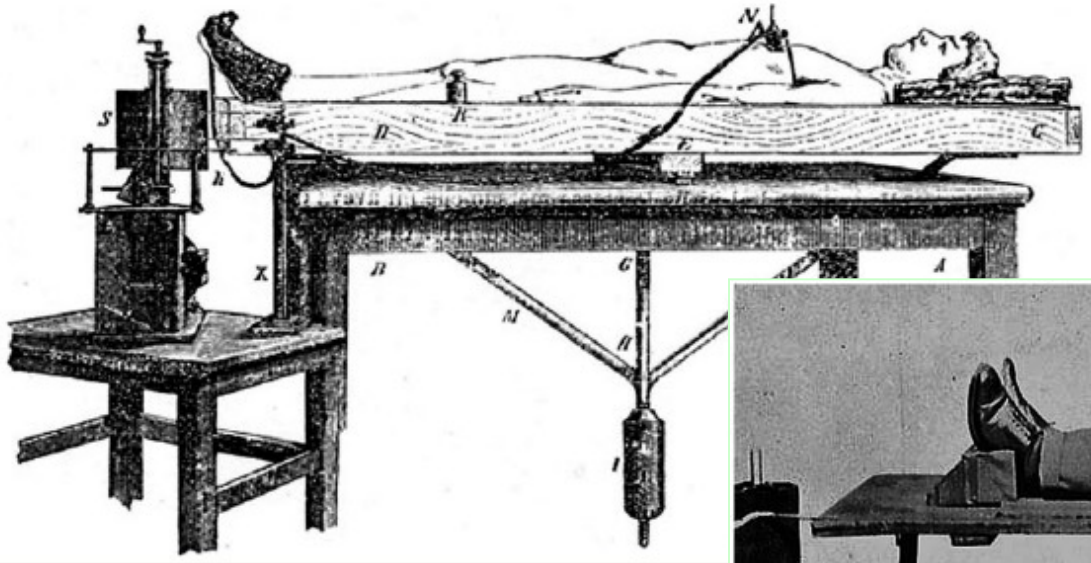
The first (and cheapest ¡) experiment



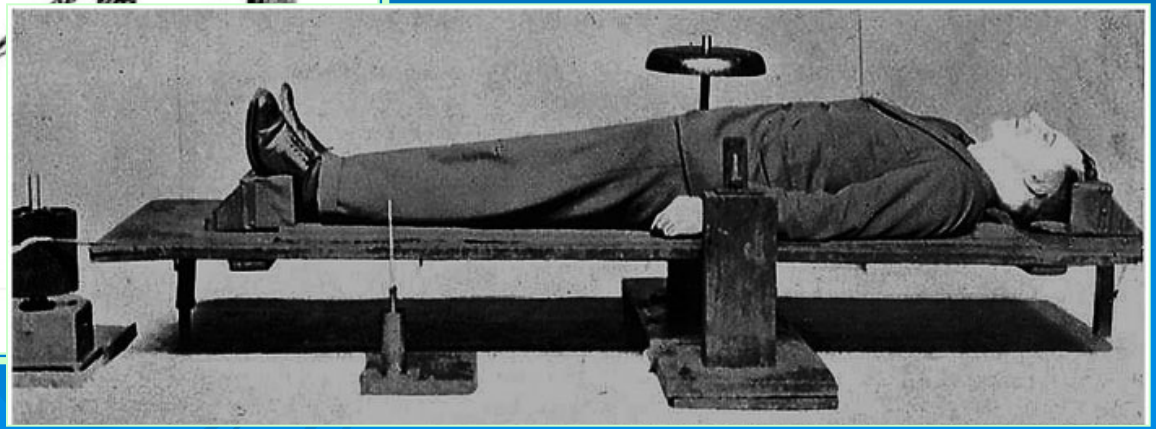
Angelo Mosso
Italian physiologist
(1846-1910)

Experiment: subject resting on a balanced table. Brain activity tilts the table towards the head. due to blood redistribution in the body.

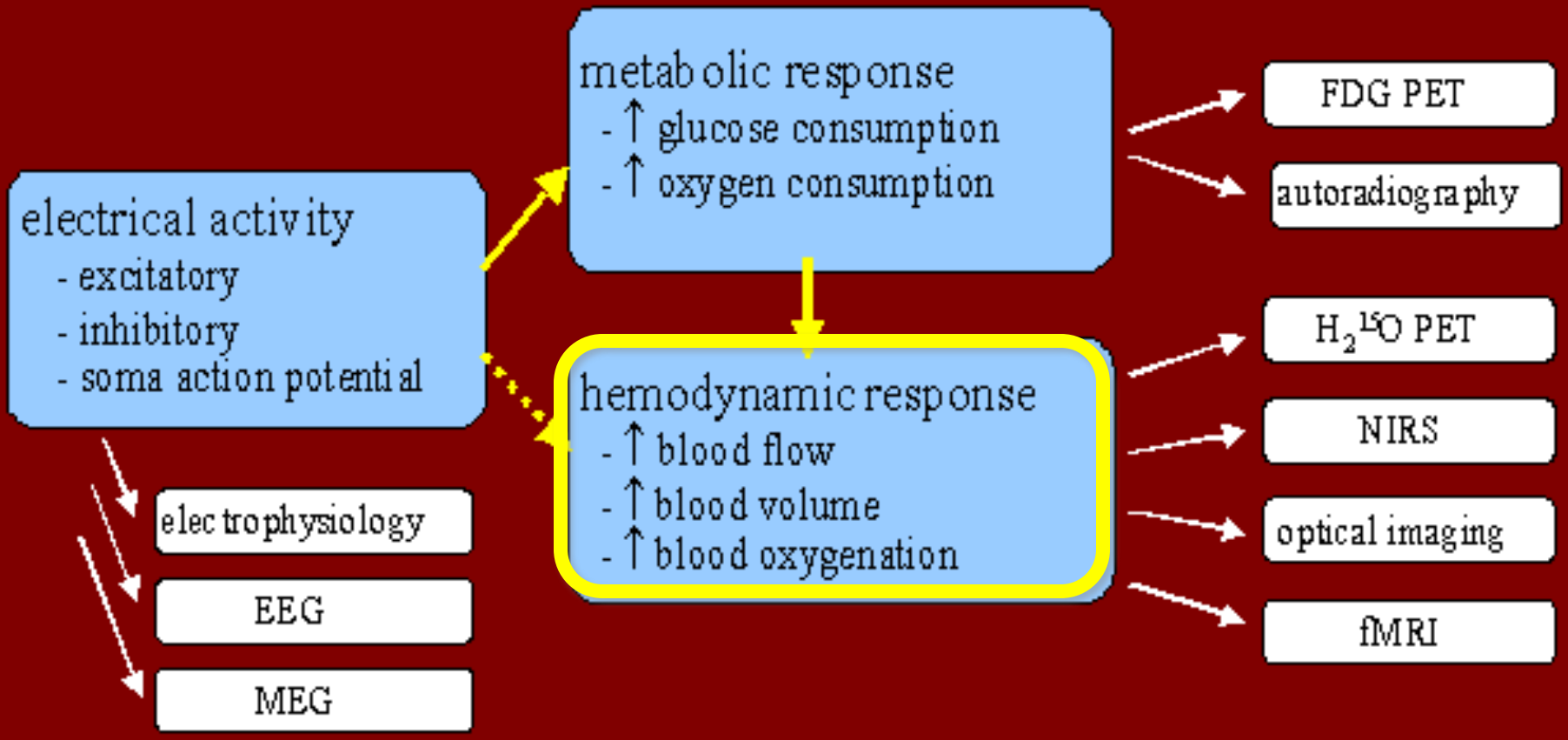
Slide from P.Ramos Cabrer, ESMRMB meeting 2008



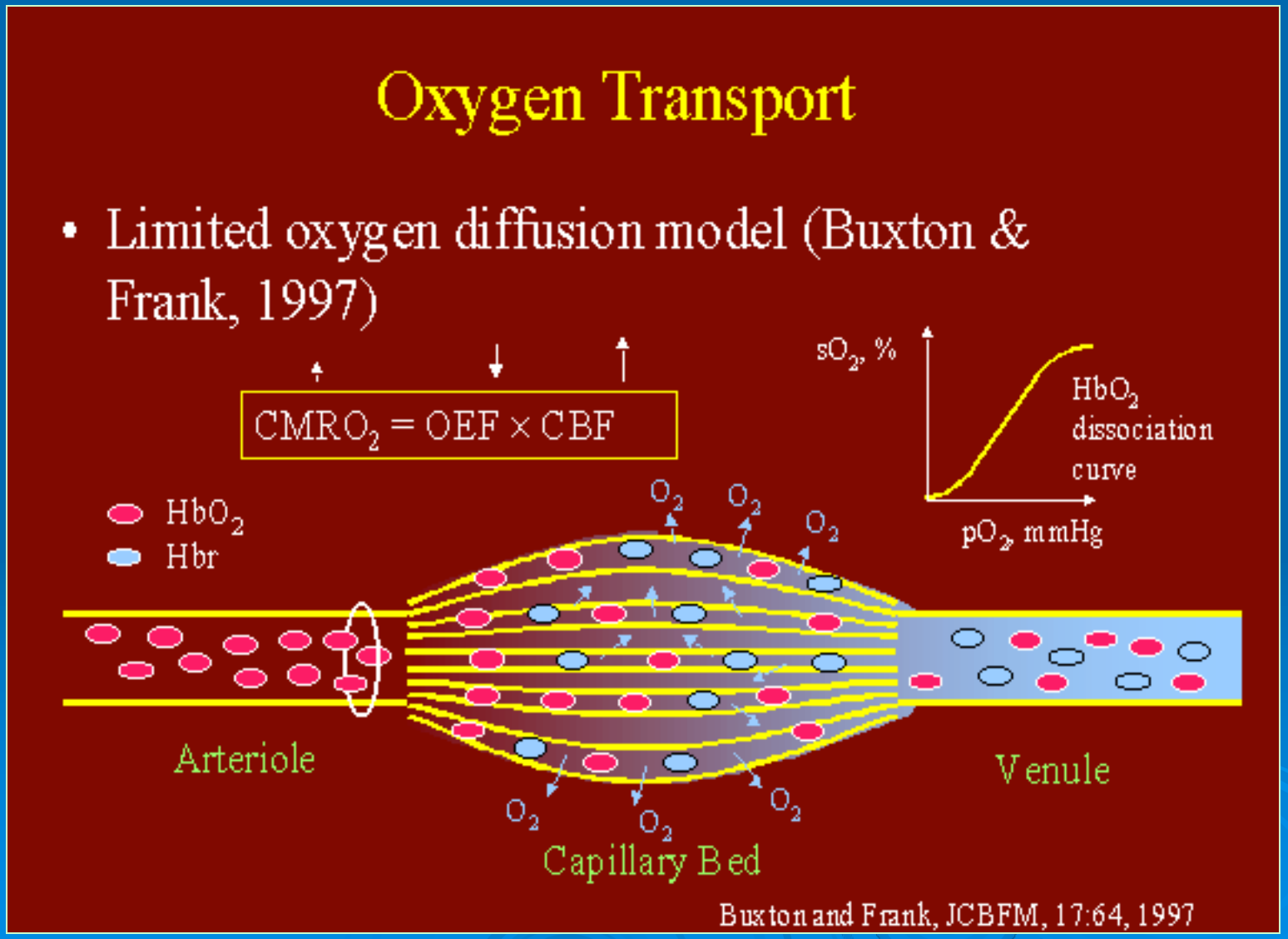
Sandrone et al (2013) Brain



Physiological Correlates of Brain Electrical Activity

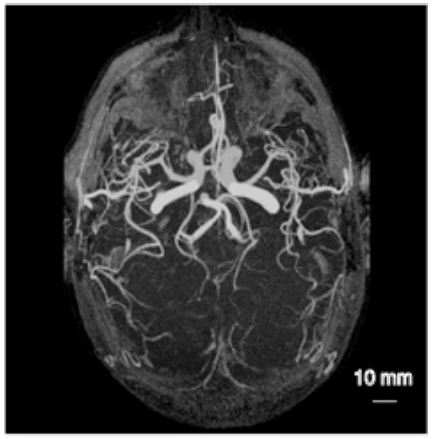


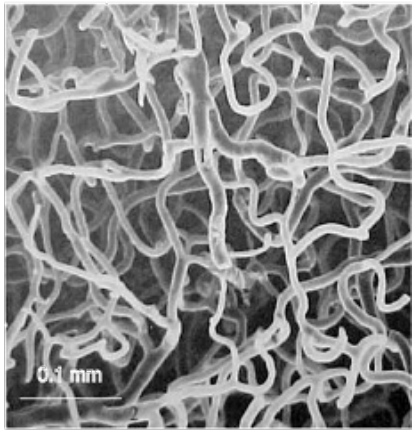
The physiology behind it

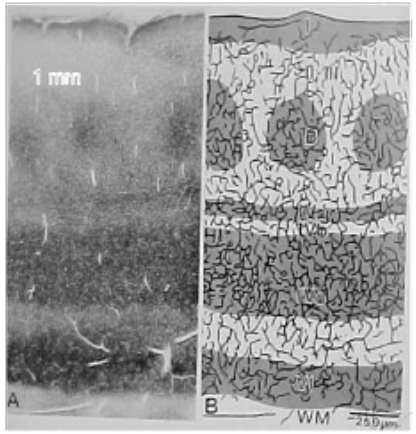


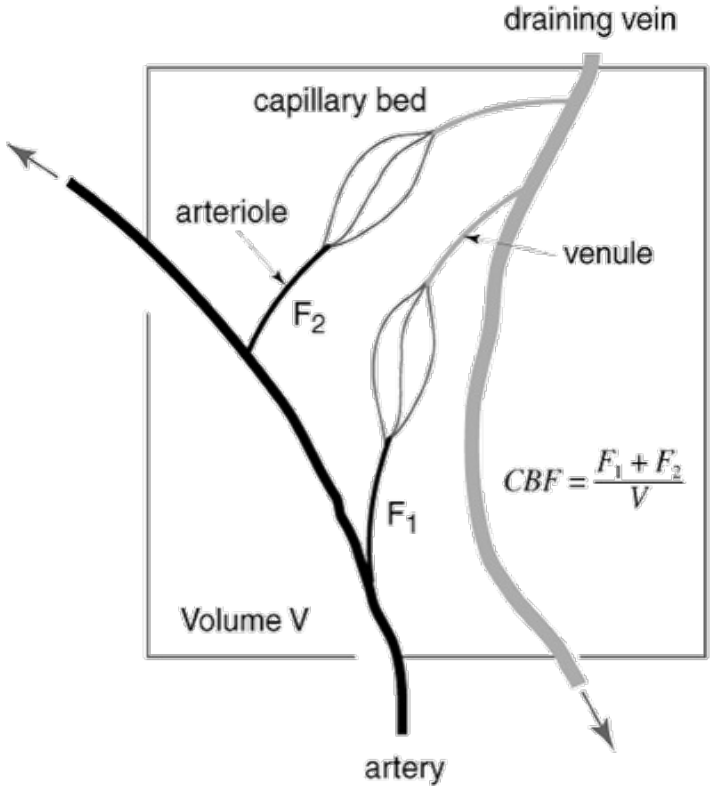
Vascular network

Cerebral Vasculature



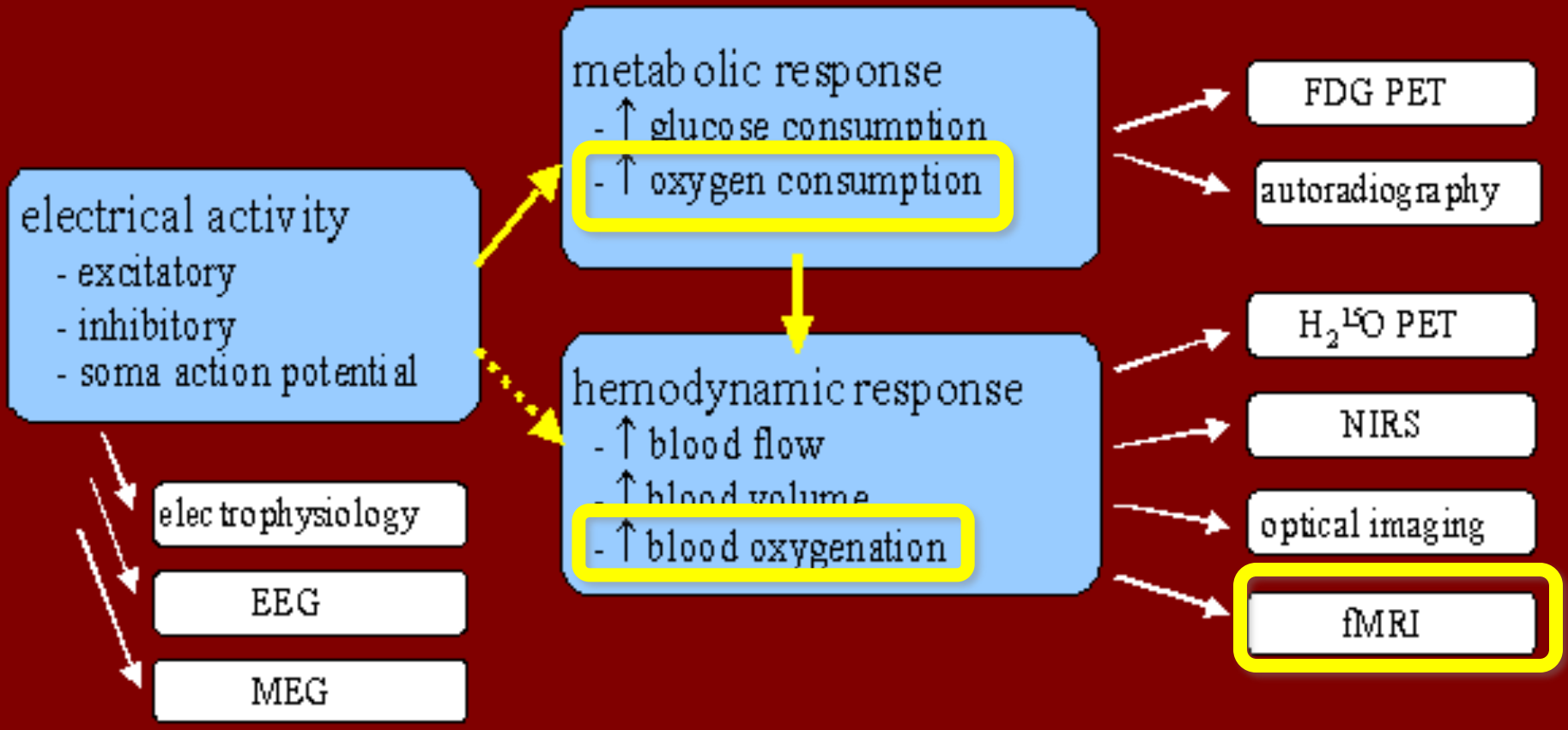






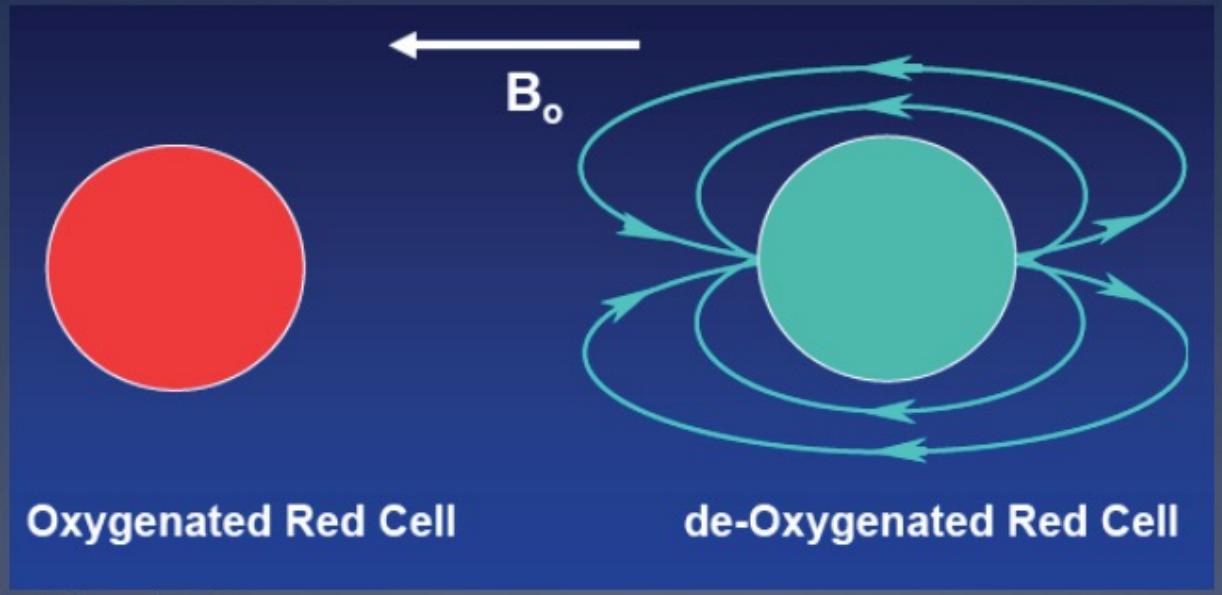
Source: Buxton book Ch 2

Physiological Correlates of Brain Electrical Activity



Magnetic properties of Red Cells

Field homogeneity & oxygenation state



- Red blood cell
  - 6 μm diameter, 1-2 μm thick
- Susceptibility
  - An object with differing magnetic properties distorts the field

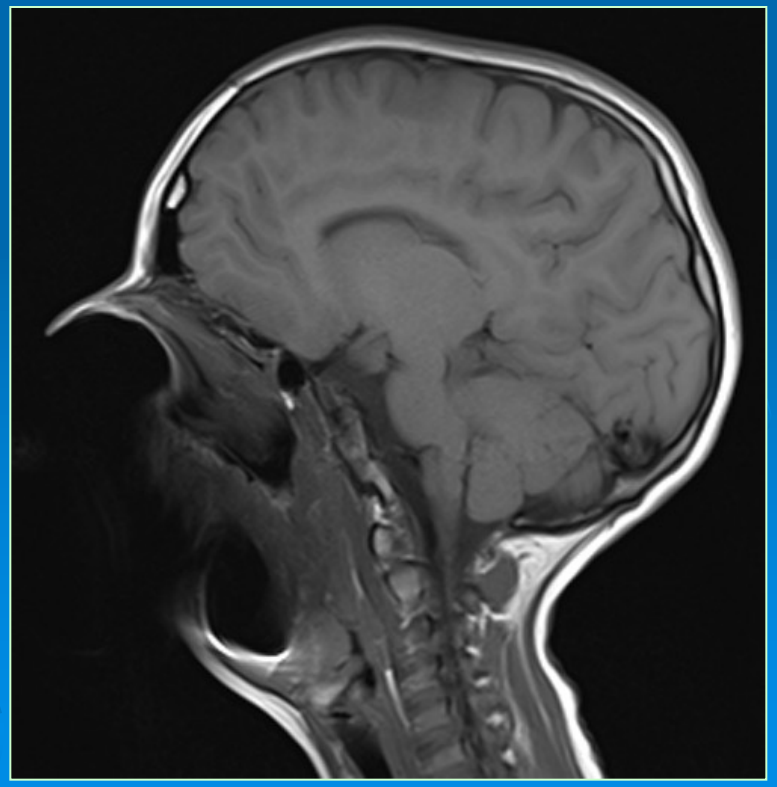
Slide by Daniel Bulte

Susceptibility Artifacts

- ✓ S*usceptibility*: generation of extra magnetic fields in materials that are immersed in an external field
- ✓ In T2*-weighted images, susceptibility determines signal loss

Effects That Cause T2* and T2 Dephasing

Causes of T2* Dephasing	Causes of T2 Dephasing
Spin-spin interactions	Spin-spin interactions
Magnetic field inhomogeneities	
Magnetic susceptibility	
Chemical shift effects	



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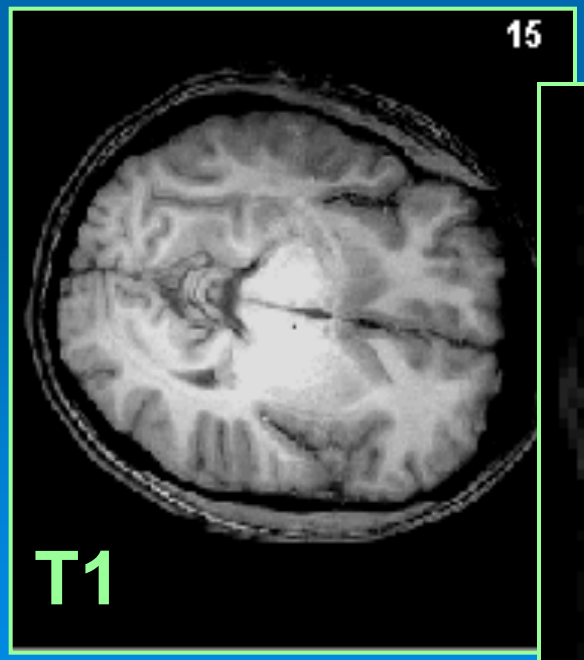
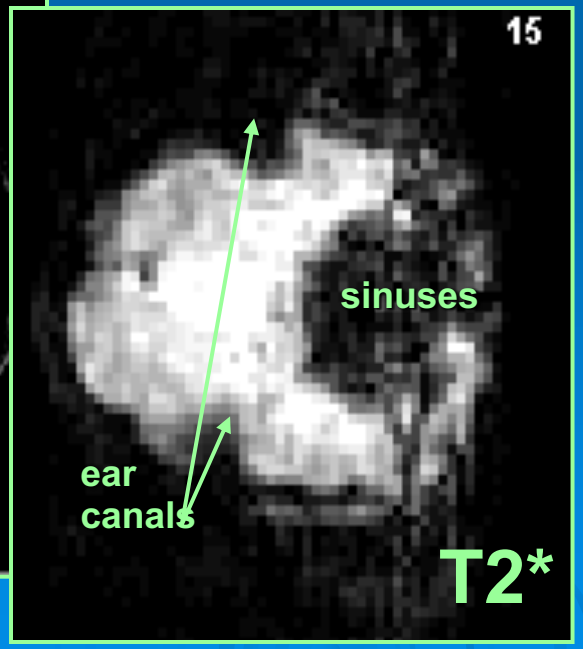
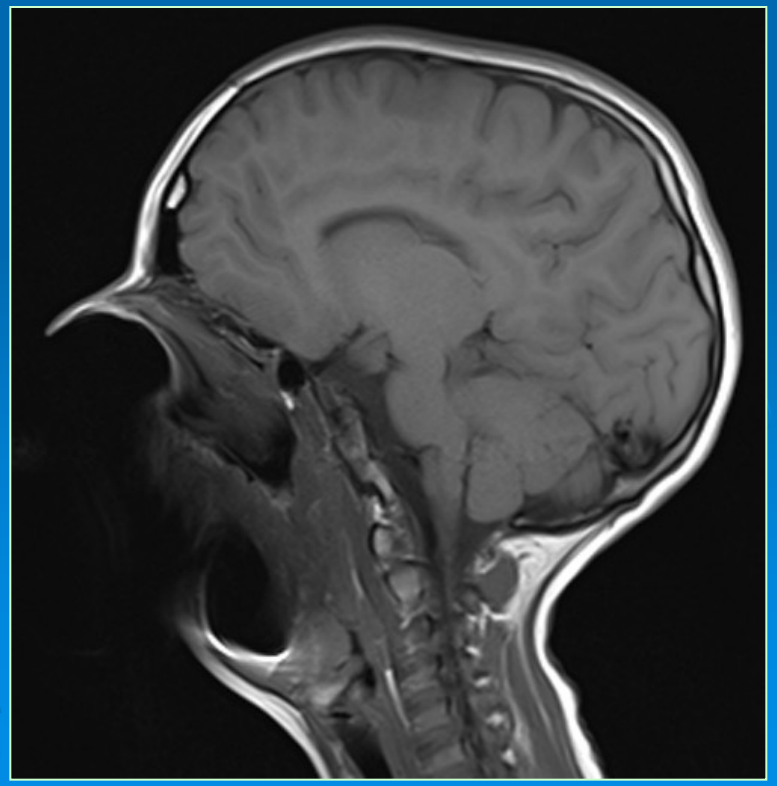
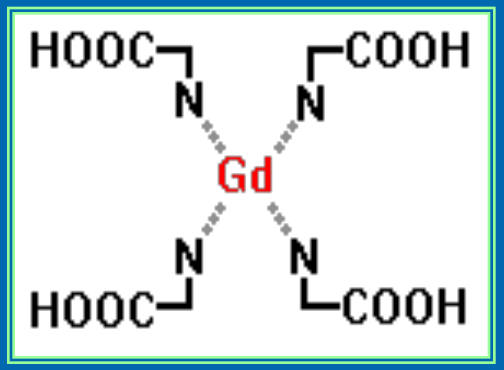
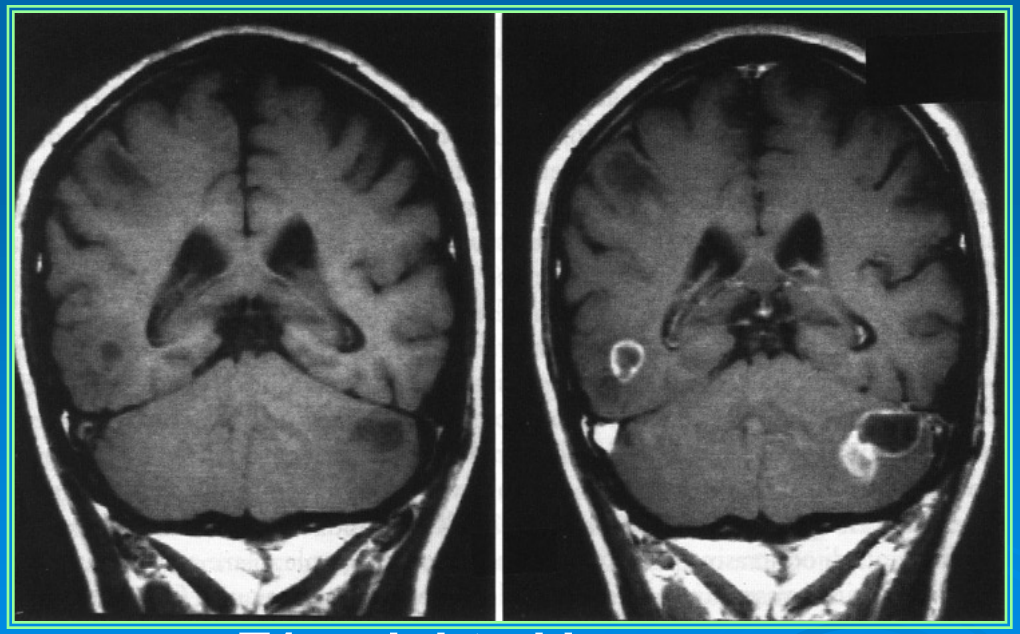






Paramagnetic contrast agents





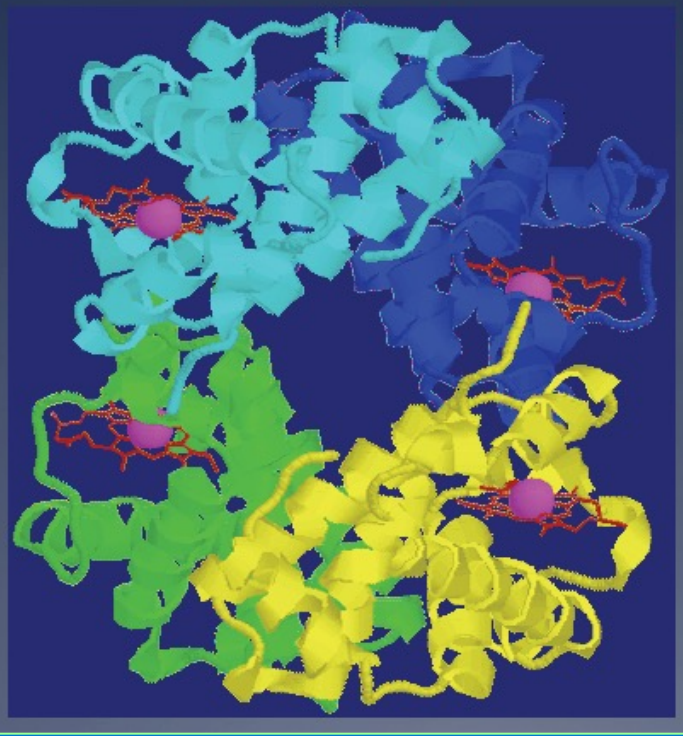
T1 weighted images

- The MRI contrast agent modulates the relaxation times of the tissues
  - Paramagnetic susceptibility
- Paul Lauterbur was the first to demonstrate the feasibility of using <u>paramagnetic contrast agents</u>
  - Nobel Prize 2003 in Medicine: Paul C Lauterbur and Peter Mansfield

www.imaios.com/en/e-Courses/e-MRI/Improving-MRI-contrast-Contrast-agents/contrast-agents

Blood magnetic properties

Deoxy-Haemoglobin

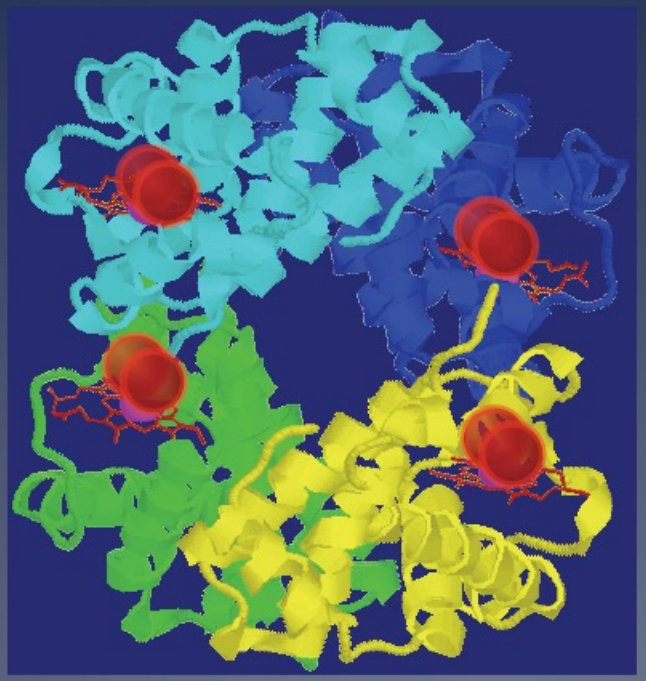


paramagnetic

different to tissue

$\Delta\chi$=0.08ppm

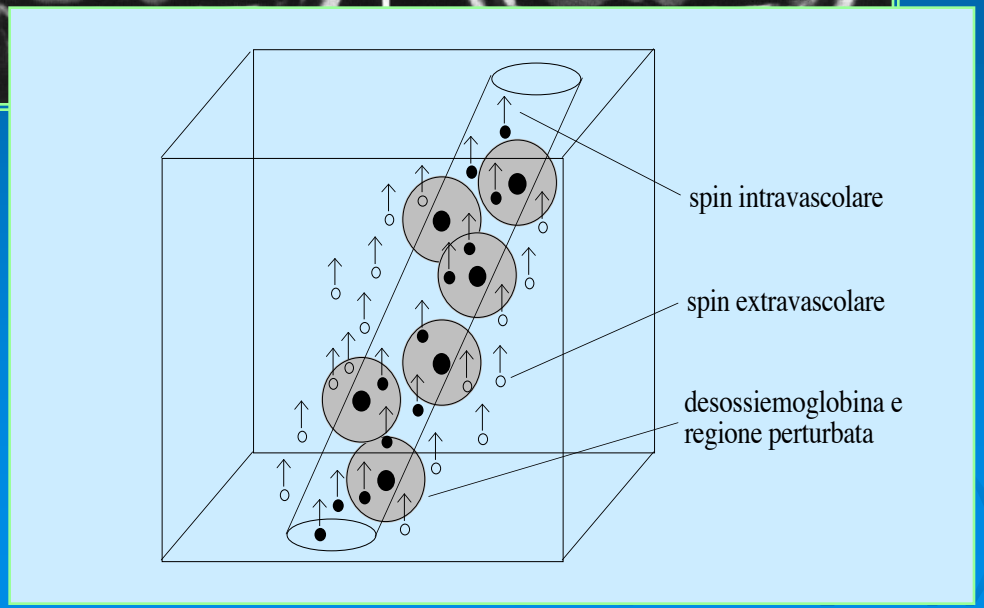
Oxy-Haemoglobin



diamagnetic

same as tissue

Paramagnetic contrast agents

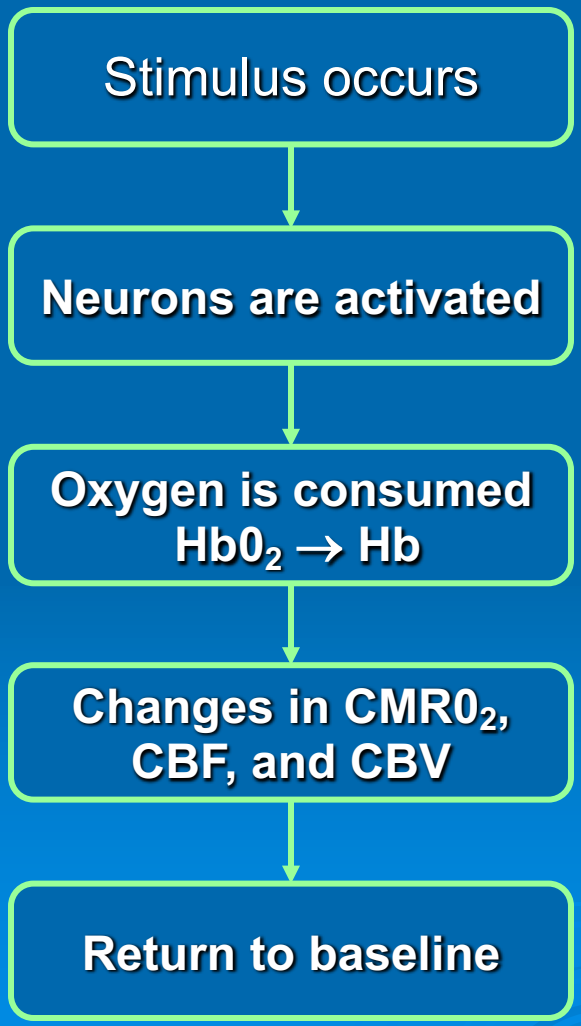


In fMRI deoxyhemoglobin is exploited as an endogenous contrast agent

- **BOLD contrast**
  - **Blood**
  - **Oxygen**
  - **Level**
  - **Dependent**

BOLD fMRI … on one slide!

Blood Oxigen Level Dependent

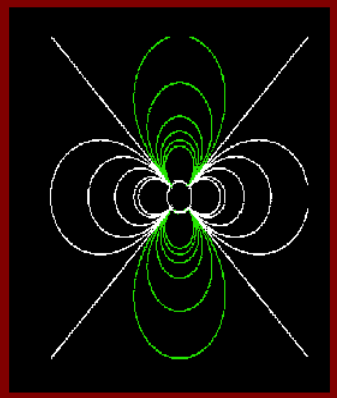


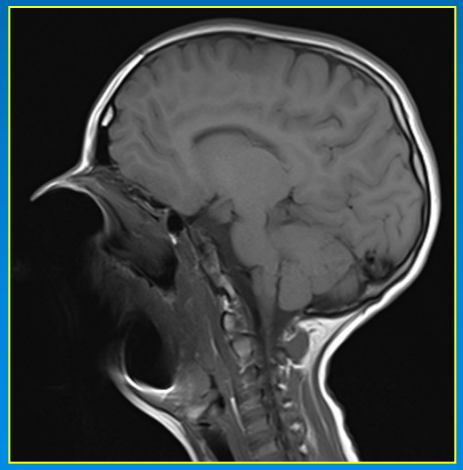
- **$Hb0_2$ is diamagnetic**
  - **creates a weak opposing magnetic field**
- **Hb is paramagnetic**
  - **a strong additive magnetic field**
- ***Increasing field strengths cause the signal to dephase more quickly, decreasing the signal***
  - **T_2* effect**

www.imaios.com/en/e-Courses/e-MRI/Functional-MRI/brain-activation-bold-contrast

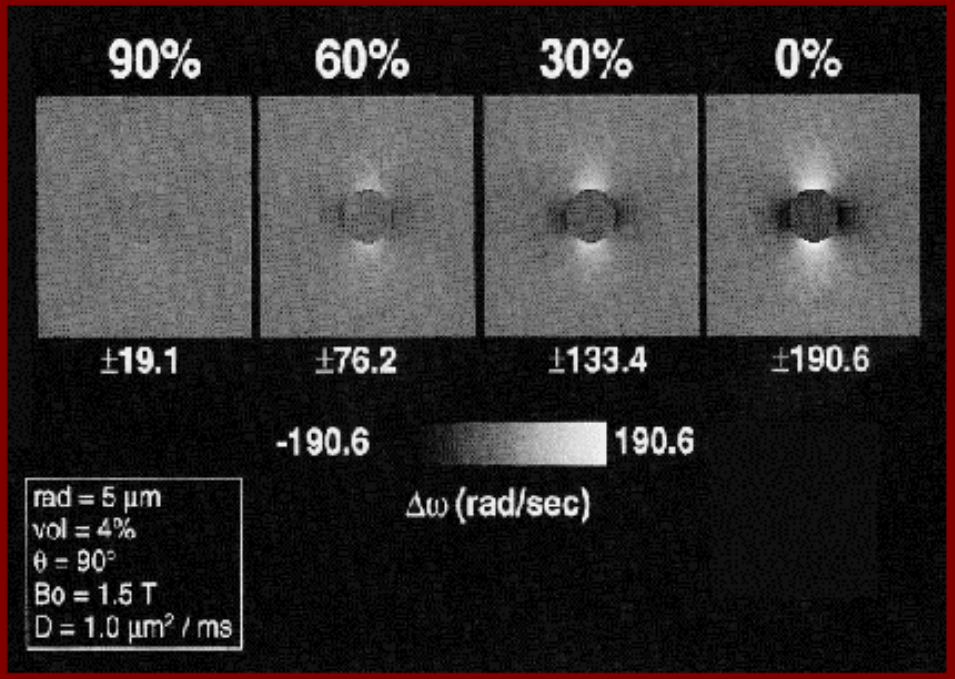
Is BOLD signal visible ?

Magnetic Field Distortions Around a Cylinder

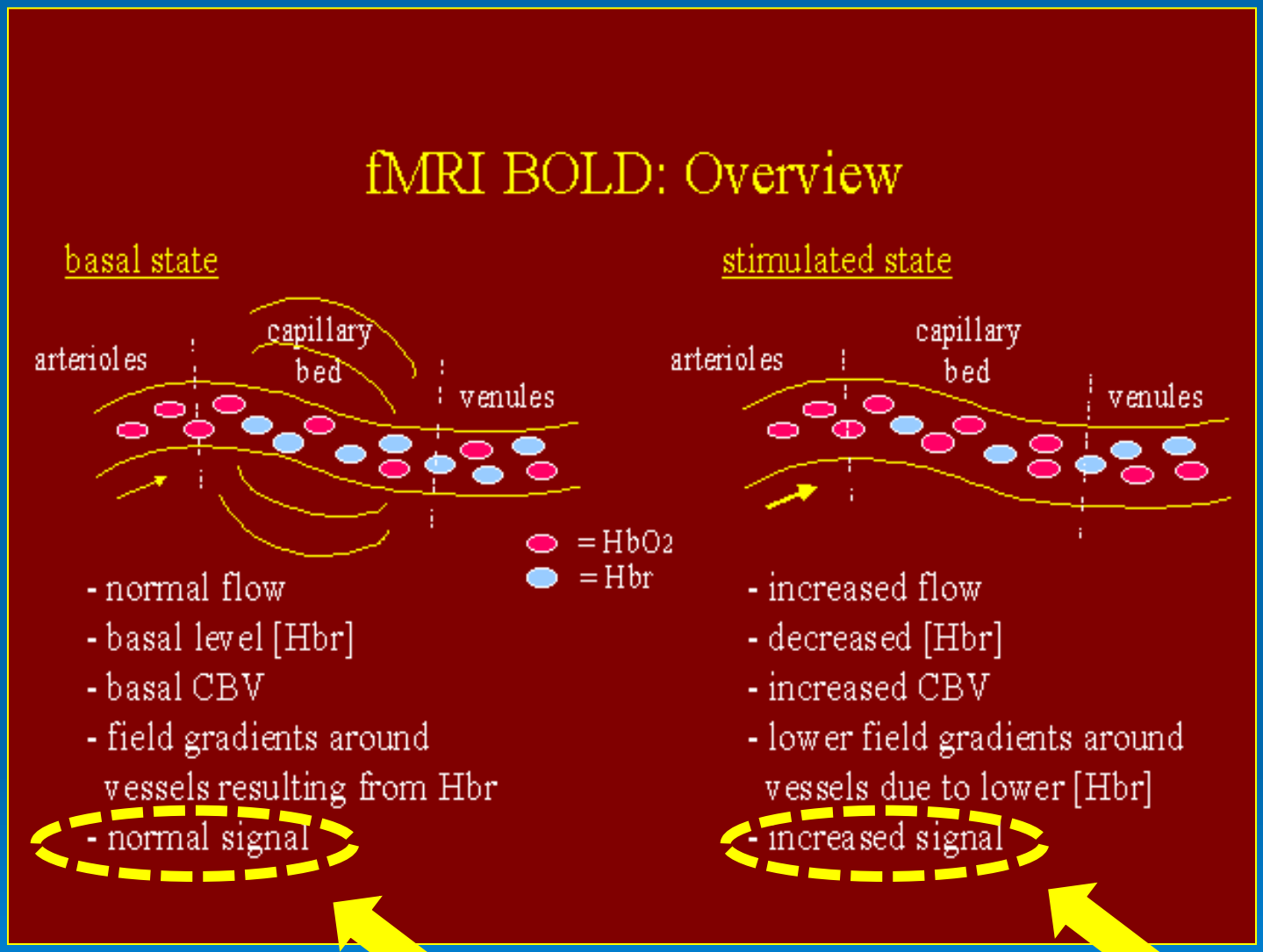




Variation with O_2 Saturation



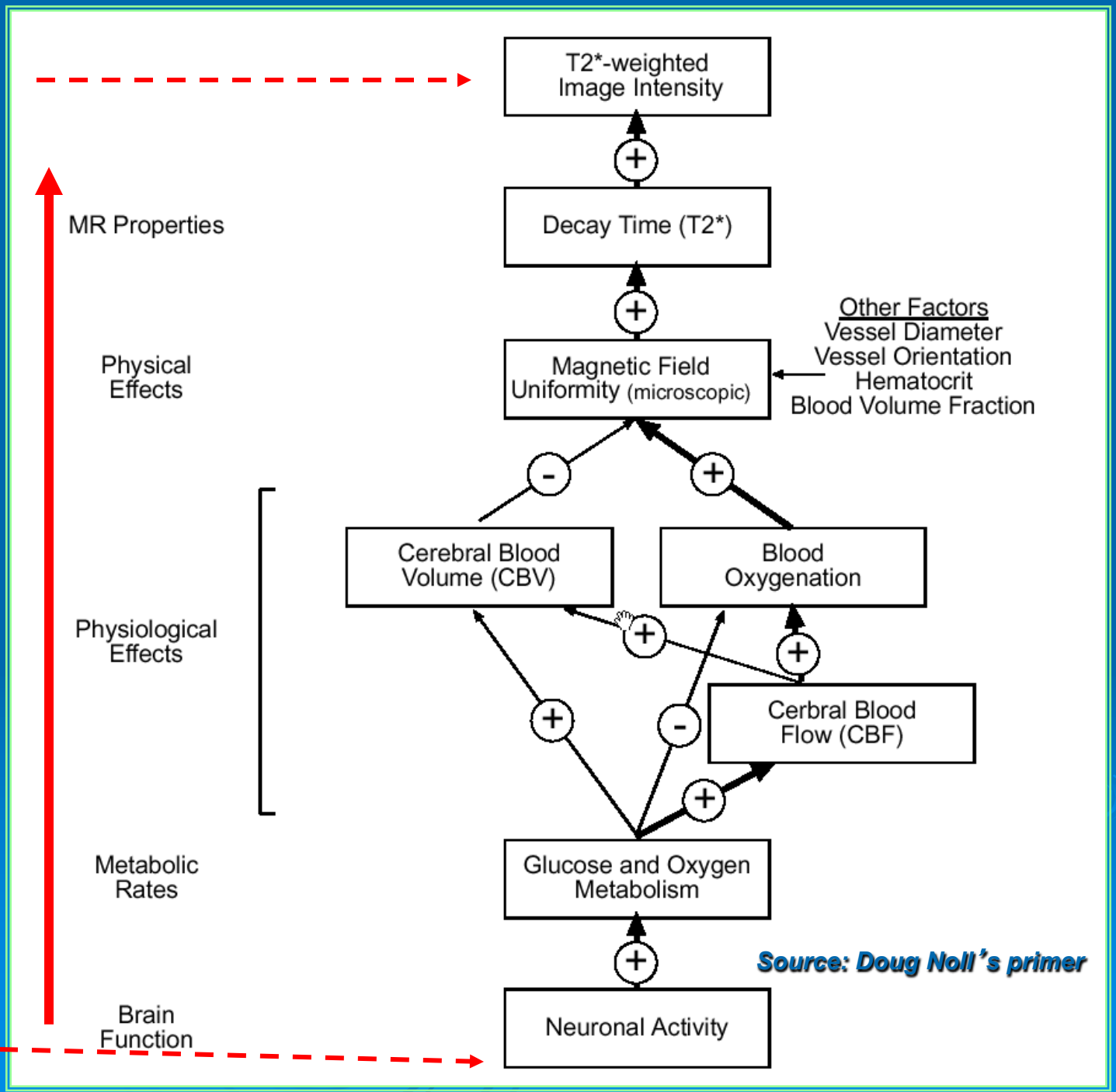
Bandettini and Wong. Int. J. Imaging Systems and Technology. **6**:133 (1995)



Blood Oxygen Level Dependent (BOLD) signal is a relative value:

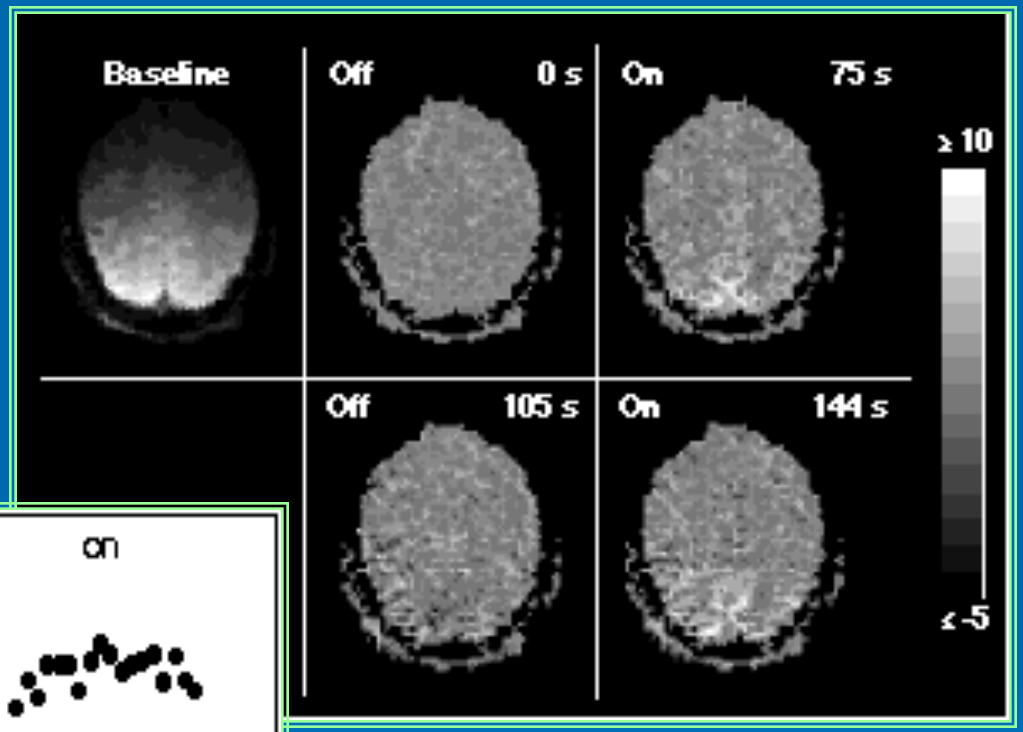
✓**It is necessary to collect both basal and stimulated images and comparing them**

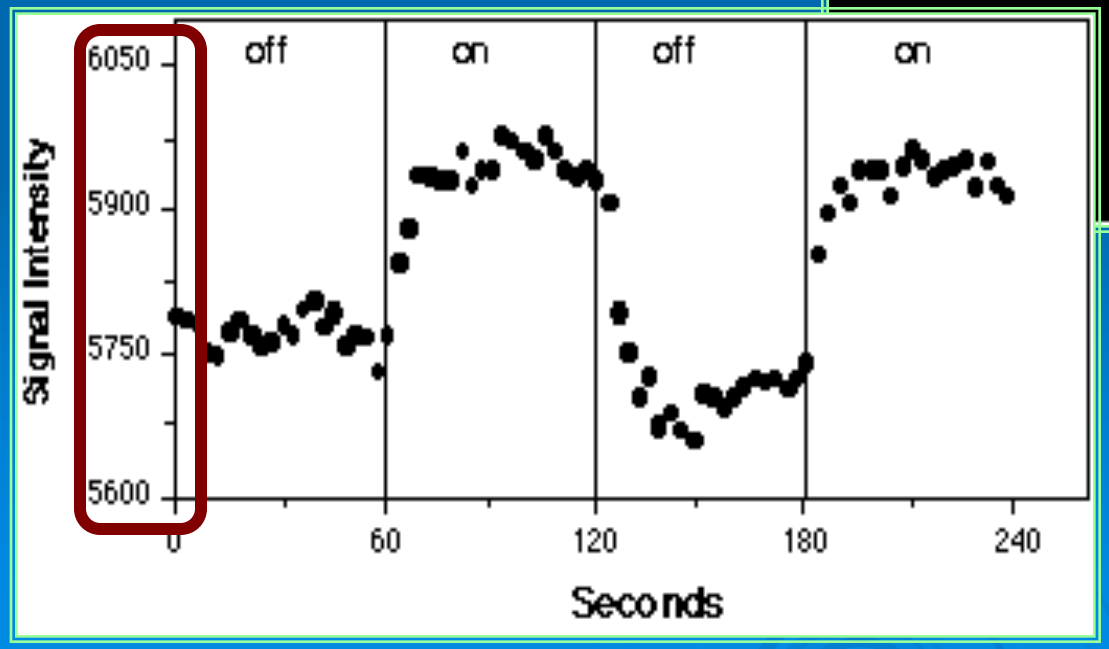
What we observe



What we want to study

First Functional Images

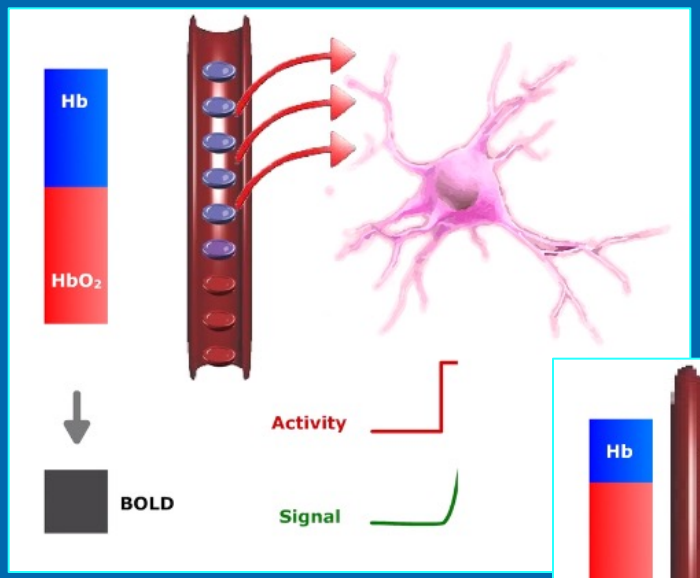


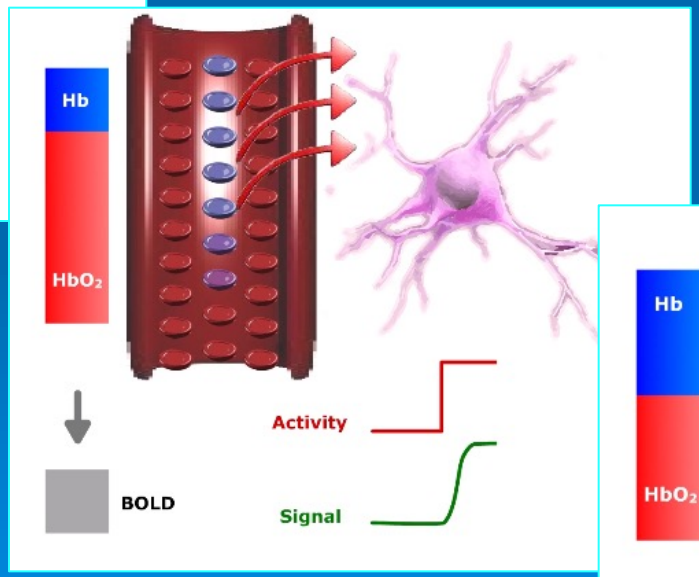


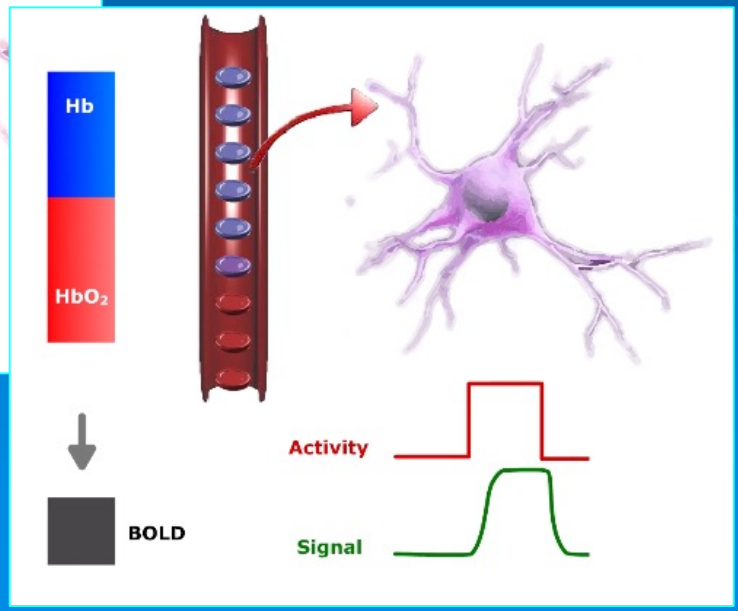
Source: Kwong et al., 1992

https://www.imaios.com/en/e-Courses/e-MRI/Functional-MRI/analysis-functional-mri-data

Hemodinamic response and MRI signal

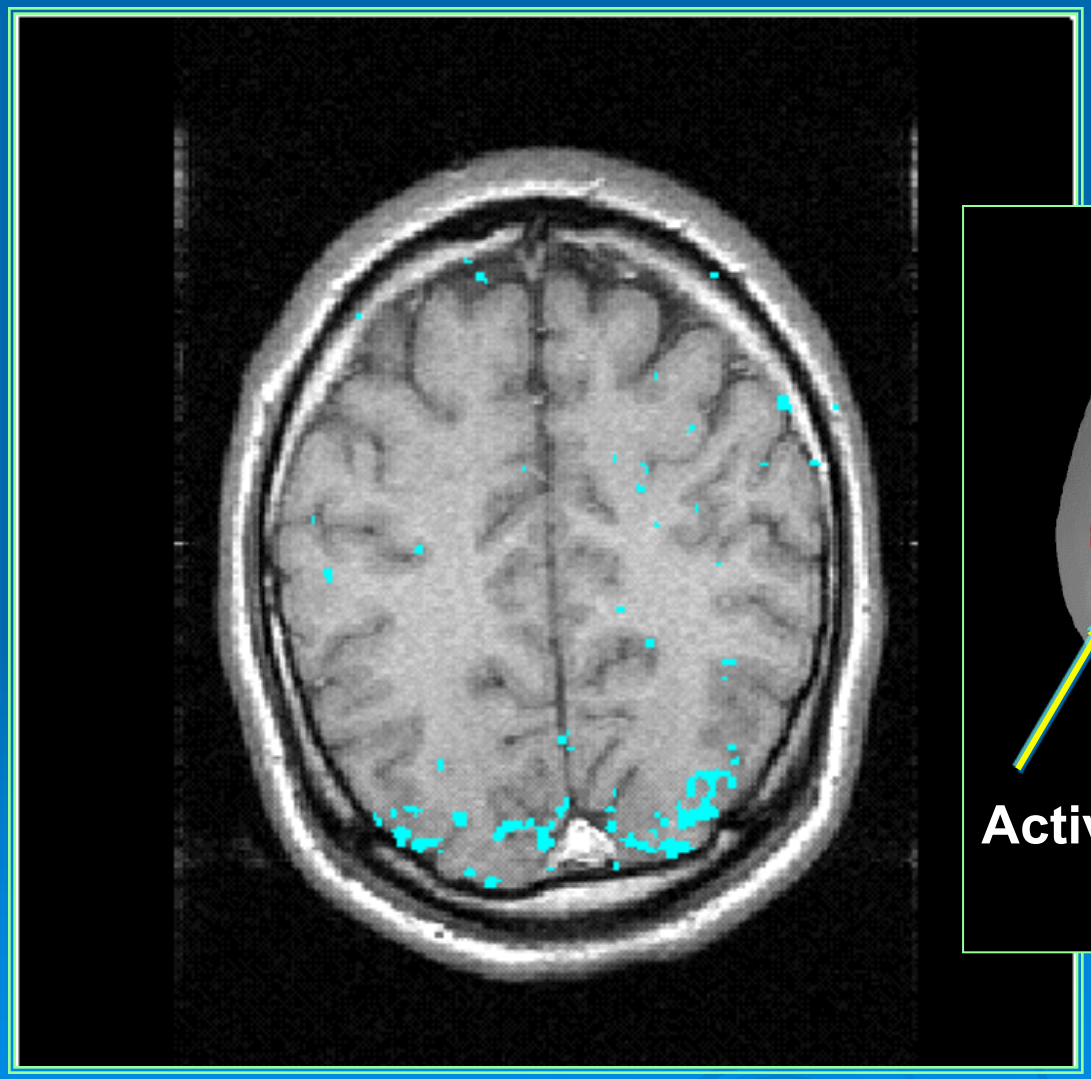


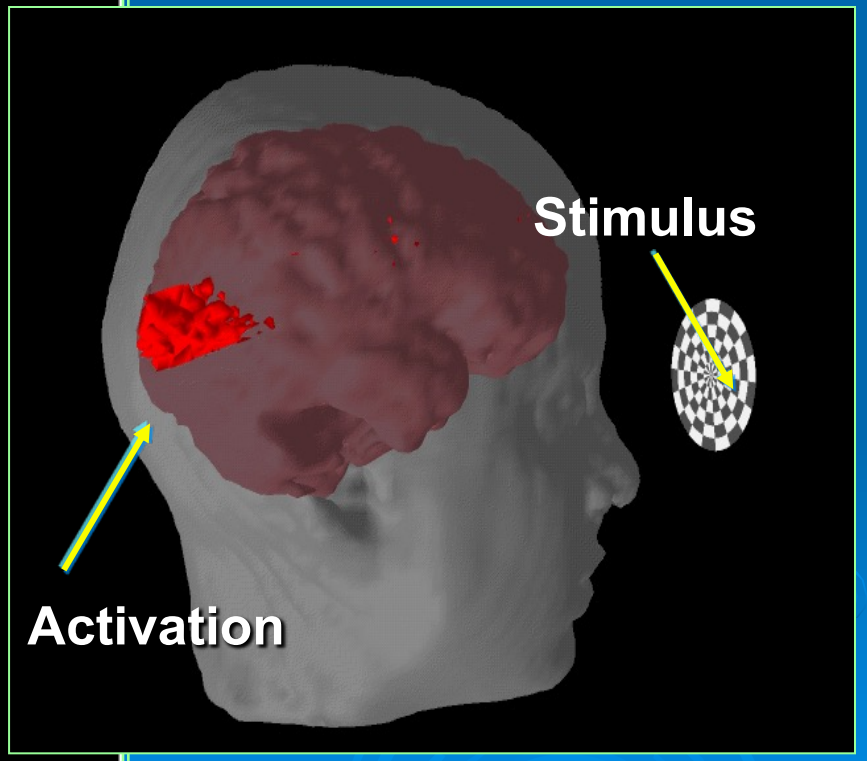




https://www.imaios.com/en/e-Courses/e-MRI/Functional-MRI/brain-activation-bold-contrast

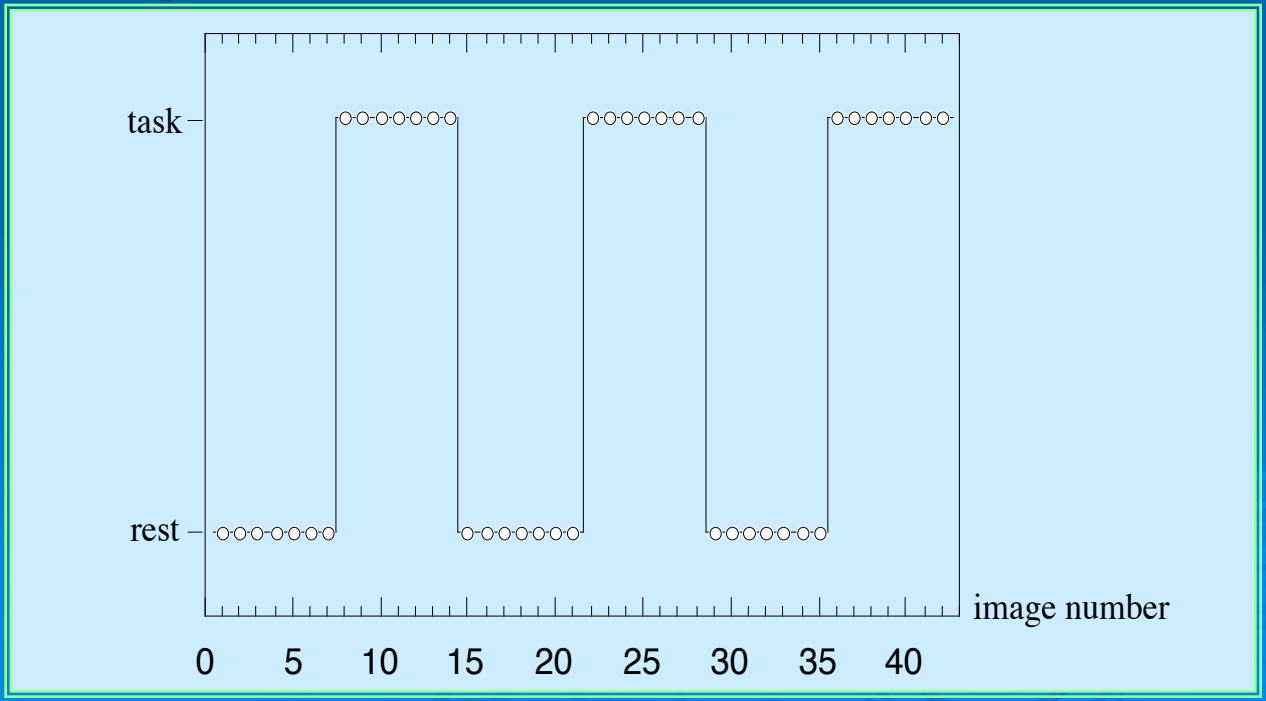
Visual stimulus





Block paradigm experimental protocol

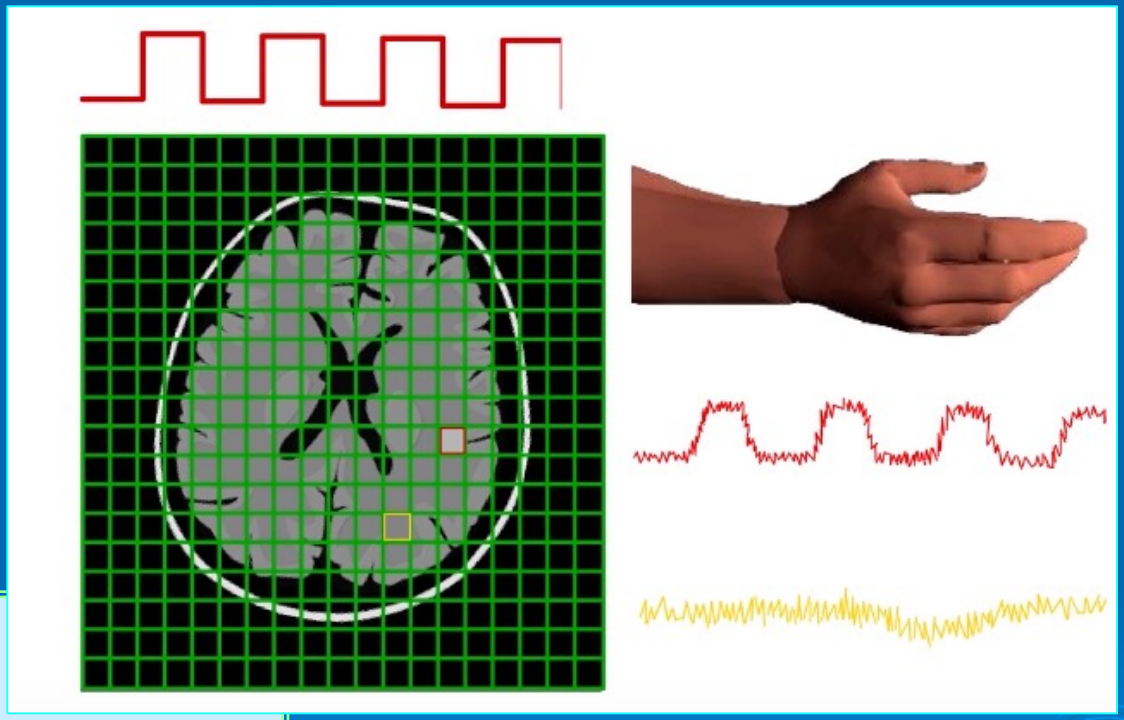
- about ~150 images
- Task and rest periods
- Total acquisition times ~5 minutes

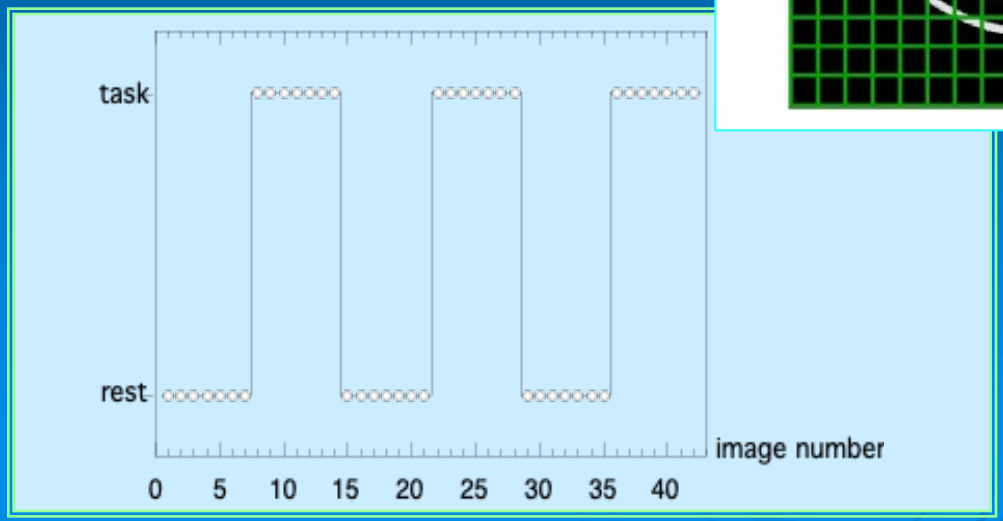


https://www.imaios.com/en/e-Courses/e-MRI/Functional-MRI/analysis-functional-mri-data

Block paradigm experimental protocol

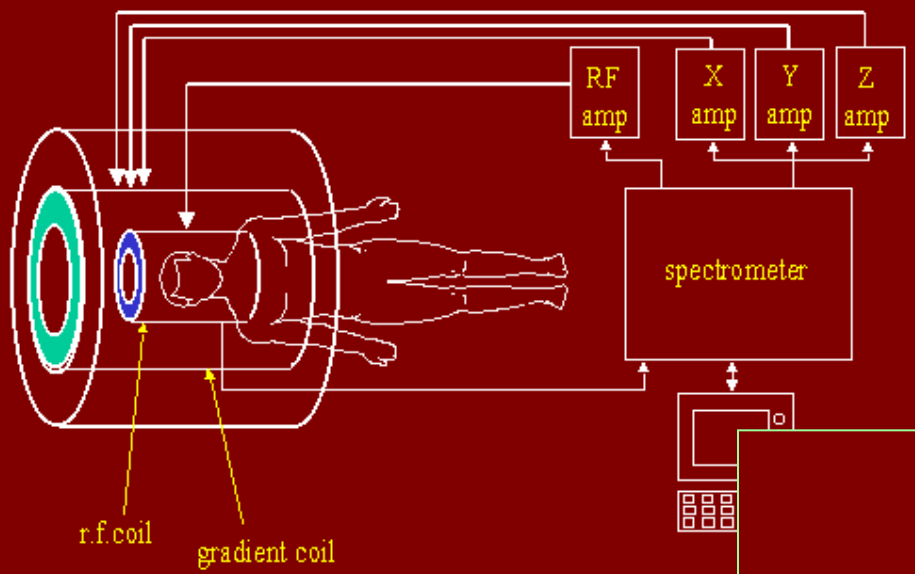
- Task and rest periods



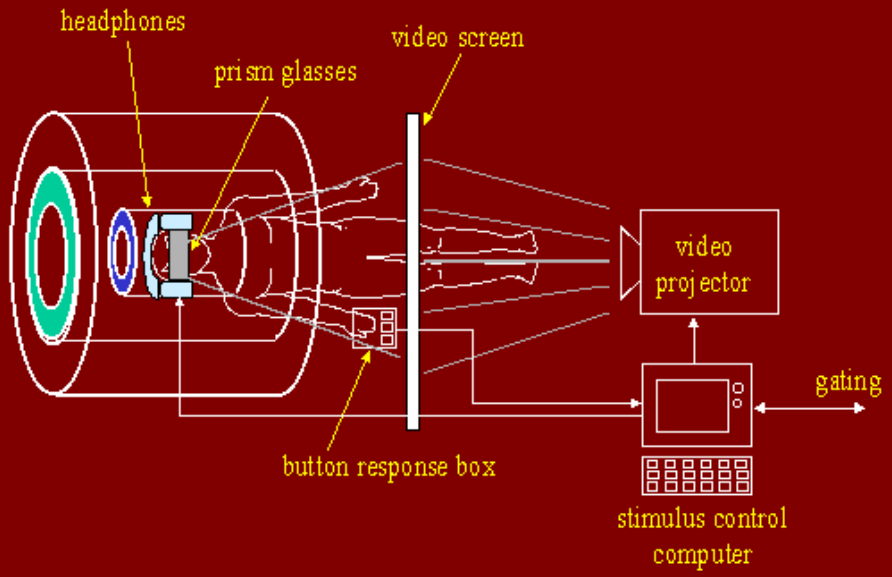


How to do

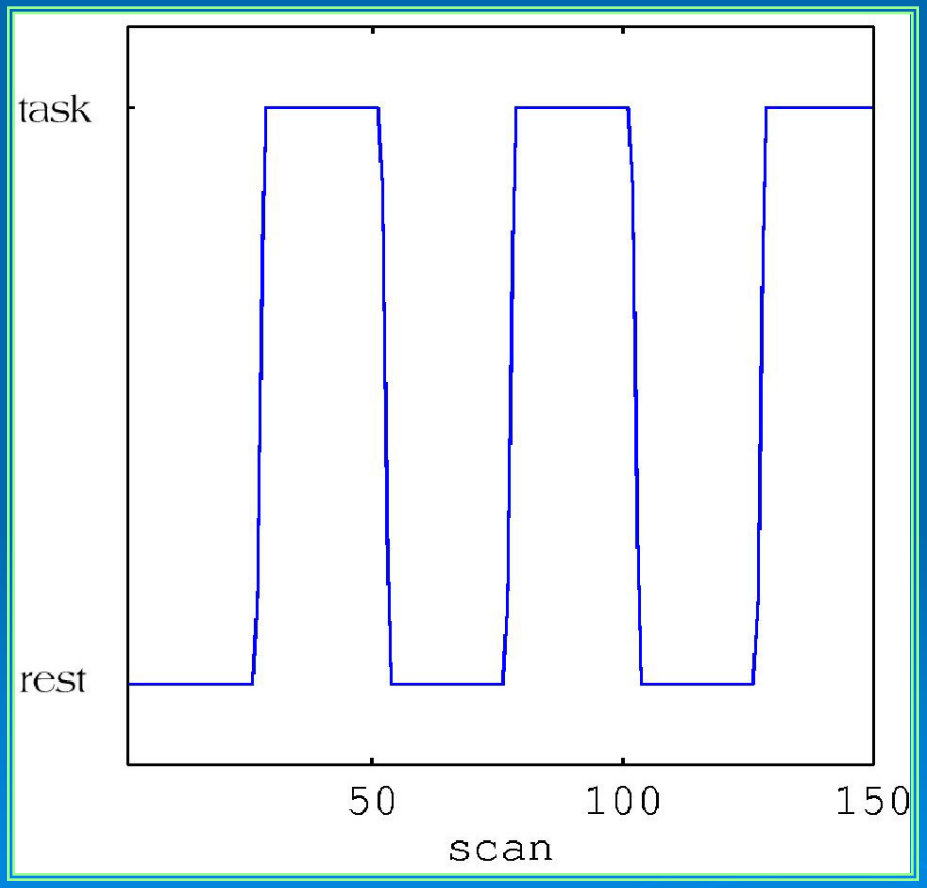
MRI System Block Diagram

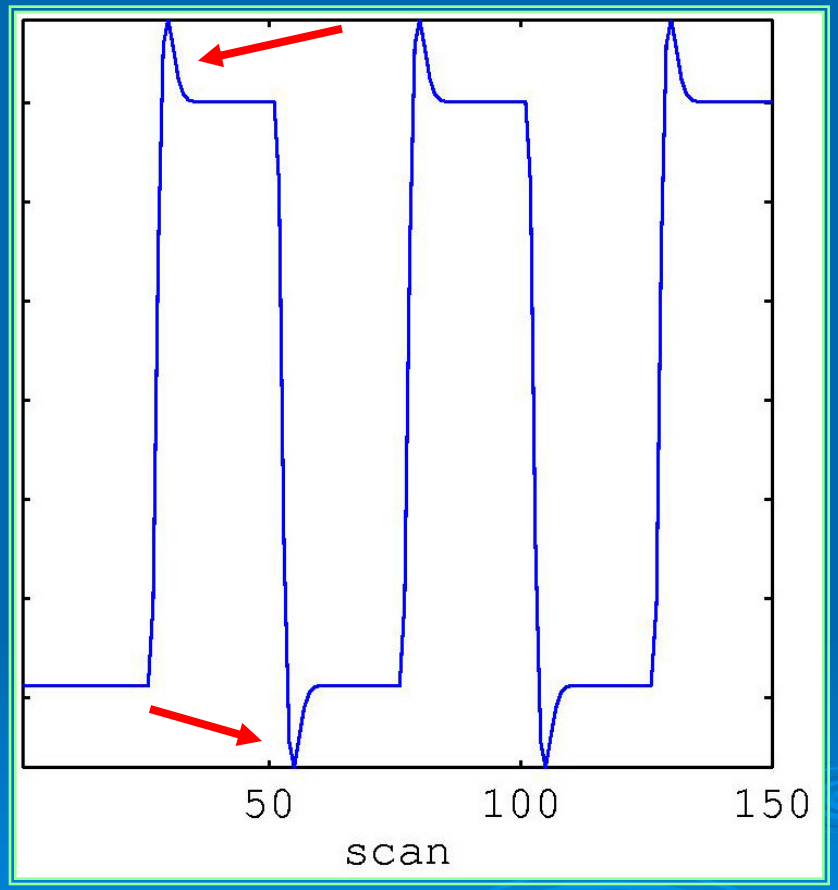


fMRI Additions



Block protocol and BOLD signal

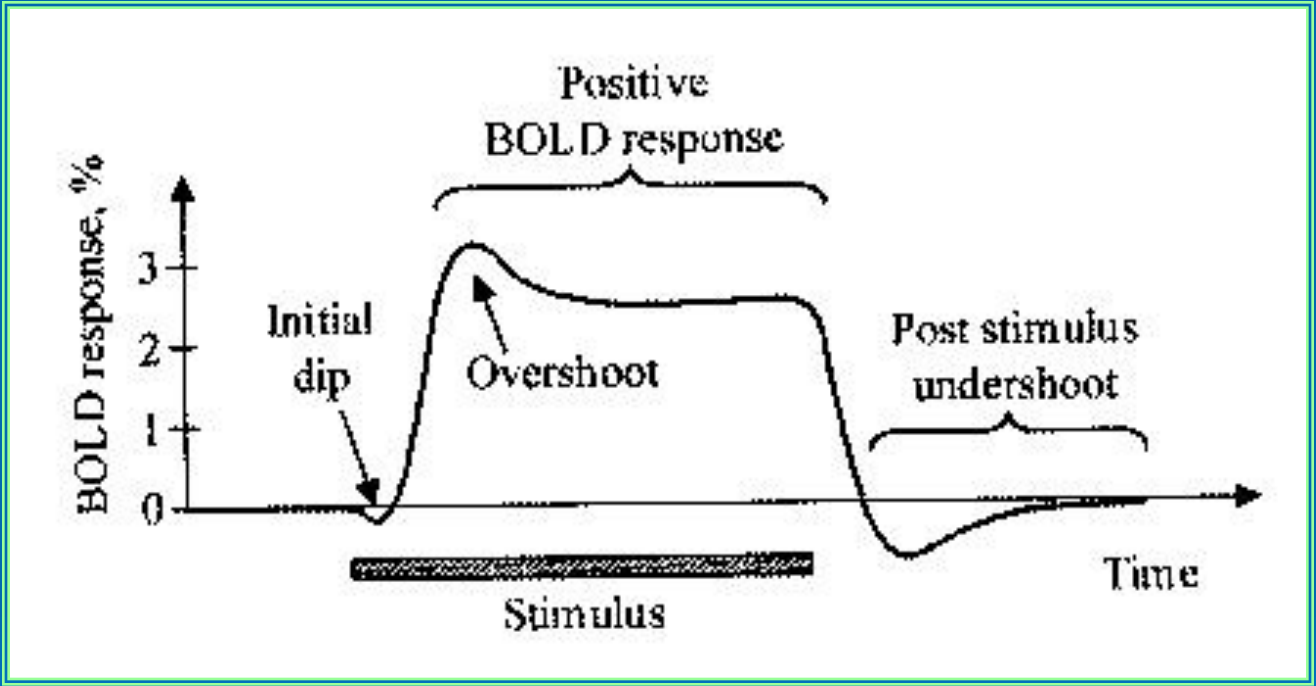




Block protocol:
Timing of the stimulus

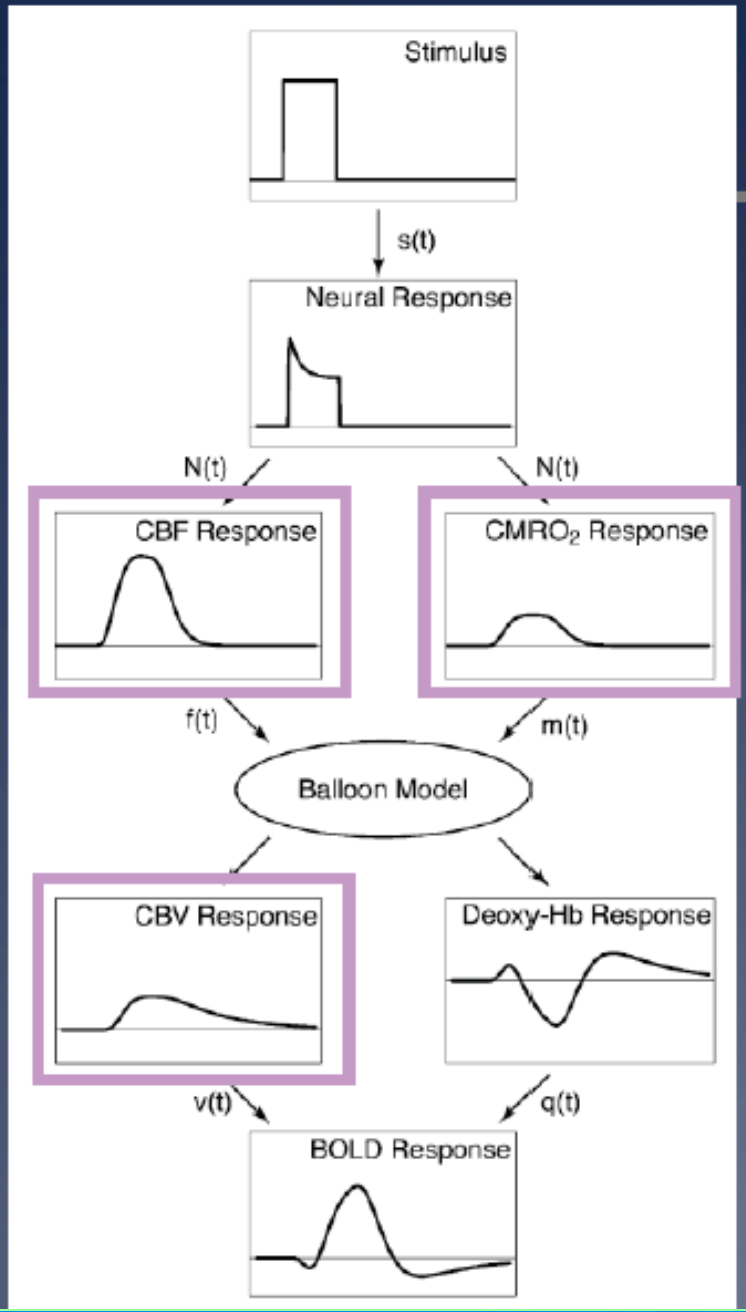
BOLD signal:
Signal intensity of a voxel during the scans (time)

Hemodynamic Response Function



- ✓ % signal change
  - = (point – baseline)/baseline
  - usually 0.5-3%
- ✓ initial dip
  - more focal
  - somewhat elusive so far
- ✓ time to rise
  - signal begins to rise soon after stimulus begins
- ✓ time to peak
  - signal peaks 4-6 sec after stimulus begins
- ✓ post stimulus undershoot
  - signal suppressed after stimulation ends

Dissecting BOLD



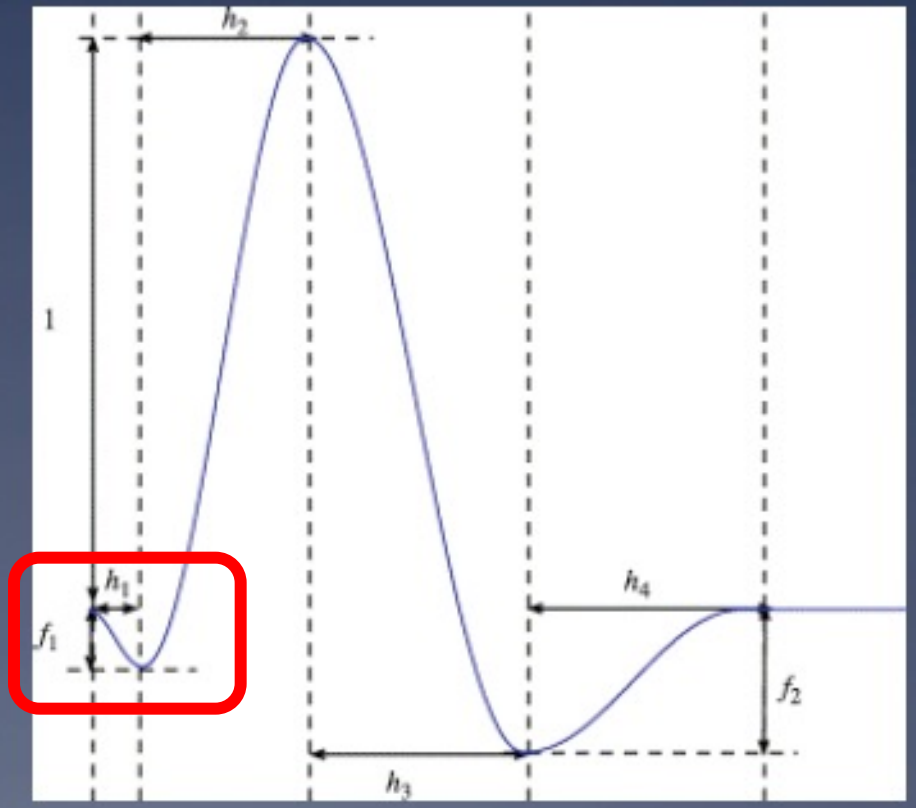
$$S_{BOLD} = f(CBV, CBF, CMRO_2)$$

Purer measures of neuronal activity?

Buxton et al. Neuroimage 2004

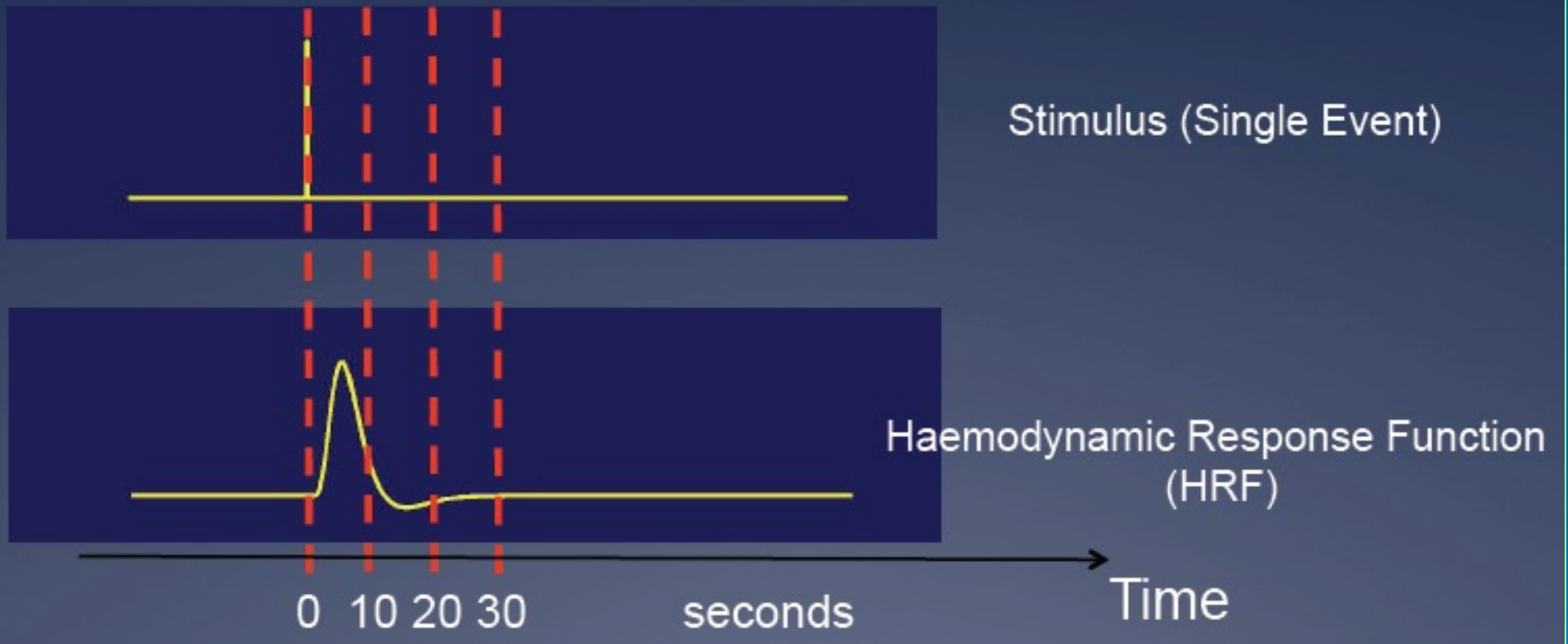
FMRI Modelling: The Haemodynamic Response

* The stimulus is convolved with an assumed or modeled impulse response function, the haemodynamic response function (HRF), to give the assumed BOLD response



✓**initial dip**
- **more focal**
- **somewhat elusive so far**

HRF



The haemodynamic response to a stimulus is blurred and delayed

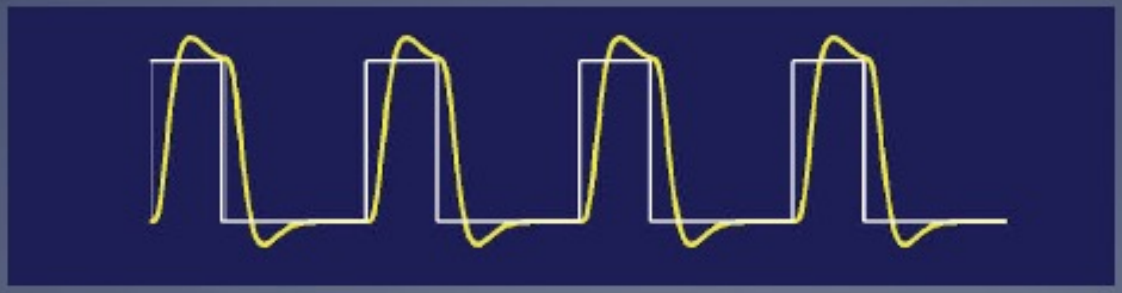
Predicted Response

* The process can be modeled by **convolving** the activity curve with the HRF

HRF

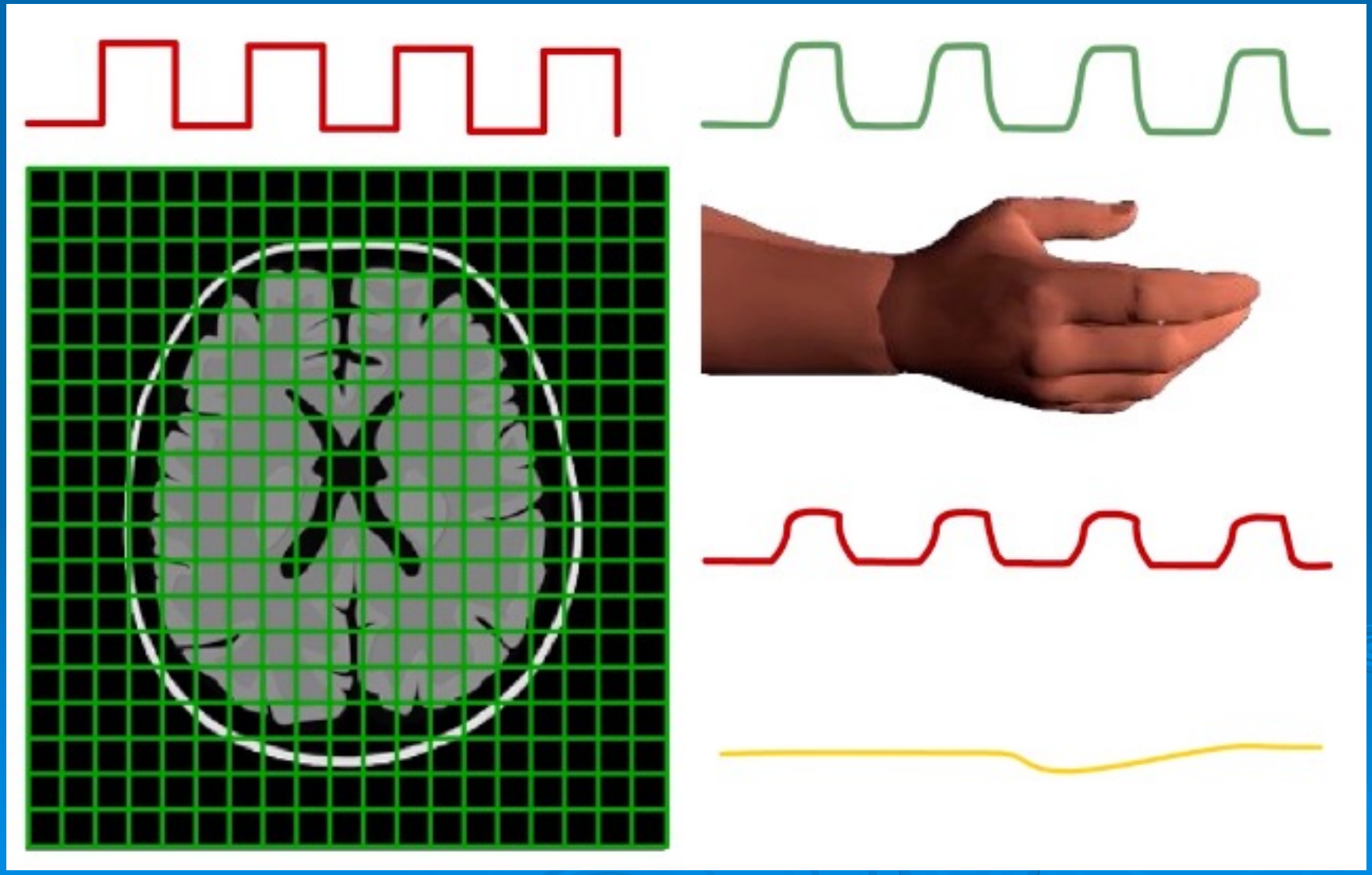
Predicted neural activity

=



Predicted response

fMRI modelling



https://www.imaios.com/en/e-Courses/e-MRI/Functional-MRI/analysis-functional-mri-data

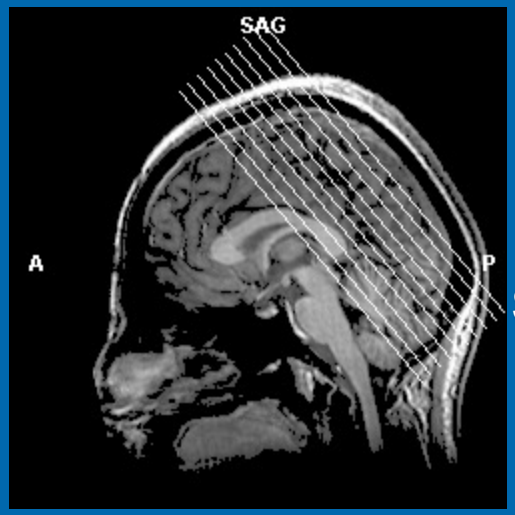
Statistical analysis

GLM

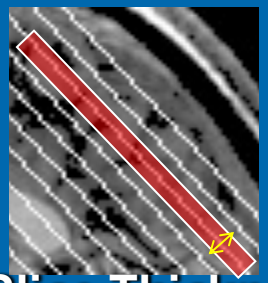
General linear model

- **Standard GLM Analysis:**
  - Correlate model at each voxel separately
  - Measure residual noise variance
  - T-statistic = model fit / noise amplitude
  - Threshold T-stats and display map
- Signals of no interest (e.g. artifacts) can affect both activation strength and residual noise variance
- Use pre-processing to reduce/eliminate some of these effects

Slice Terminology

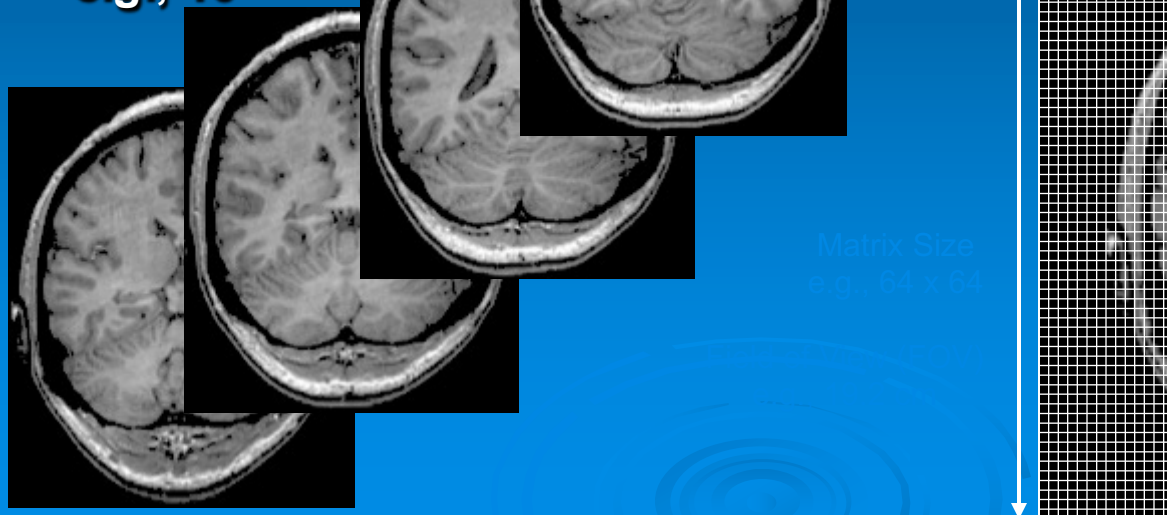


SAGITTAL SLICE



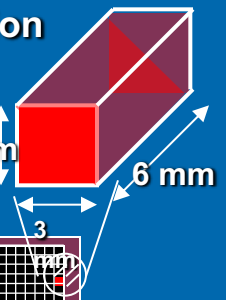
Slice Thickness
e.g., 6 mm

Number of Slices
e.g., 10

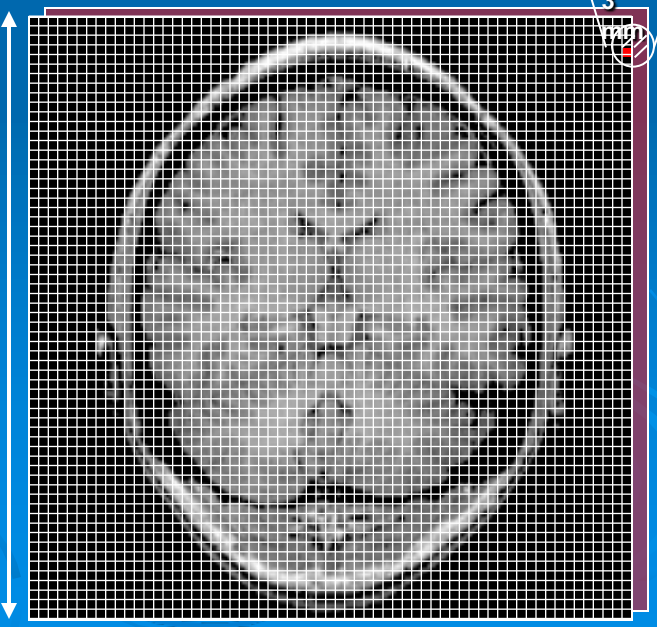


VOXEL
(Volumetric Pixel)

In-plane resolution
e.g., = 3 mm



IN-PLANE SLICE



Matrix Size
e.g., 64 x 64

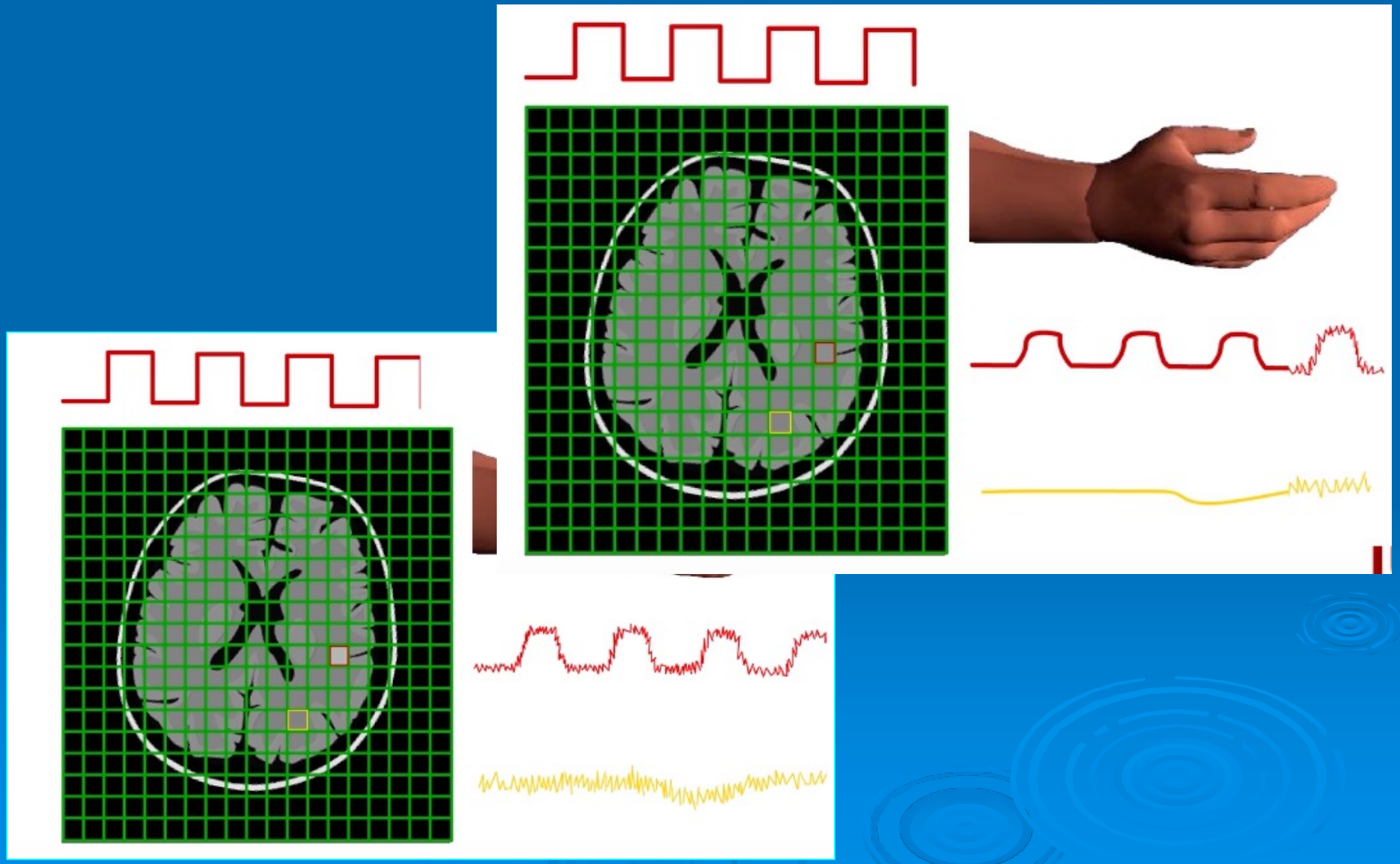
Statistical analysis

GLM

General linear model

- **Standard GLM Analysis:**
  - Correlate model at each voxel separately
  - Measure residual noise variance
  - T-statistic = model fit / noise amplitude
  - Threshold T-stats and display map
- Signals of no interest (e.g. artifacts) can affect both activation strength and residual noise variance
- Use pre-processing to reduce/eliminate some of these effects

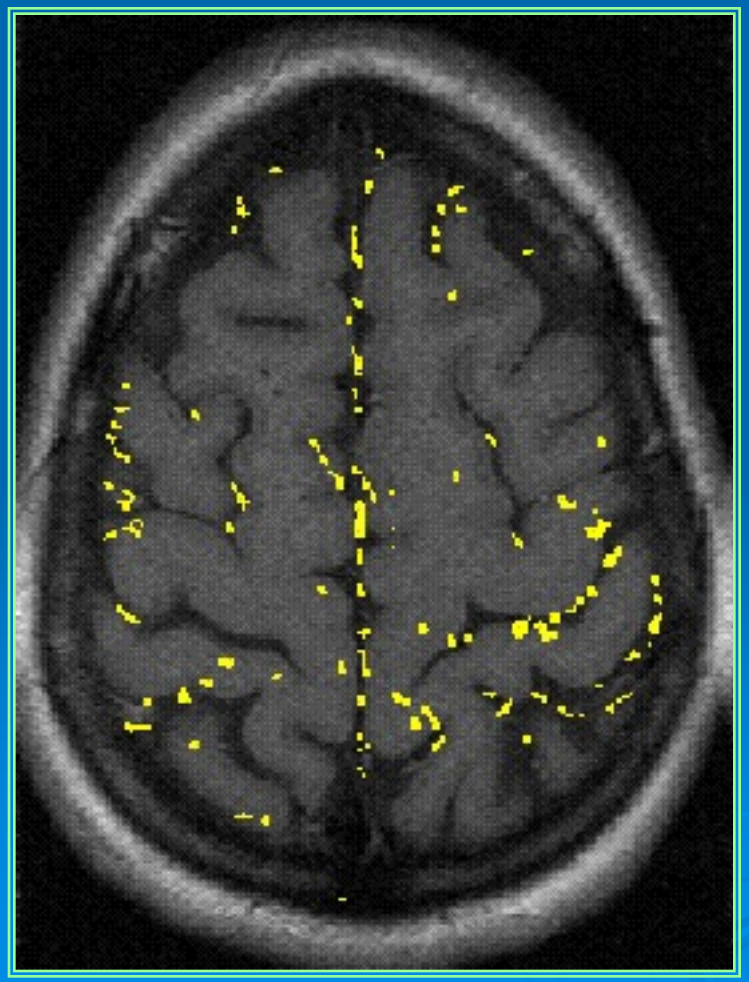
fMRI pre-processing



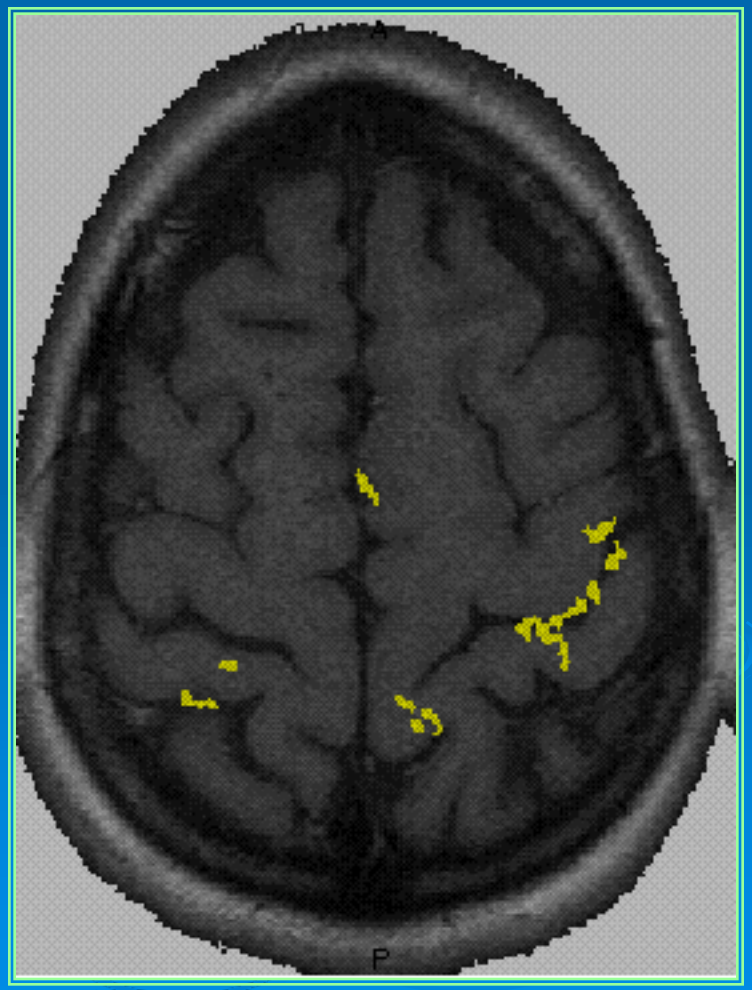
https://www.imaios.com/en/e-Courses/e-MRI/Functional-MRI/analysis-functional-mri-data

Head Motion: Main Artifact

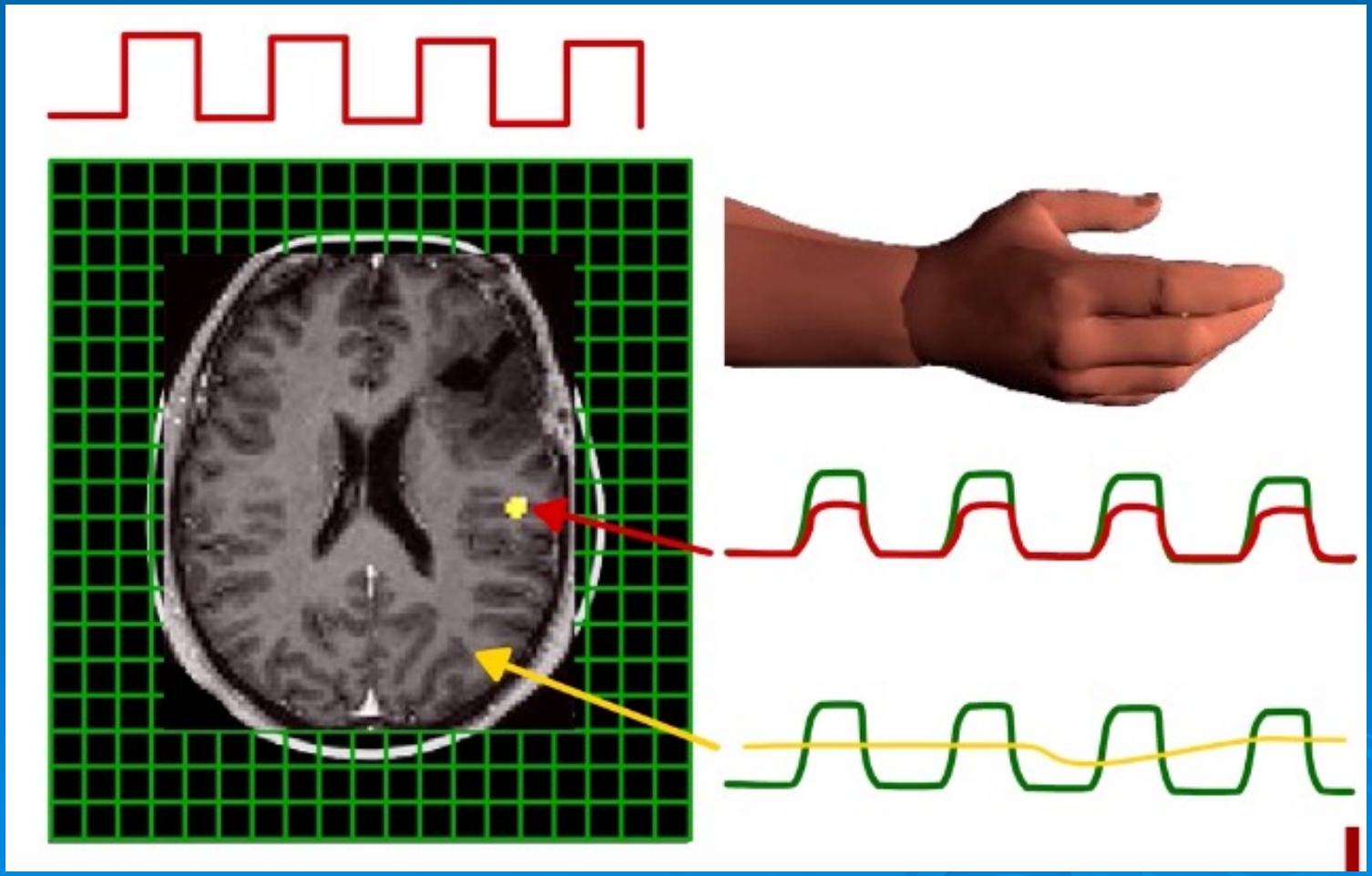
before registration



after registration

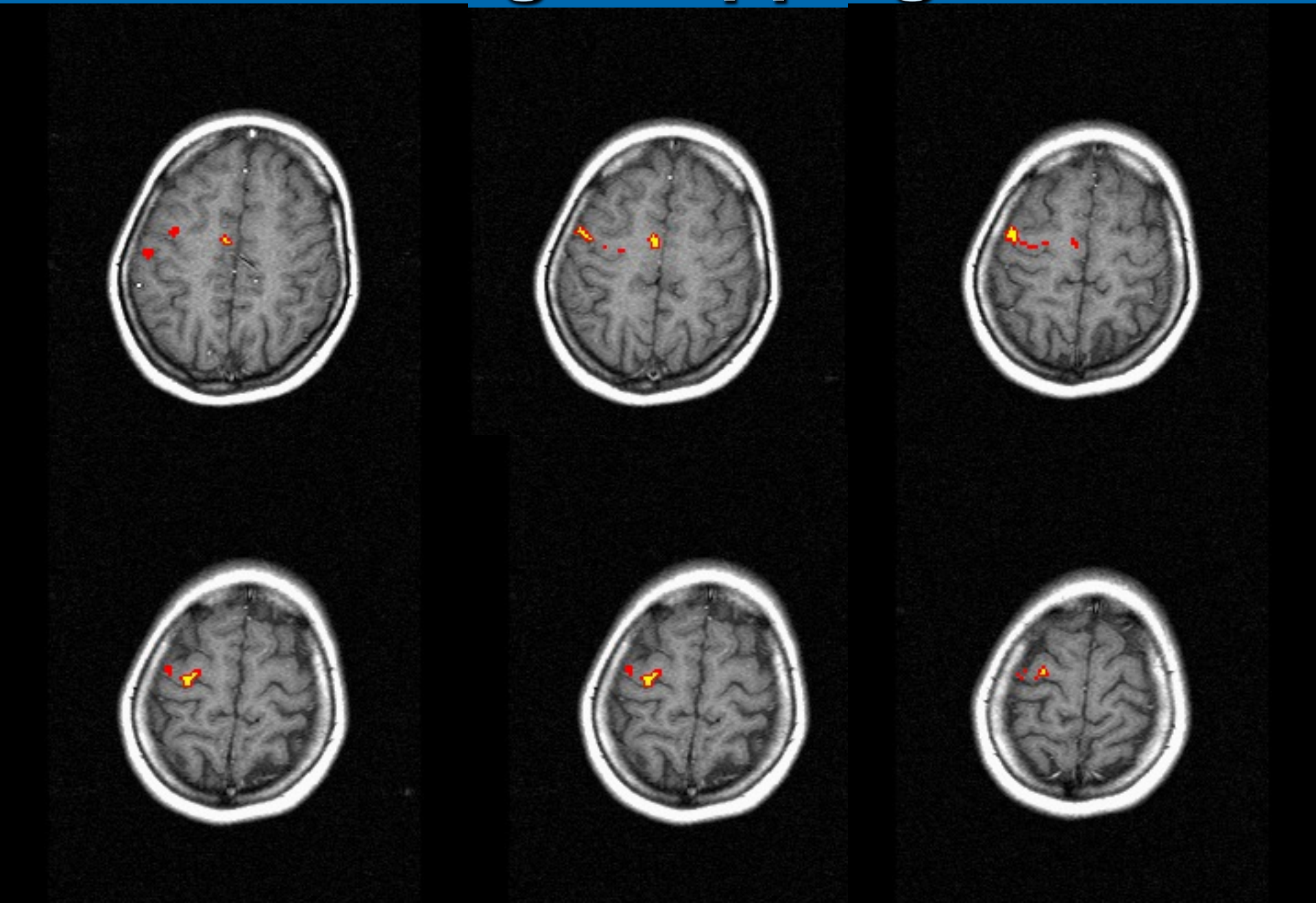


fMRI processing and display

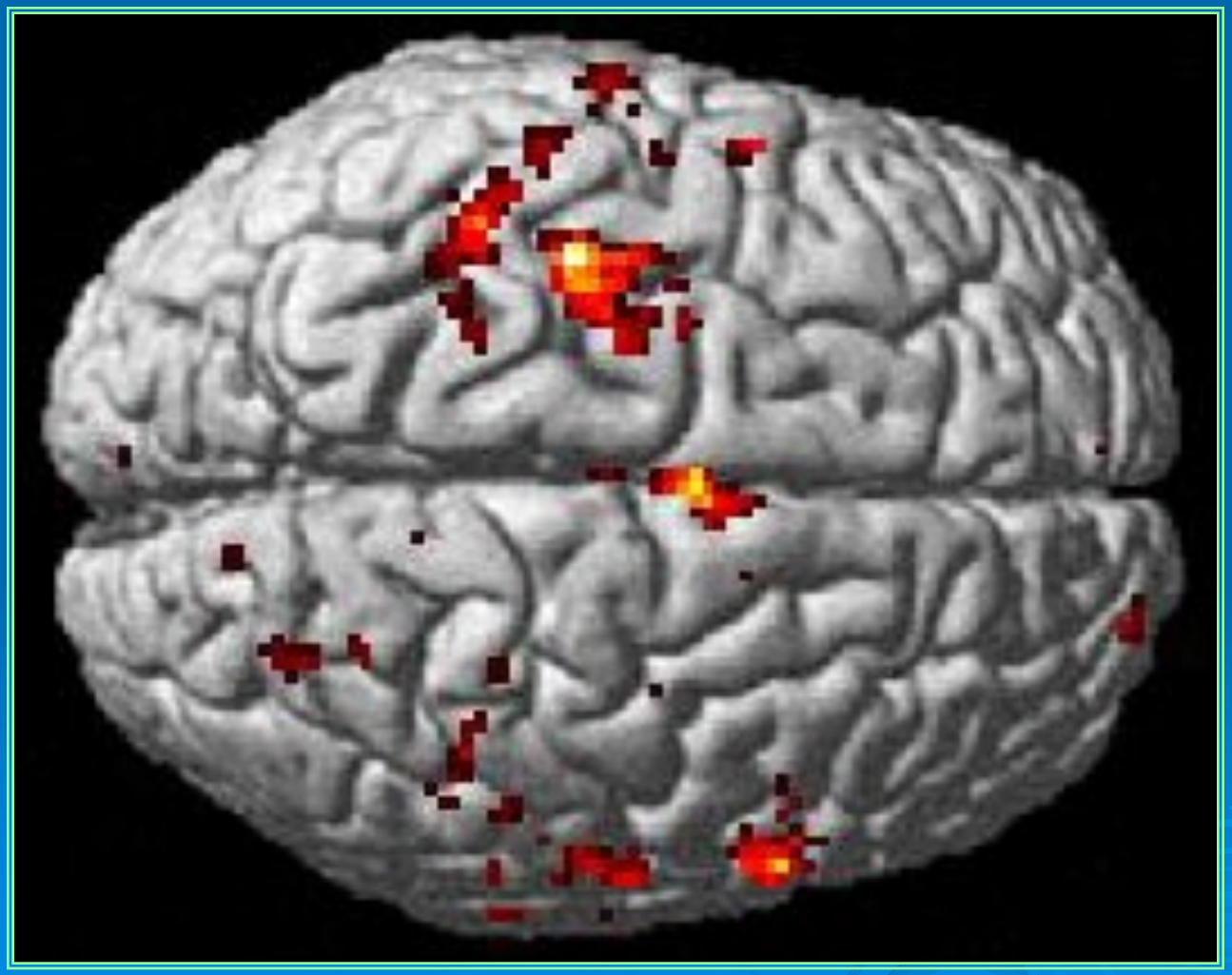


https://www.imaios.com/en/e-Courses/e-MRI/Functional-MRI/analysis-functional-mri-data

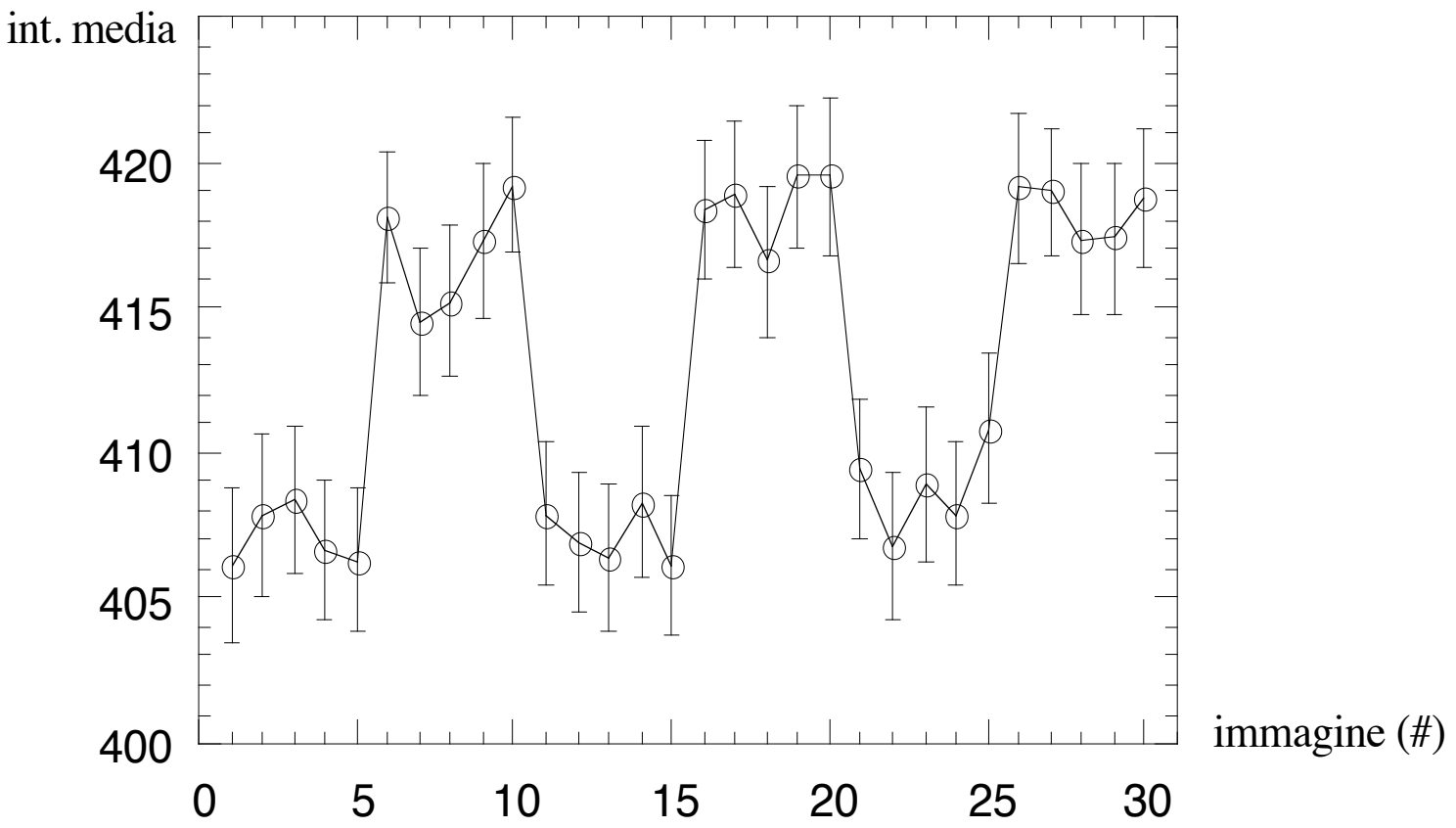
Finger tapping



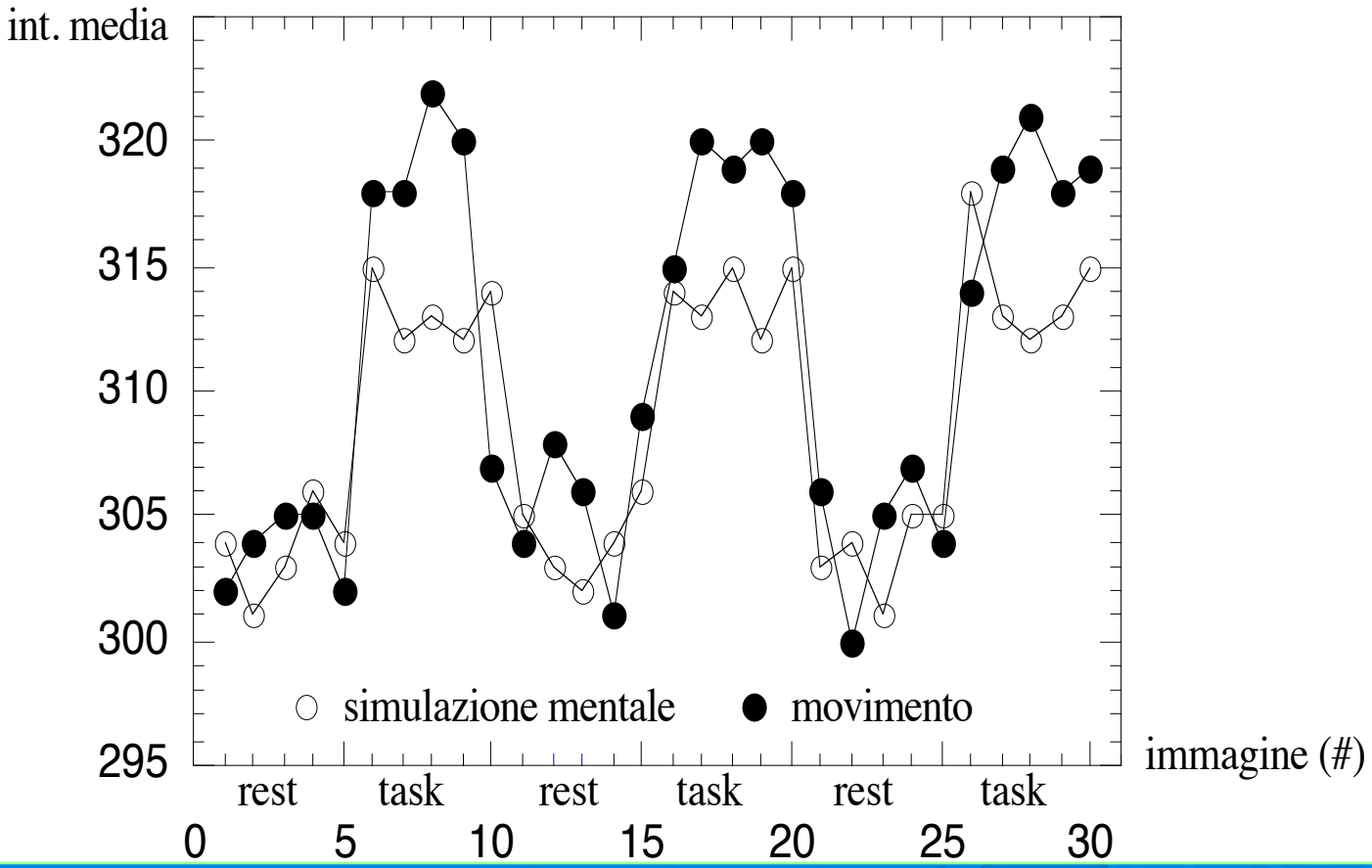
Finger tapping dx con comando acustico



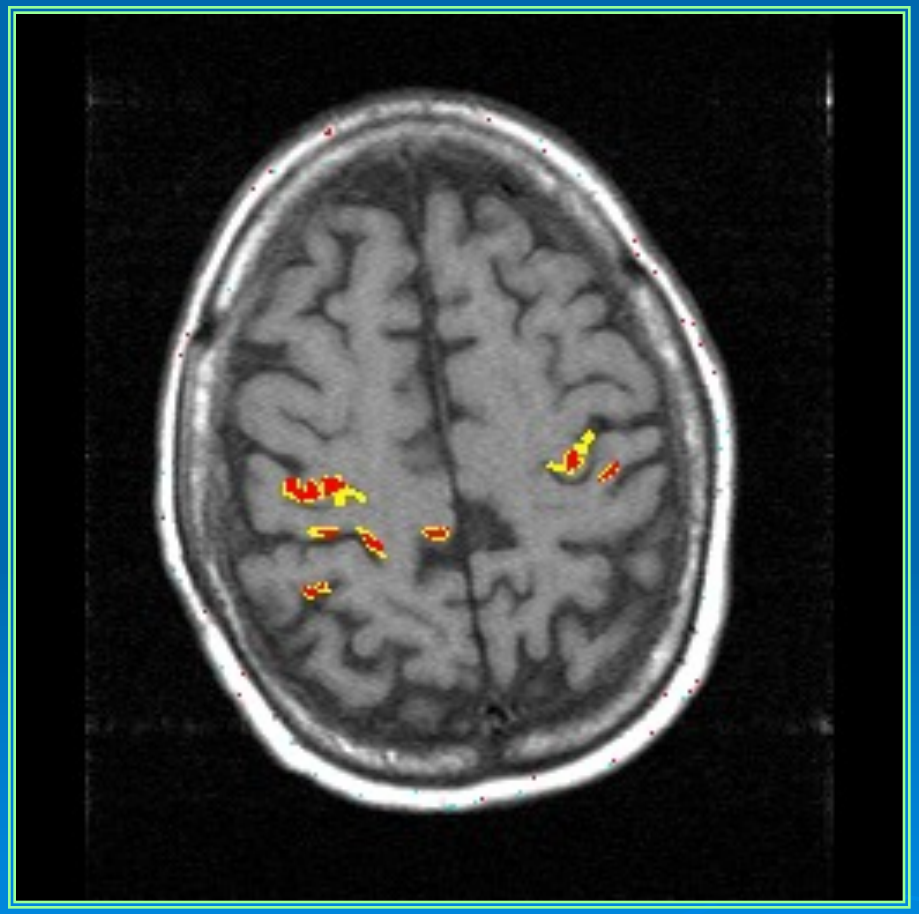
Experimental results



Task vs. imaginary task (finger tapping)



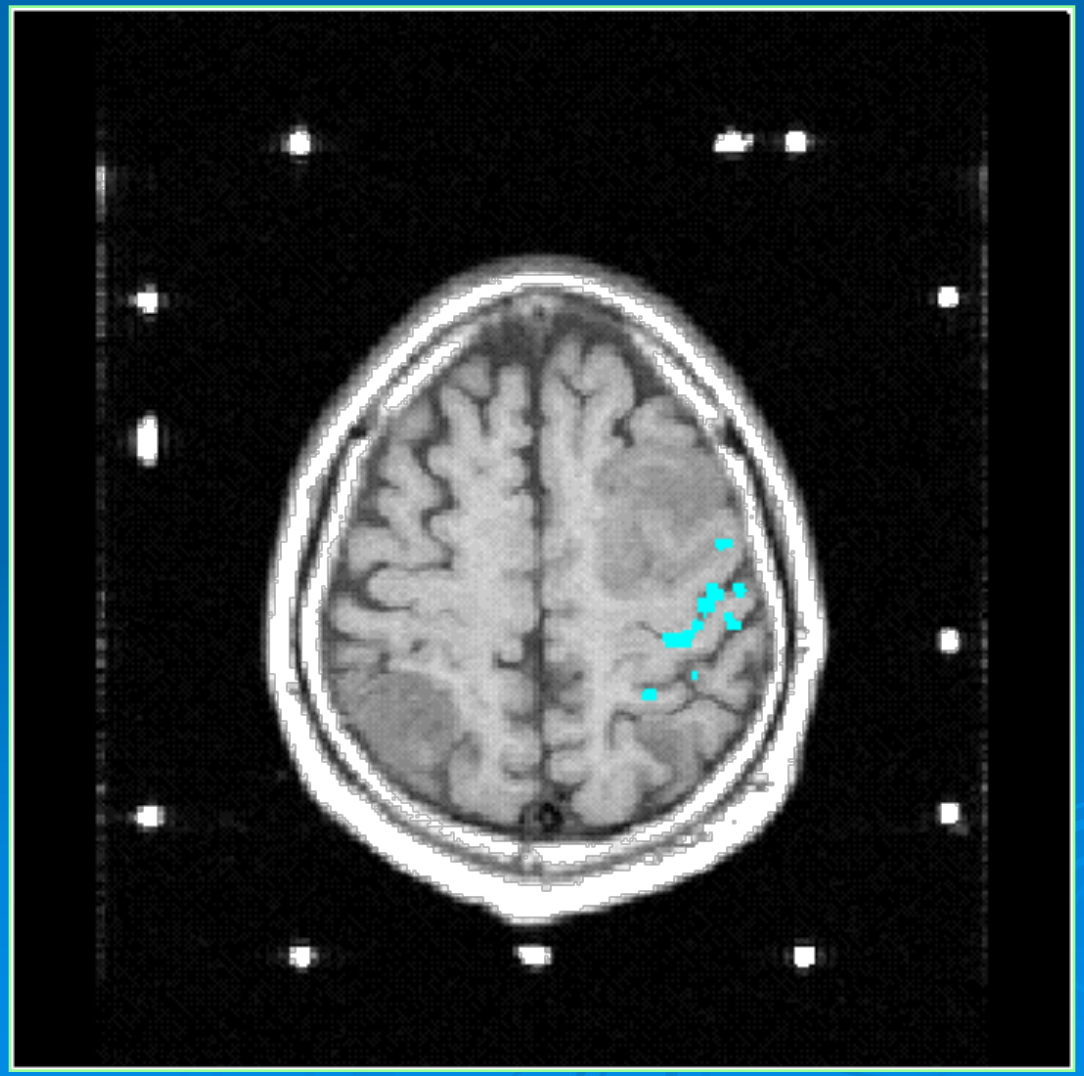
Finger tapping



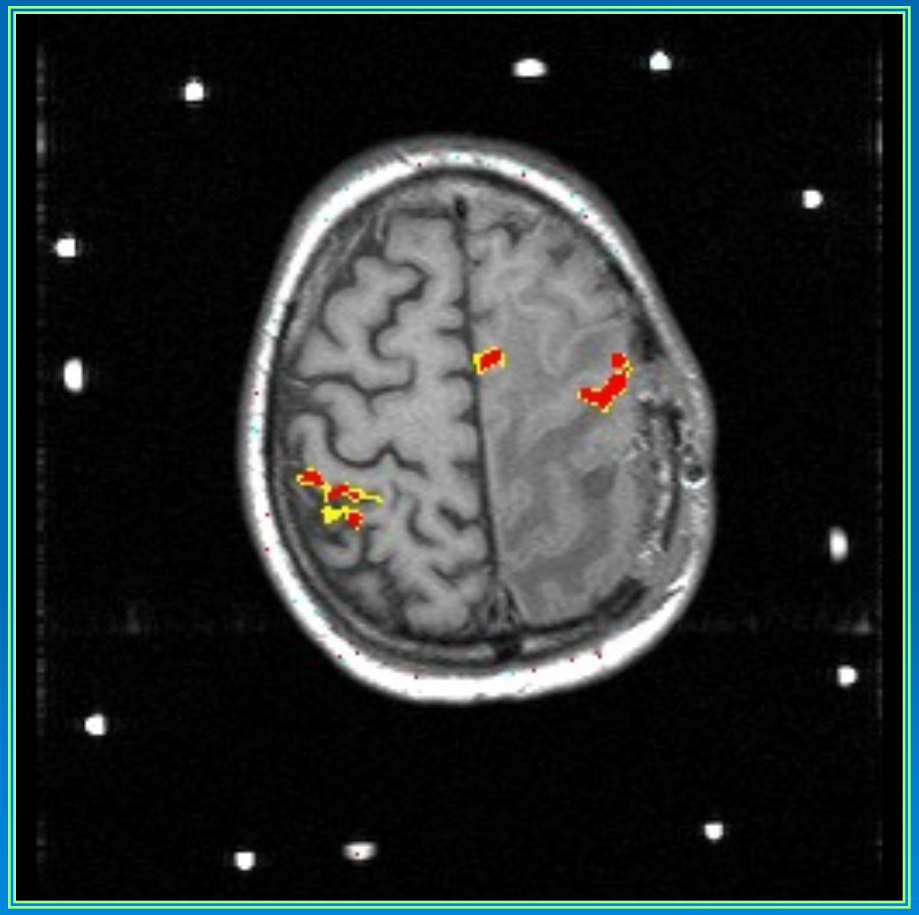
Left hand

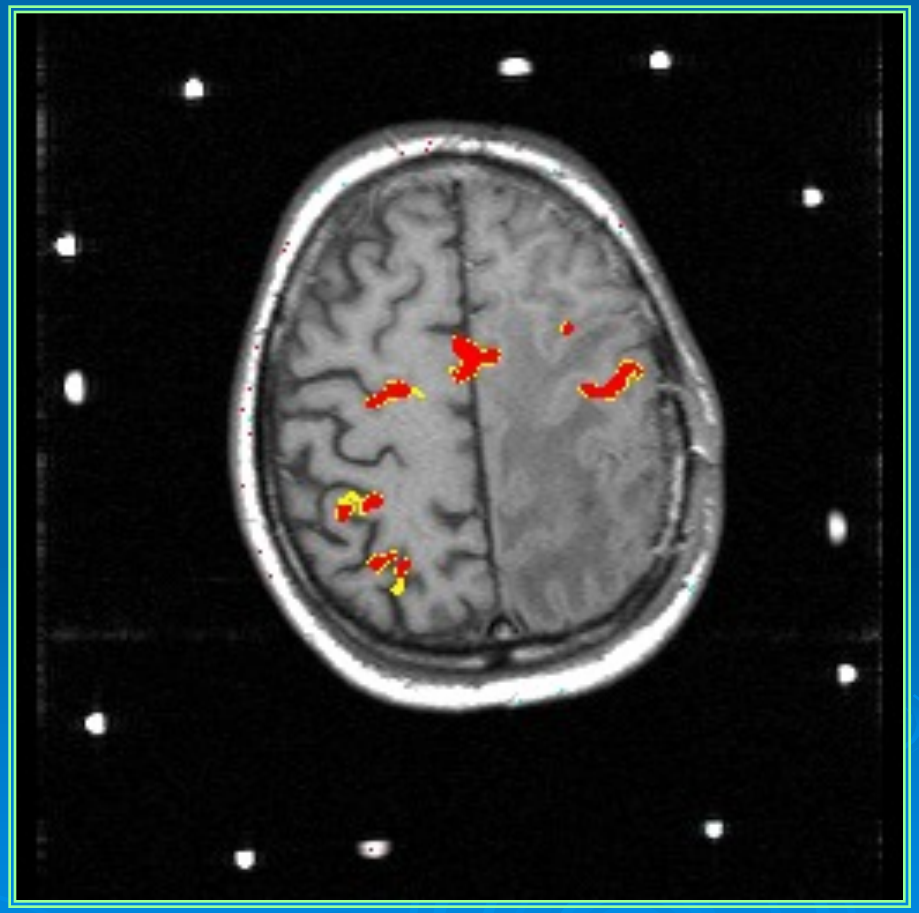
Right hand

Clinical applications: stereotactic surgery

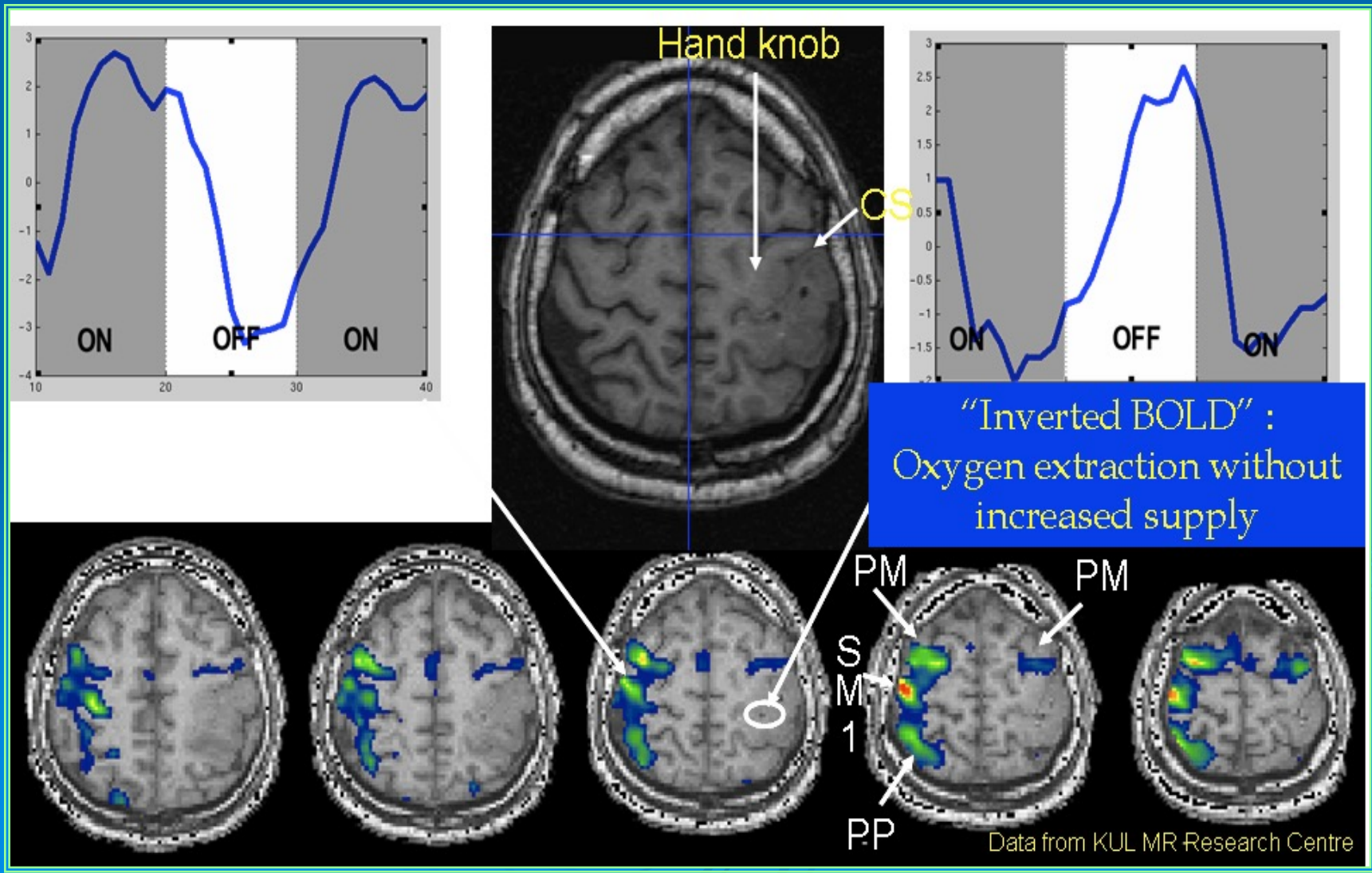


Clinical applications: stereotactic surgery





Inverted BOLD in tumor



Calendar neuroimaging
prof. Renata Longo and prof. Maja Ukmar

High Field Magnetic Resonance in Neuroscience

Thursday 14 December 4 pm

dr Gisela Hagberg

Max Planck Institute for Biological Cybernetics

Tübingen, Germany

Functional imaging summary

Functional imaging methods are based on acquiring MR images at different states of the function: the changes are assumed related to the function

- Cardiac function:
  - the heart are imaged at several phases of the cardiac cycle and the ventricular and atrial volumes are measured as a function of cardiac phase
    - by means of cardiac-gated acquisition

Functional imaging

- In fMRI images of the brain, brainstem, and/or spinal cord are acquired at different states of neural function

- Any regions of the central nervous system that change in the images between the two states are assumed to be somehow involved with the function that was varied

fMRI

The essential steps to create maps of neural function out of the MRI methods are:

- to repeatedly acquire images over time in order to describe a time series
- to make the MRI signal intensity depend on neural activity
  - BOLD contrast
  - Other contrast mechanisms

fMRI

Images are acquired multiple times while the person being studied performs tasks to systematically vary the neuronal activity

- time series
- type of task: cognitive, sensory, motor, etc

The primary limitation of fMRI is that it can only show differences in neural function between states