Brain Mapping *for* Surgical Planning

School of Advanced Medical Sciences and Technologies, SUMS

National Brain Mapping Lab

NBML.IR

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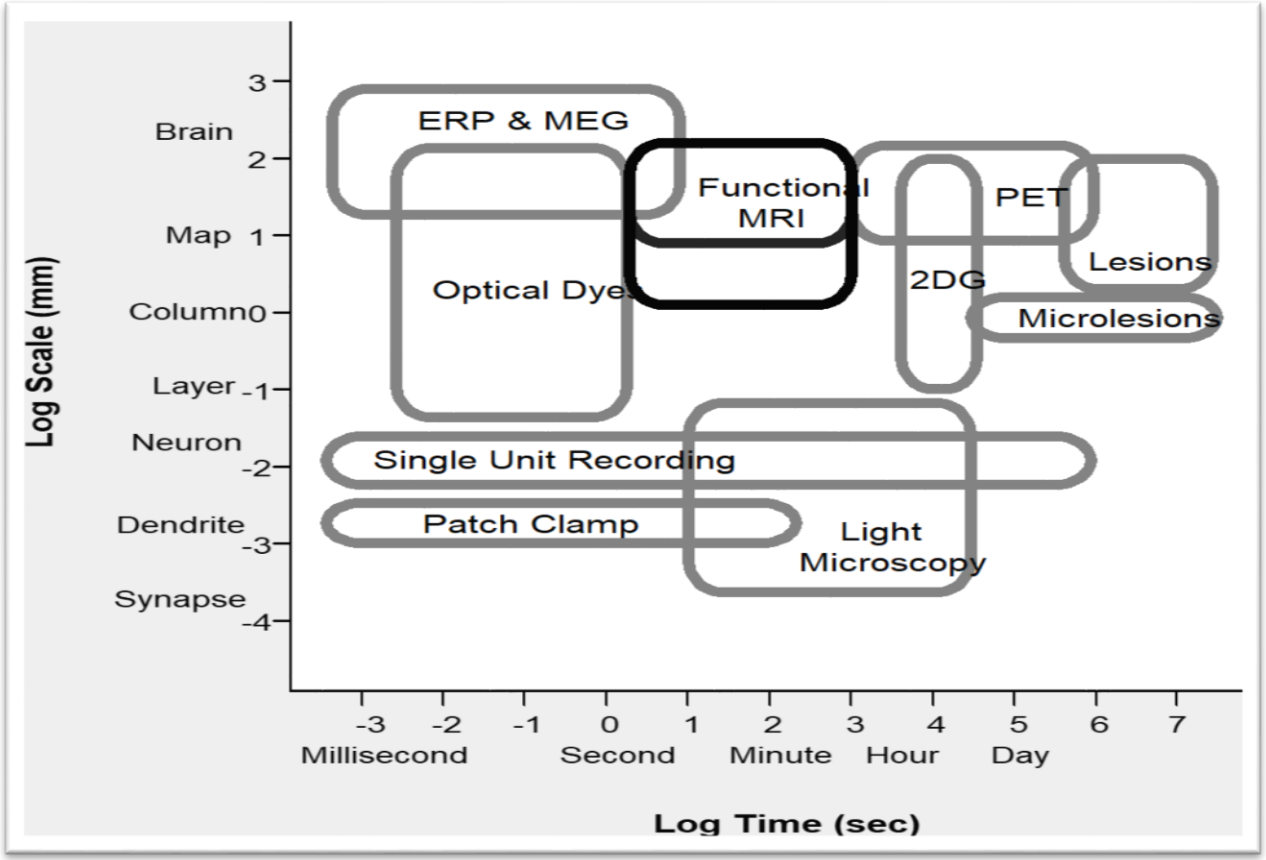
NEW METHODS



What is being measured?

- **electrical activity**
- **chemical activity**
- **metabolism**
- **blood flow**

Brain Mapping for Surgical Planning

Preoperative Image Information

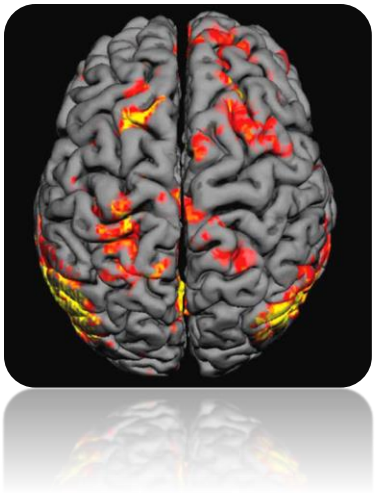
- fMRI
- PET/SPECT/MRS data
  - Metabolism
  - perfusion
  - Voxel based Neurochemistry
- MR Angiography, vessel models
- Diffusion Tensor MRI
- QEEG

Functional Neuro-Imaging

- fMRI
- PET
- QEEG
- DTI
- MRS
- SPECT

Intraoperatiove ECoG

- Functional brain mapping using ECoG



Main Concepts in Functional MRI

Structural MRI vs. *Functional* MRI

***Structural* MRI reveals brain anatomy**

***Functional* MRI (fMRI) reveals brain function**

History of *f*MRI

*f*MRI

-1990: Ogawa observes BOLD effect with T2*
blood vessels became more visible as blood oxygen decreased

-1991: Belliveau observes first functional images using a contrast agent

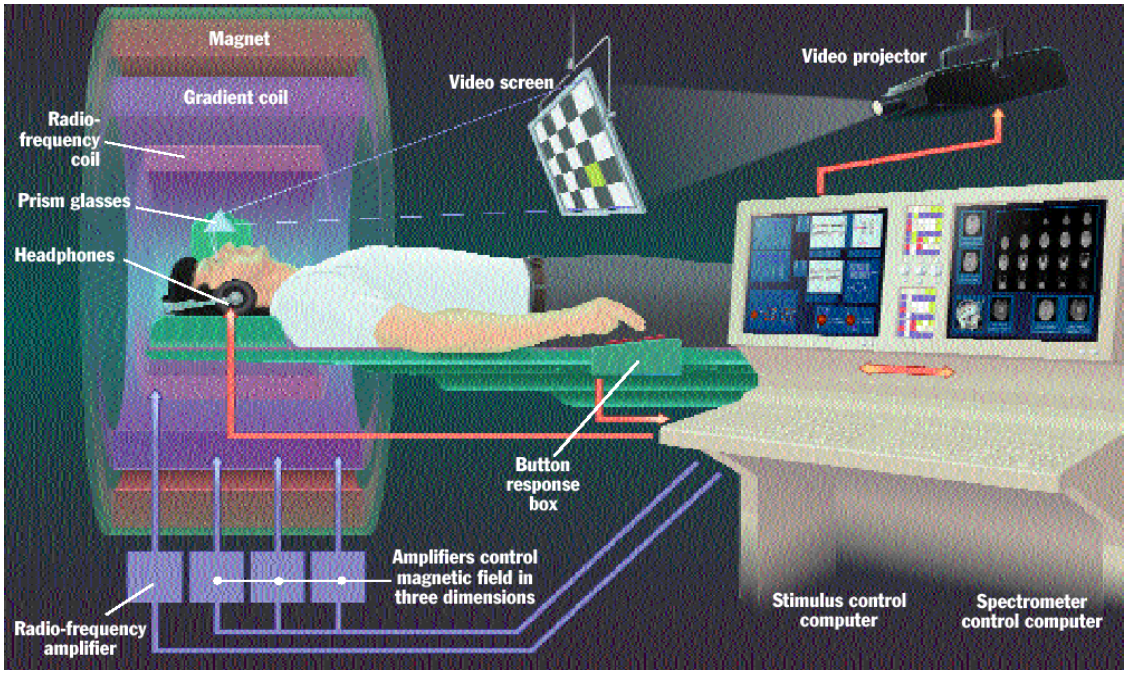
-1992: Ogawa & Kwong published first functional images using BOLD signal

T1-weighted = gray/white/CSF delineation
T2-weighted = detection of tissue abnormalities
T2*-weighted = venography

Functional MRI

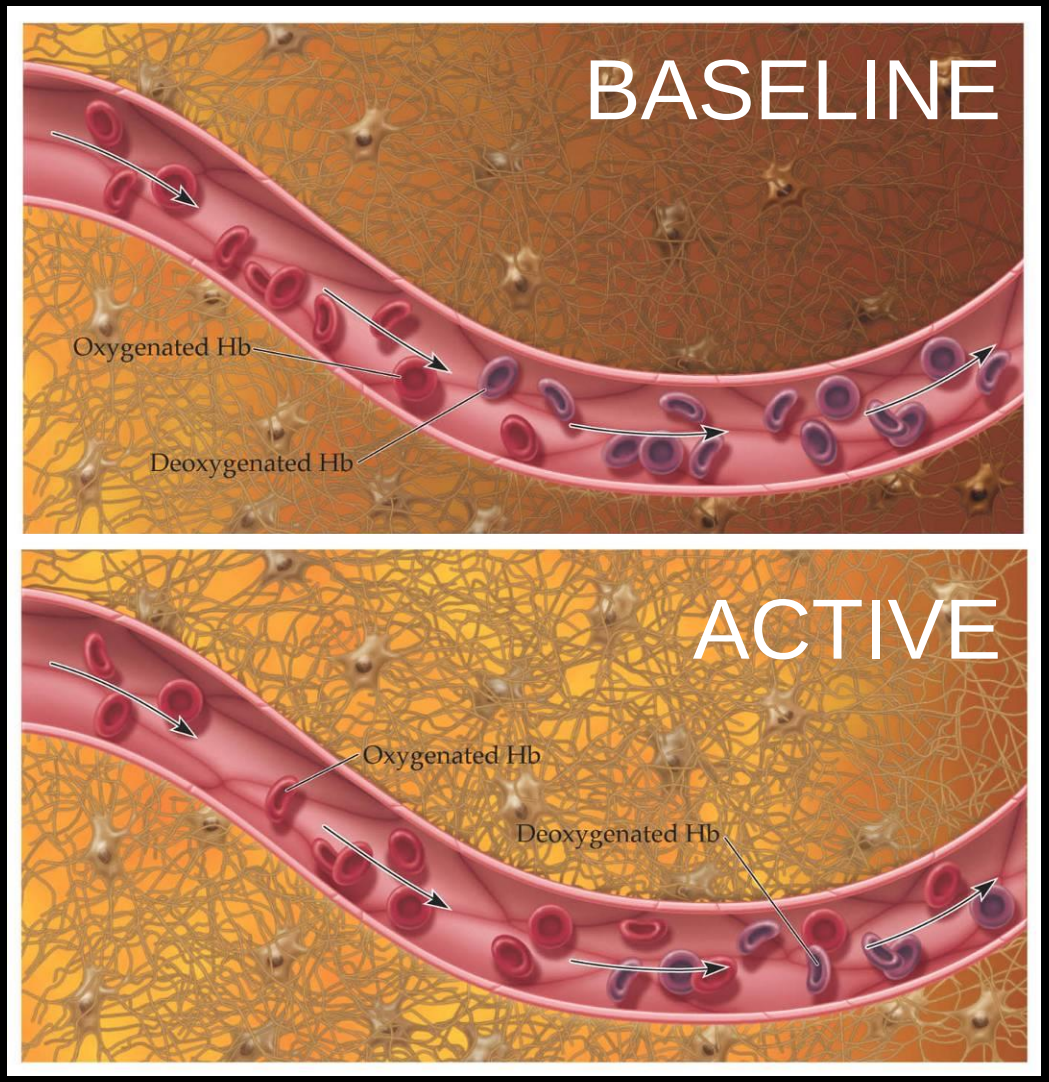
Uses Standard MRI Machine

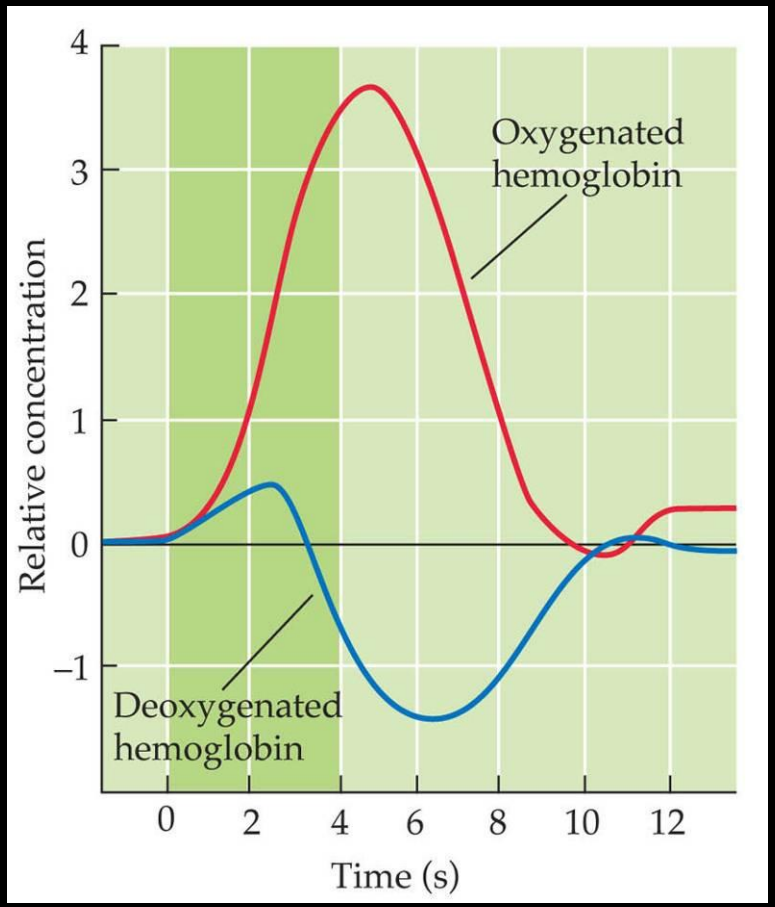
But Requires Custom Software and Additional Hardware Devices



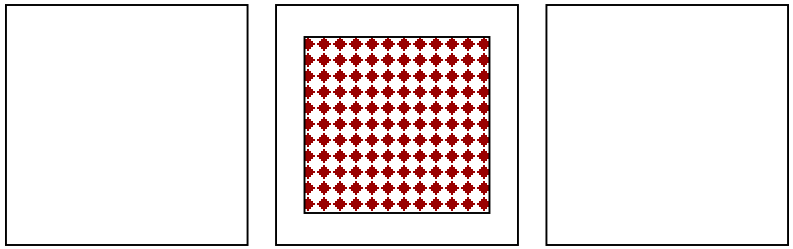
The fMRI Blood-Oxygenation-Level-Dependent (BOLD) Response

Increased neuronal activity results in increased MR (T_2) signal*

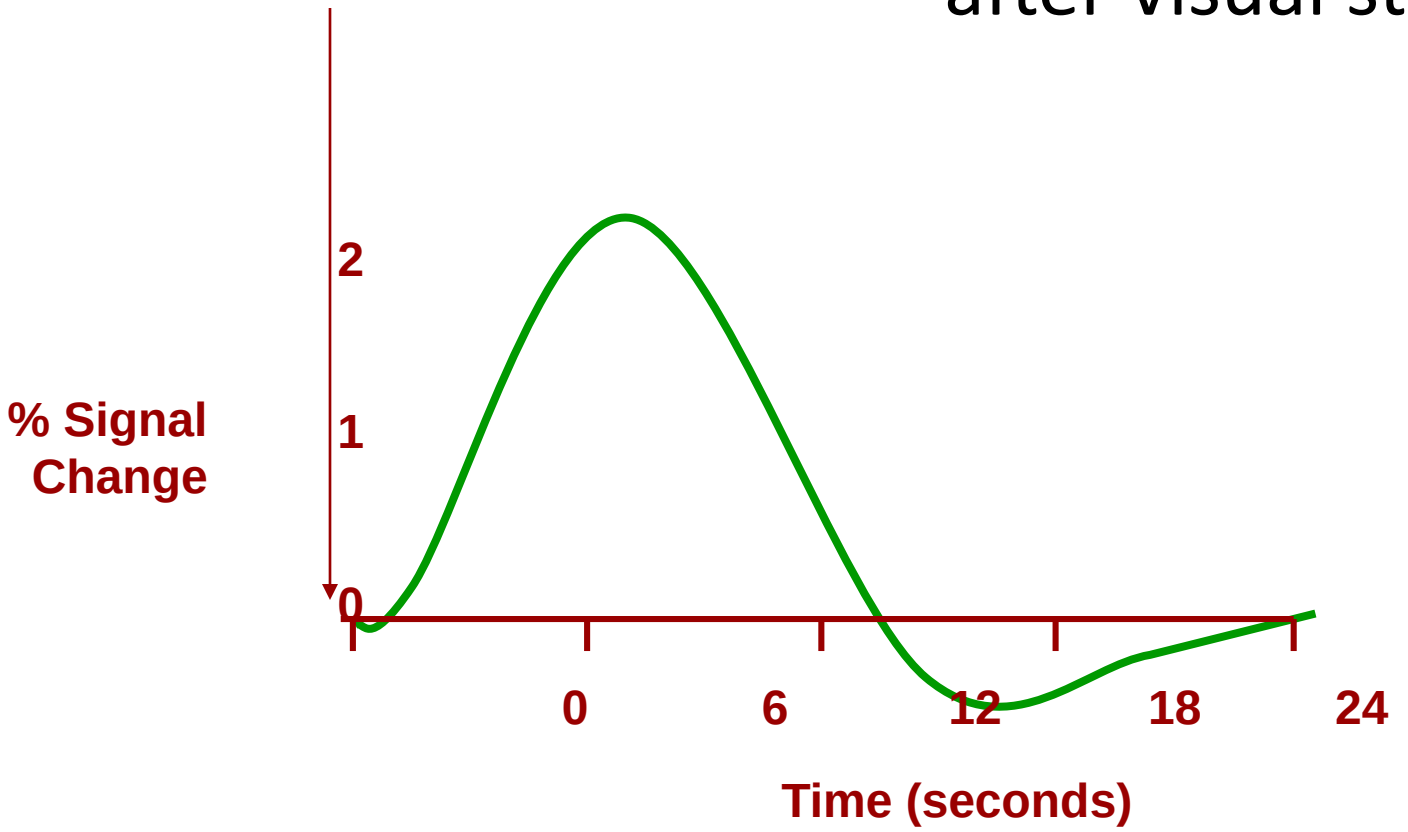




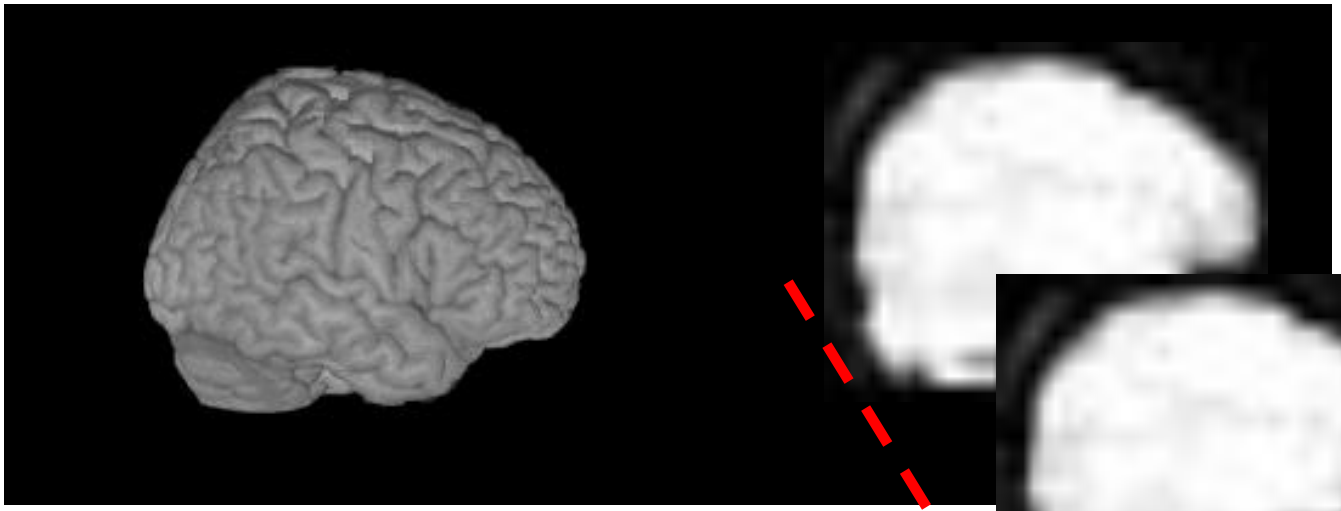
Hemodynamic Response Function



- Visual cortex shows peak response ~5s after visual stimuli.



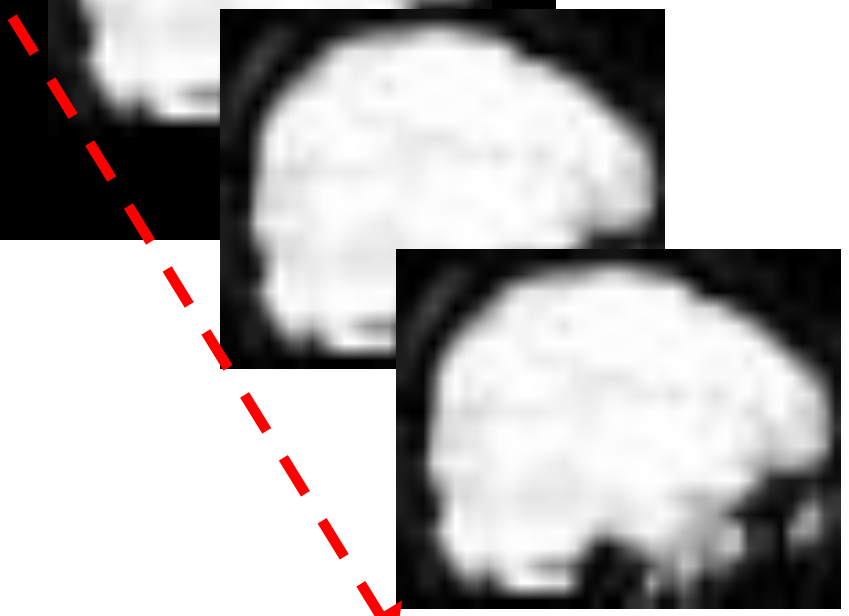
MRI vs. fMRI



Lower Resolution
(~3 mm^3)

Only one image collected (one full head volume)

High Resolution
(<1 mm^3)

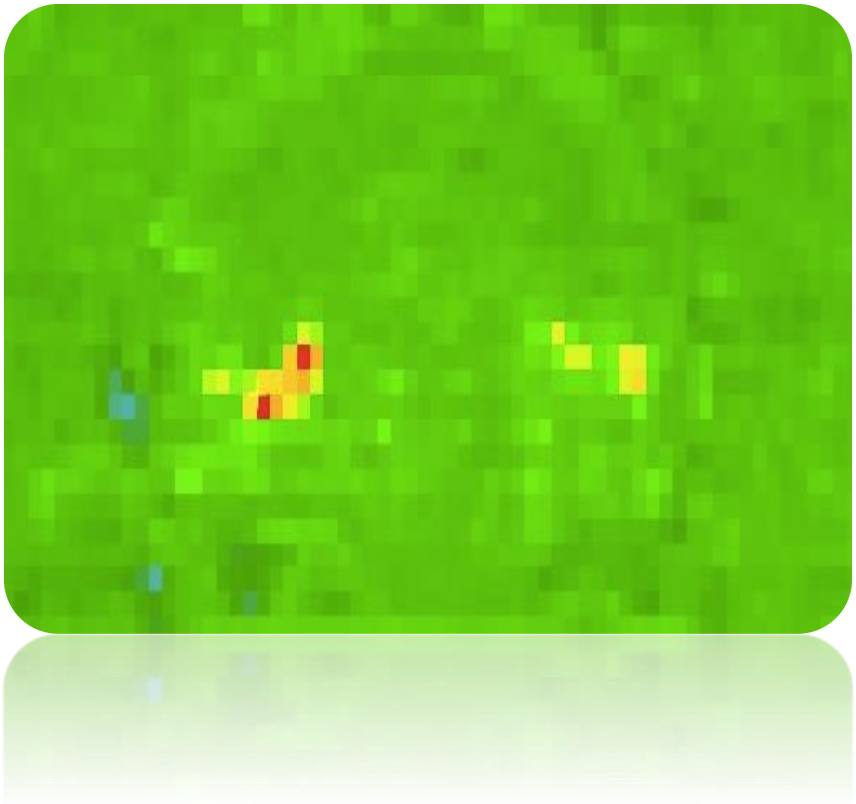


...

Series of several images collected over time
(e.g., 1 full head volume every 2 seconds over the course of several minutes)

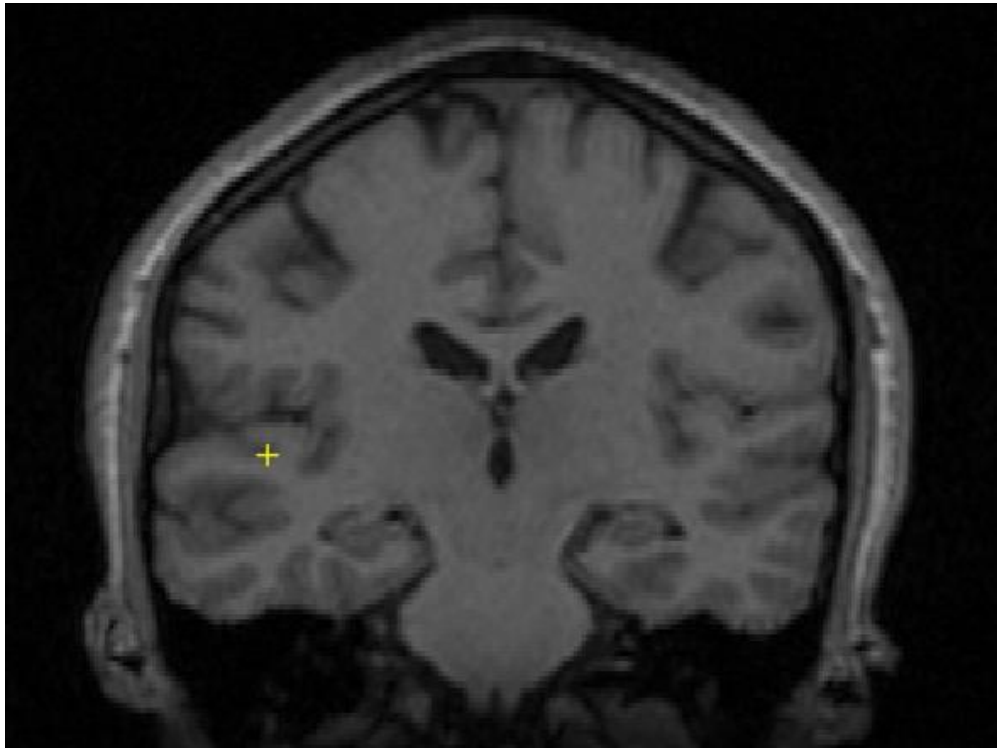
Structural and Functional Imaging

- This is a Functional MRI Image !?



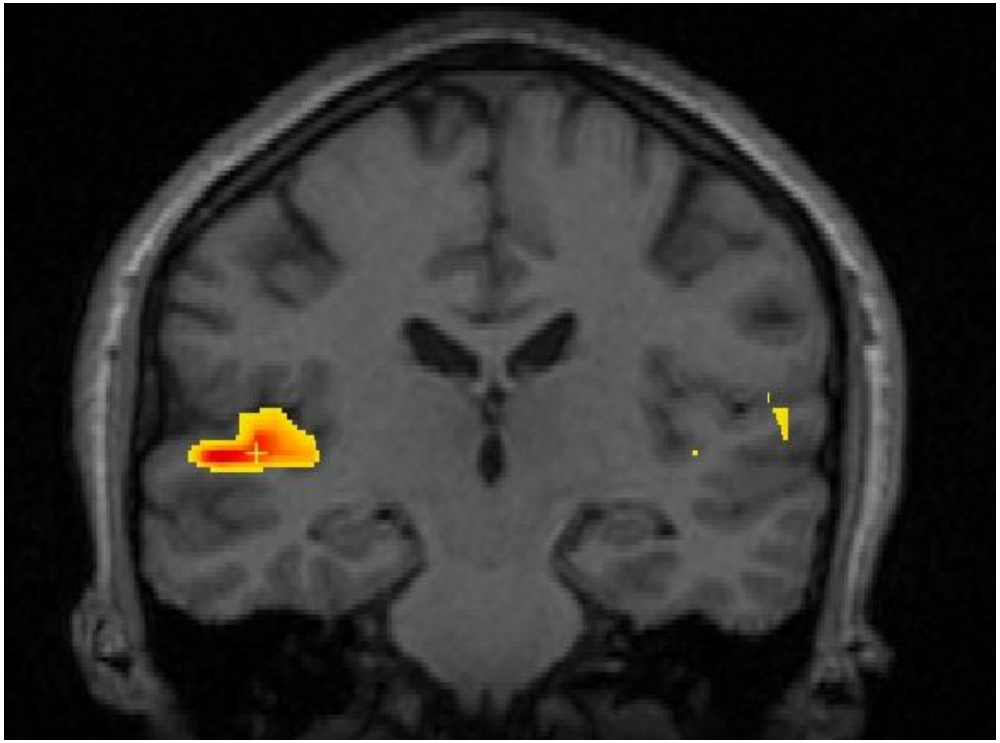
Structural and Functional Imaging

- This is a structural MRI image (an "anatomical" image)



Structural and Functional Imaging

- What you really want is both images *co-registered*



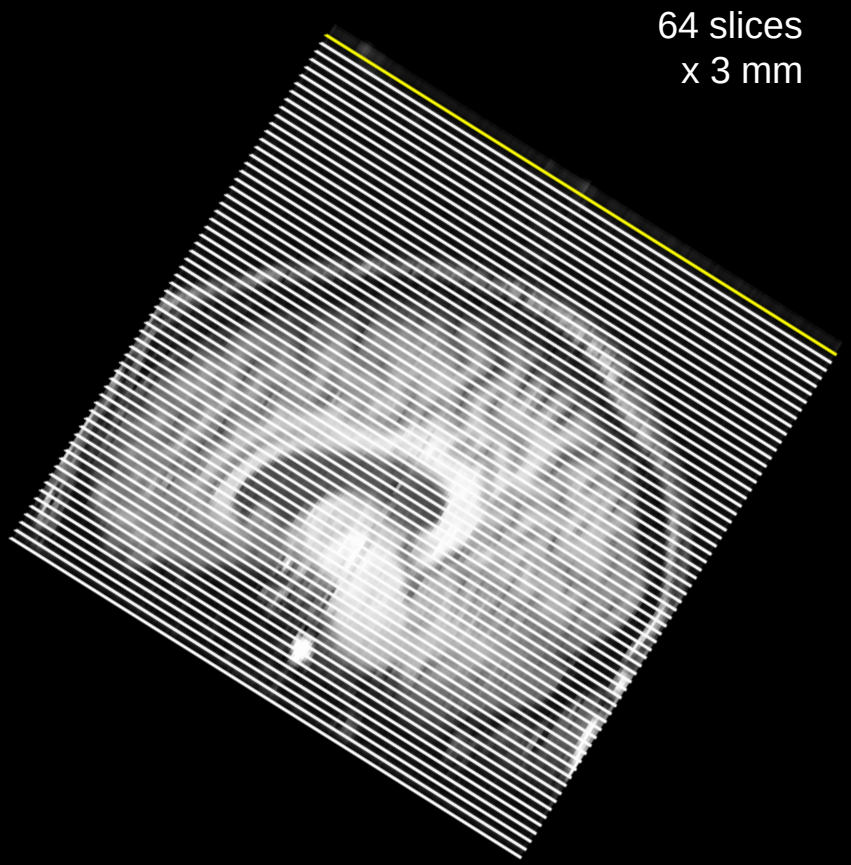
fMRI Experiment Stages: Anatomicals

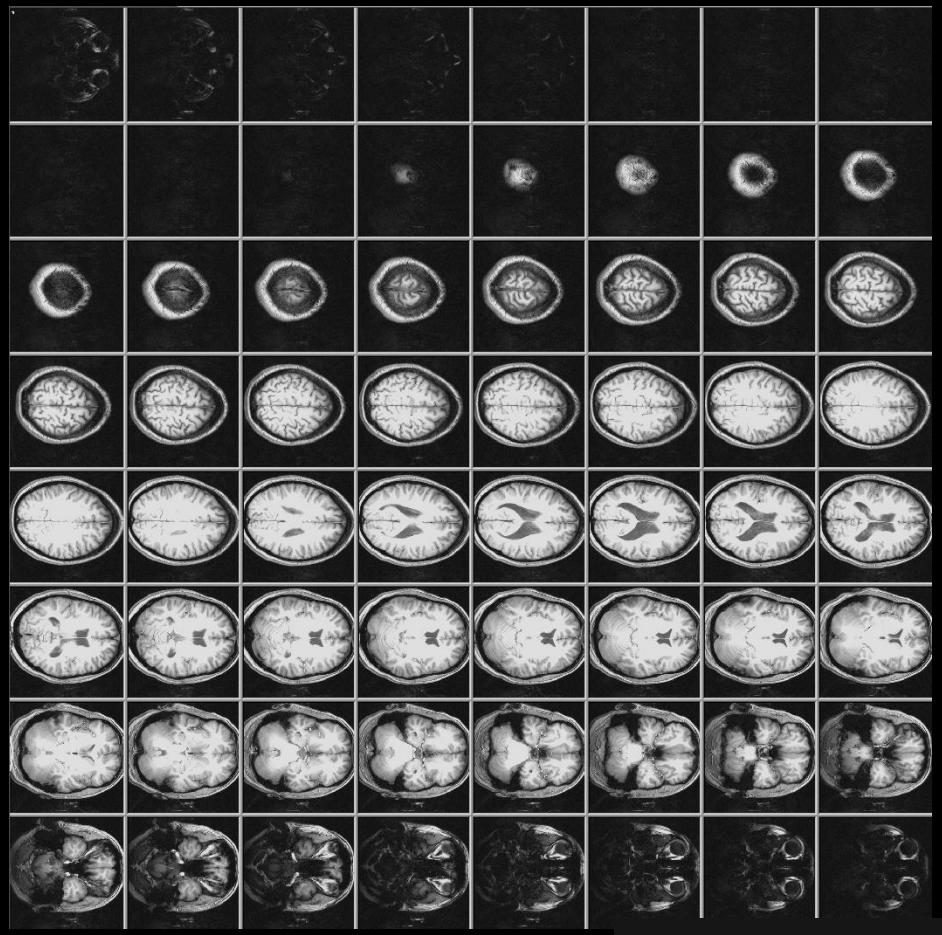
1. Take anatomical (T1) images

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

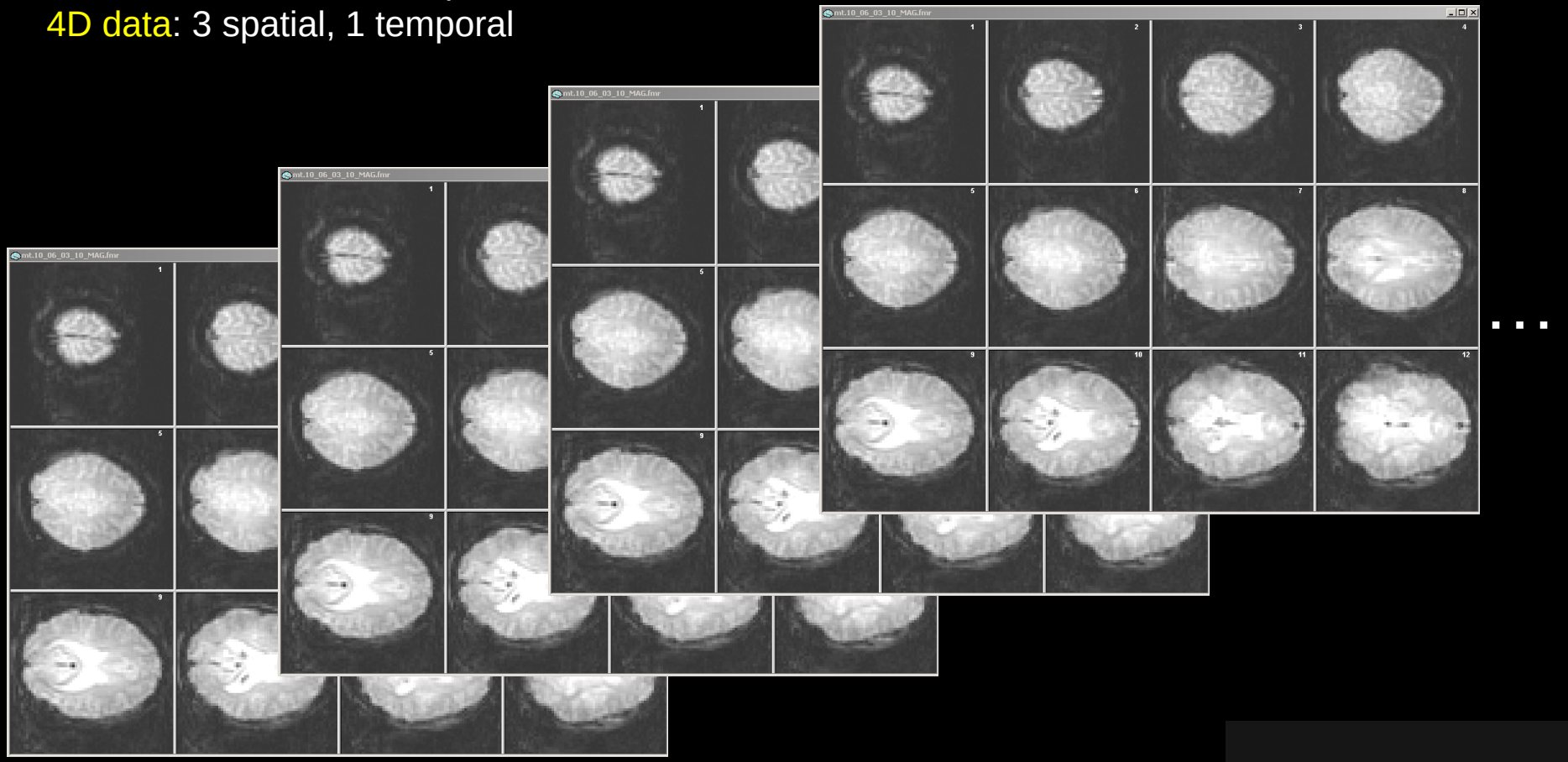




fMRI Experiment Stages: Functionals

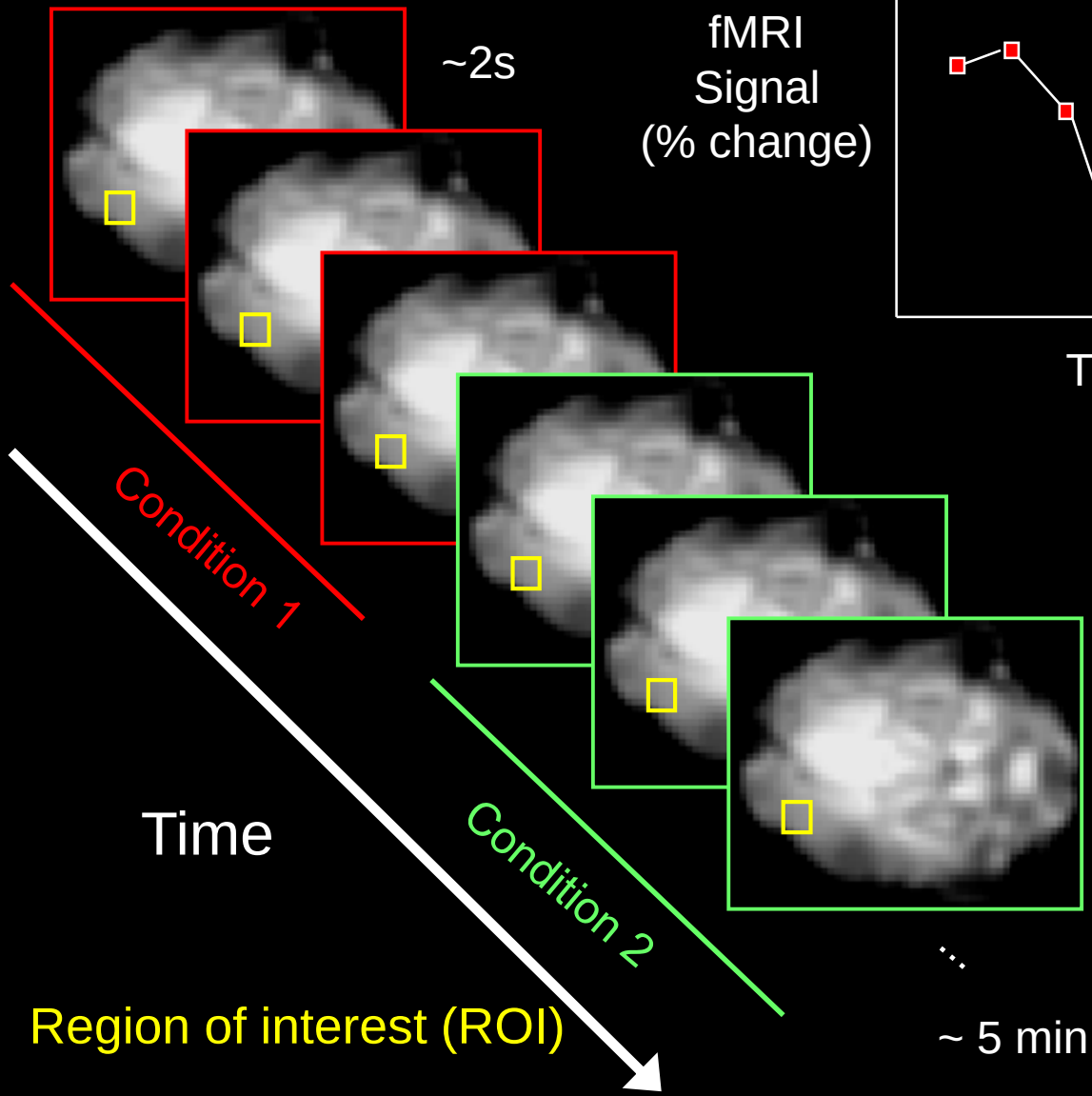
2. Take functional (T2*) images

- 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

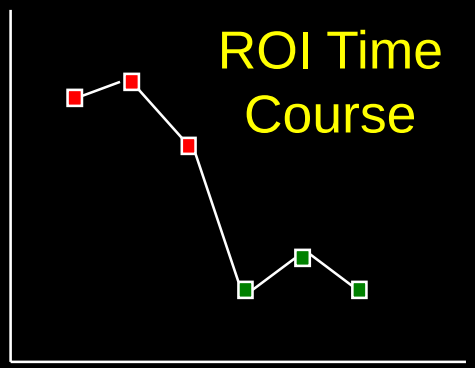


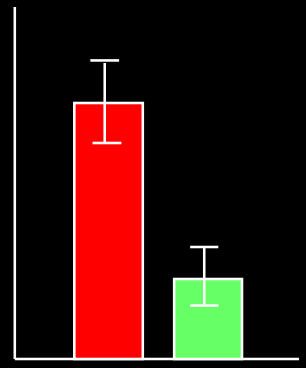
Activation Statistics

Functional images

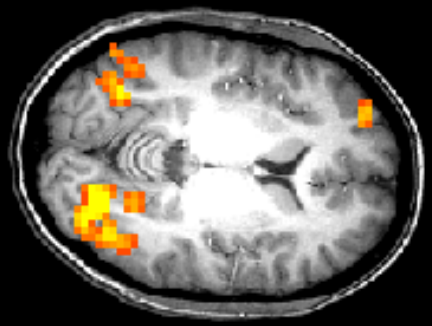


fMRI Signal (% change)

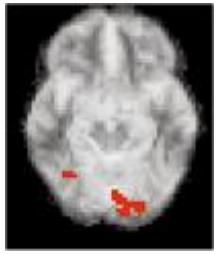




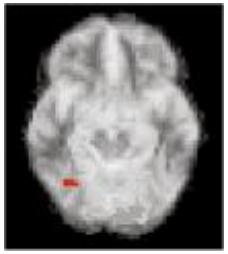
Statistical Map
superimposed on anatomical MRI image



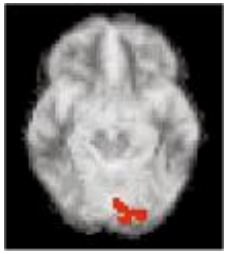
Contrast between groups



Condition 1 Group Statistics Map



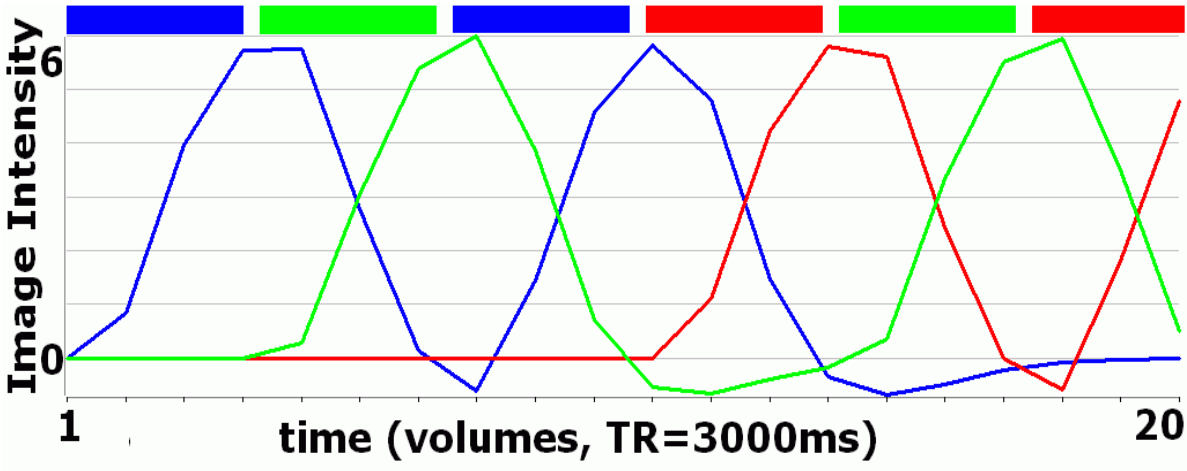
Condition 2 Group Statistics Map



Brain area activated by Condition 1 and Not Condition 2

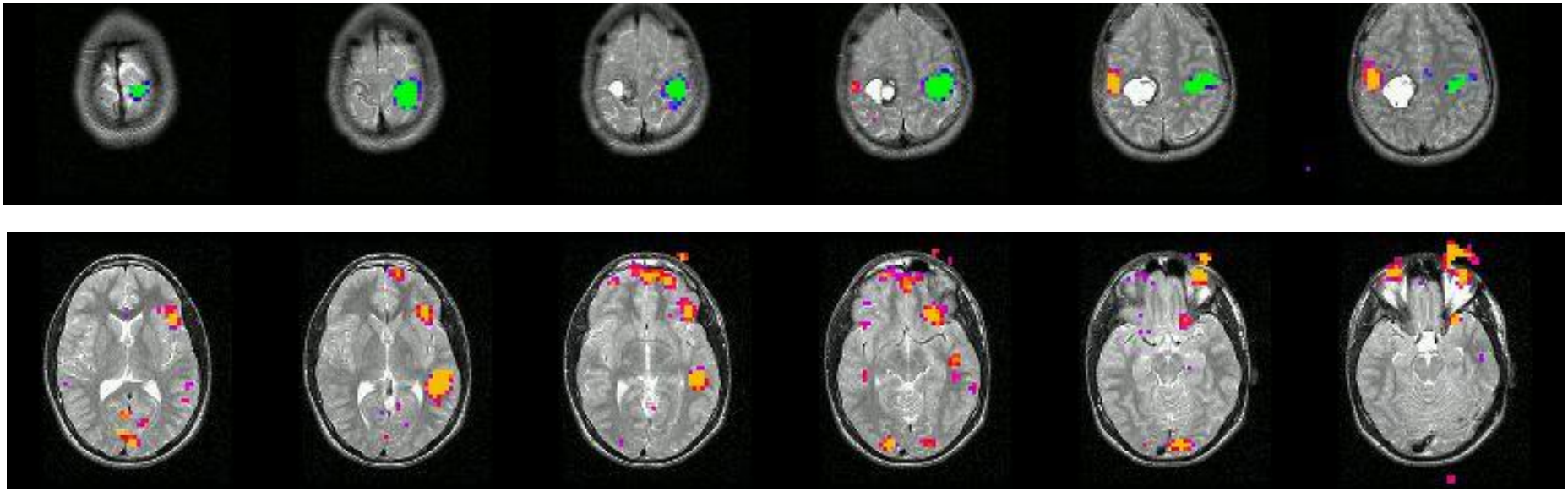
Optimal Design

- Block designs are optimal.
  - Present trials as rapidly as possible for ~12 sec
  - Consider experiment:
    - Three conditions, each condition repeated 14 times (once every 900ms)
    1. Press left index finger when you see ←
    2. Press right index finger when you see →
    3. Do nothing when you see ↑



Functional MRI

- Color Overlay of Statistical Maps on Anatomical Images



Readouts

- Location of activation
- 3D extent of activation
- Distance of border of activation cluster to lesion
- Laterality index of language (Lt vs Rt)
  - Based upon signal magnitude change
  - (Edinbrough handedness inventory and LI>80)

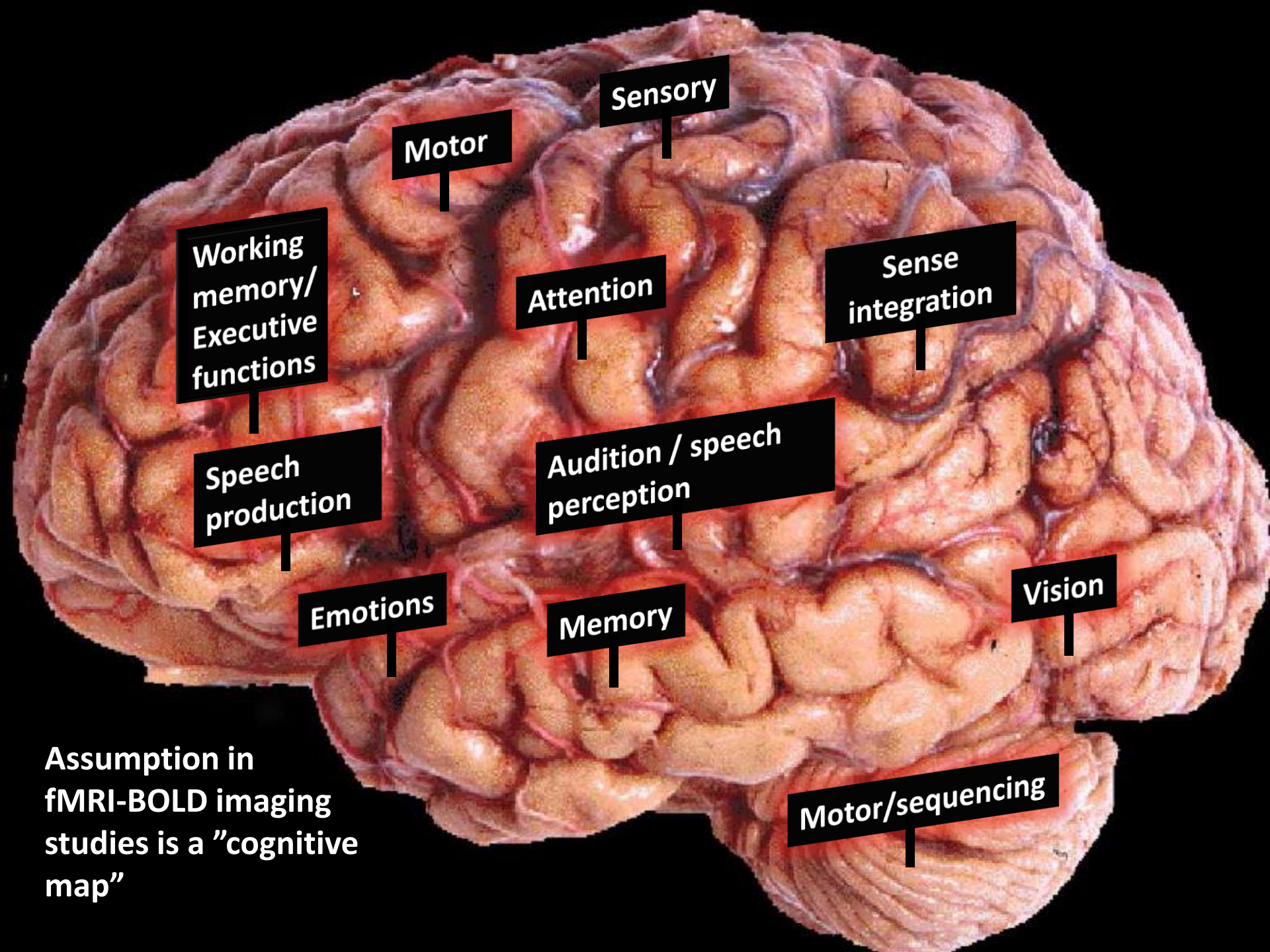
Advantages of fMRI

- Noninvasively record brain signals without risks of radiation
- It can record on a spatial resolution in the region of 3-6 millimeters.

Disadvantages of fMRI

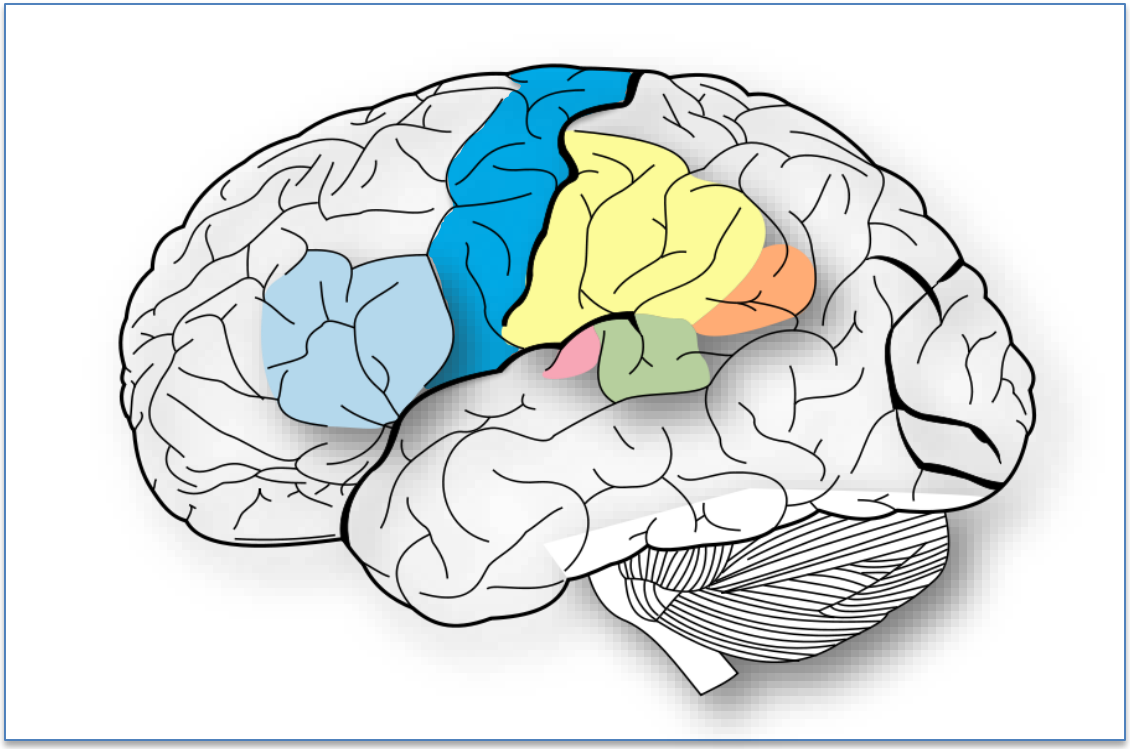
- BOLD signal is an indirect measure of neural activity
- It is susceptible to influence by non-neural changes in the body
- The temporal response of the blood supply is poor relative to the electrical signals that define neuronal communication.

fMRI has a low temporal resolution
Alternative options: TMS,ERP,…



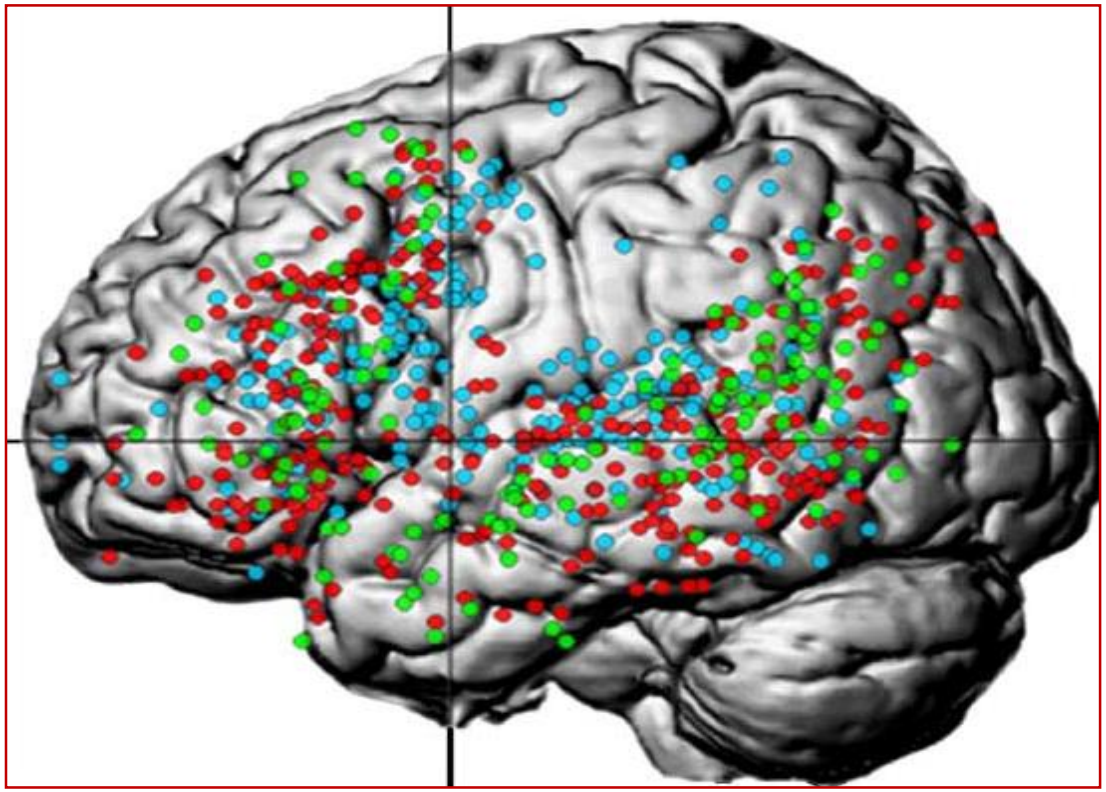
Assumption in fMRI-BOLD imaging studies is a ”cognitive map”

„Eloquent brain“



Broca's area (blue) - language production, speech and sign production, and ability to understand.
Wernicke's area (green) - language comphrehension
Supramarginal gyrus (yellow) or Brodmann area 40 - activates human's imitation
Angular gyrus (orange) or Brodmann area 39 - written word is translated to internal monologue and understanding metaphors
Primary auditory cortex (pink) - sounds development

Interindividual language variability
Probabilistic maps based on a meta-analysis



730 activation peaks from 130 reports

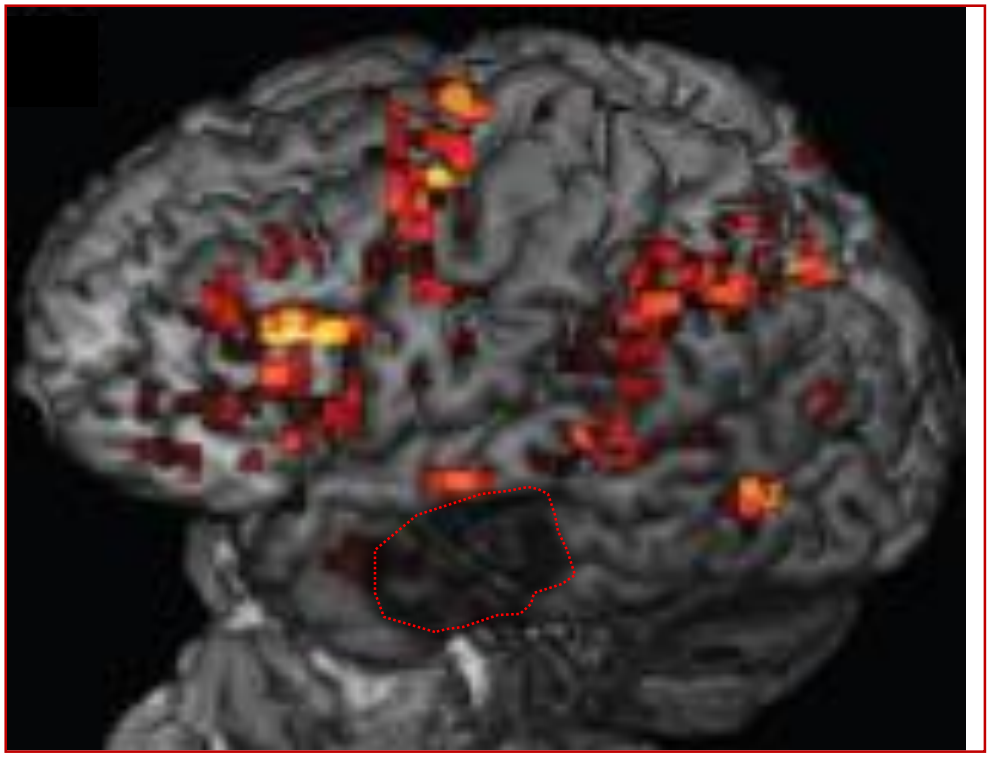
Phonology

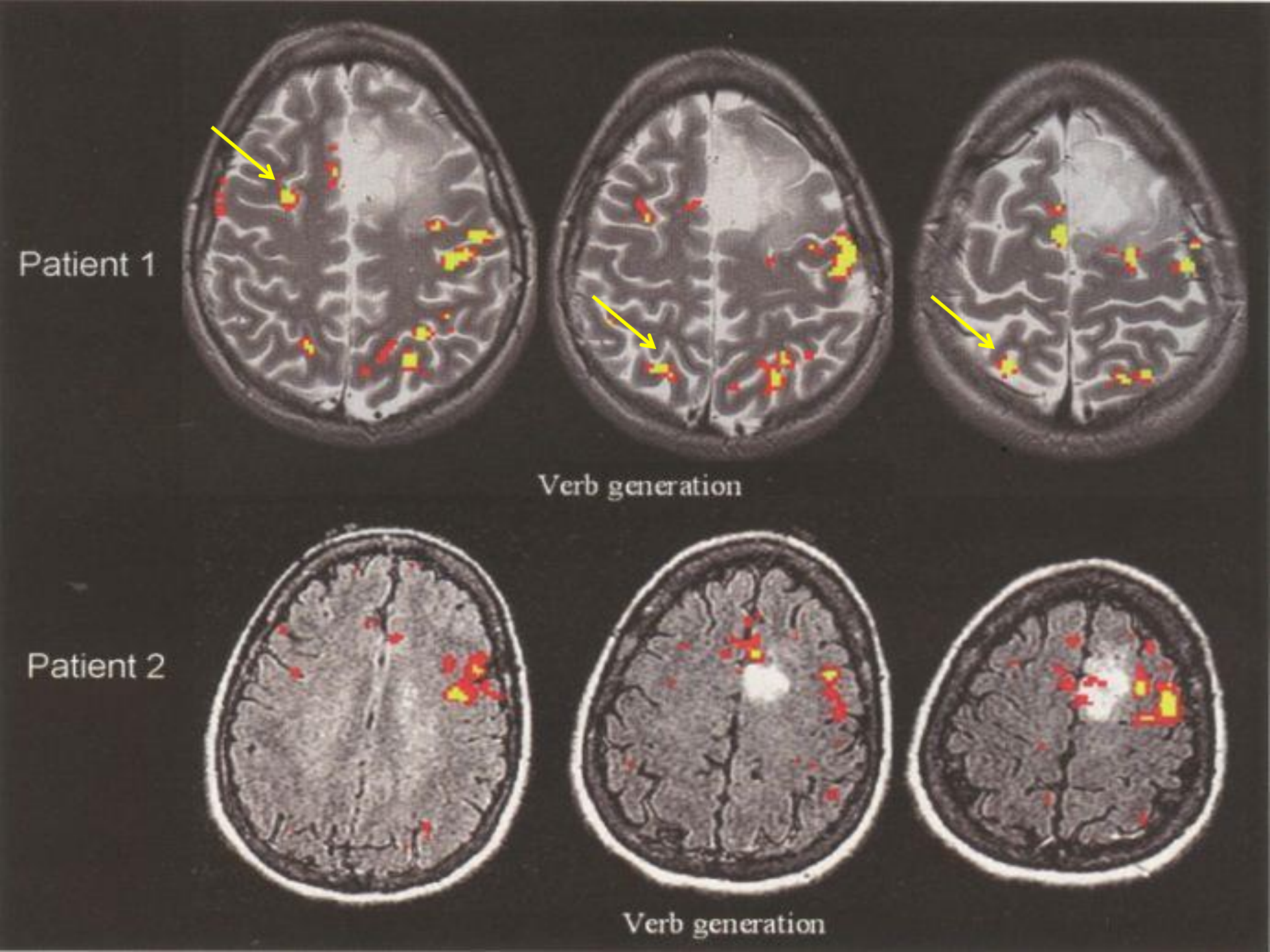
Semantics

Syntax

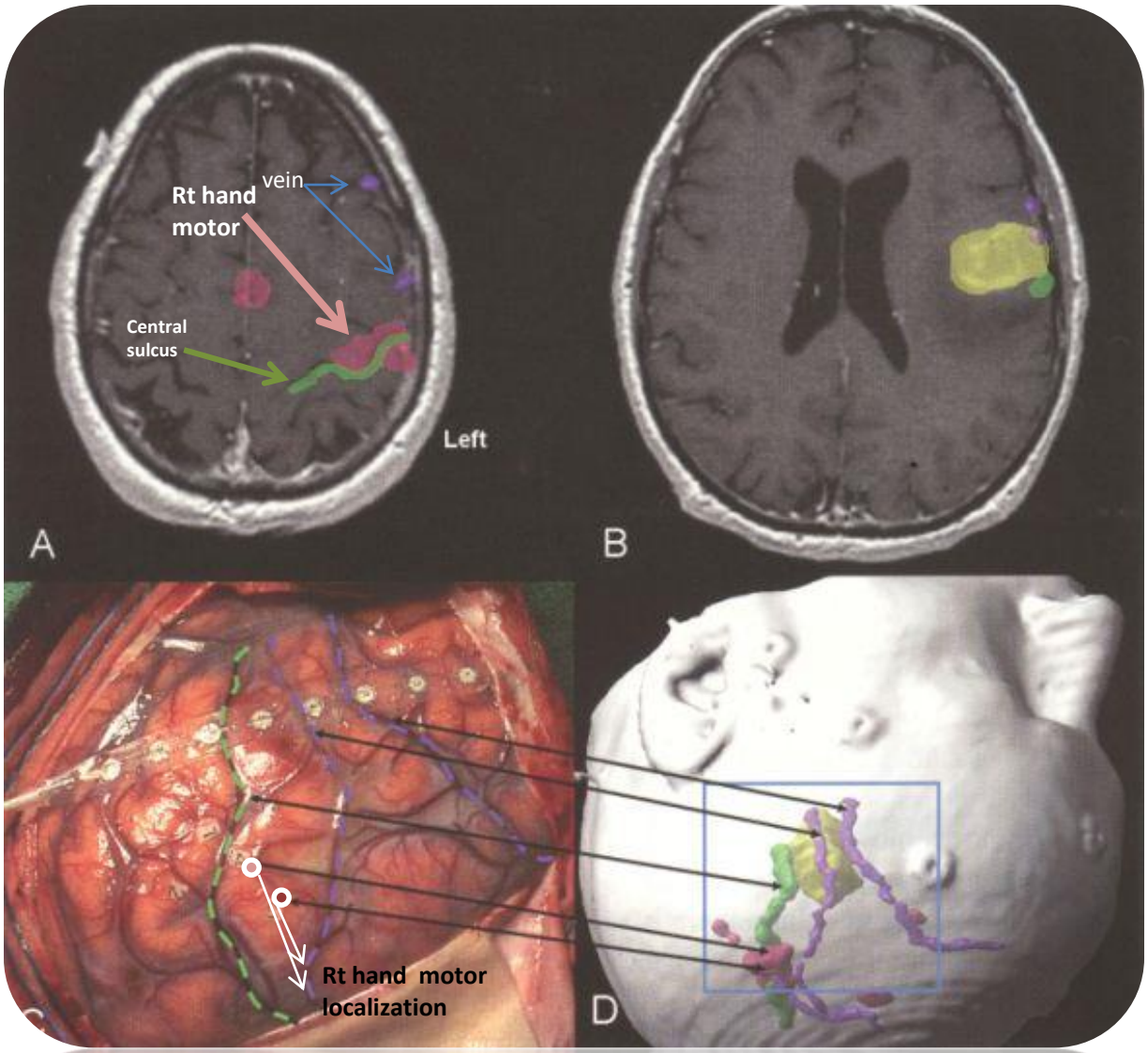
Vigneau et al., NeuroImage 2010

fMRI verb generation
(covert verb generation test)



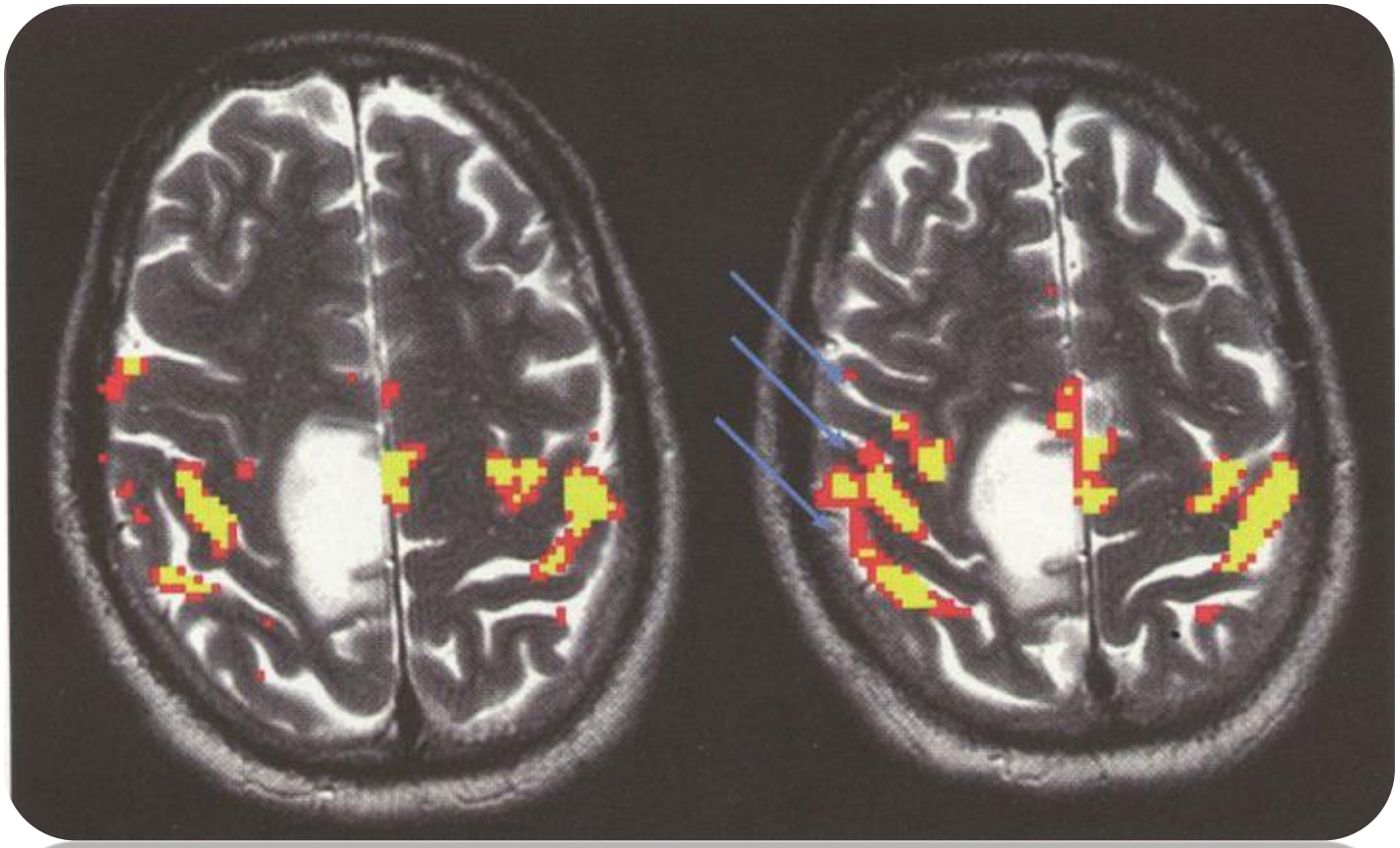

Patient 1
Verb generation
Patient 2
Verb generation

Motor fMRI integrated into the neuro-navigational system for guidance during the neurosurgical procedure

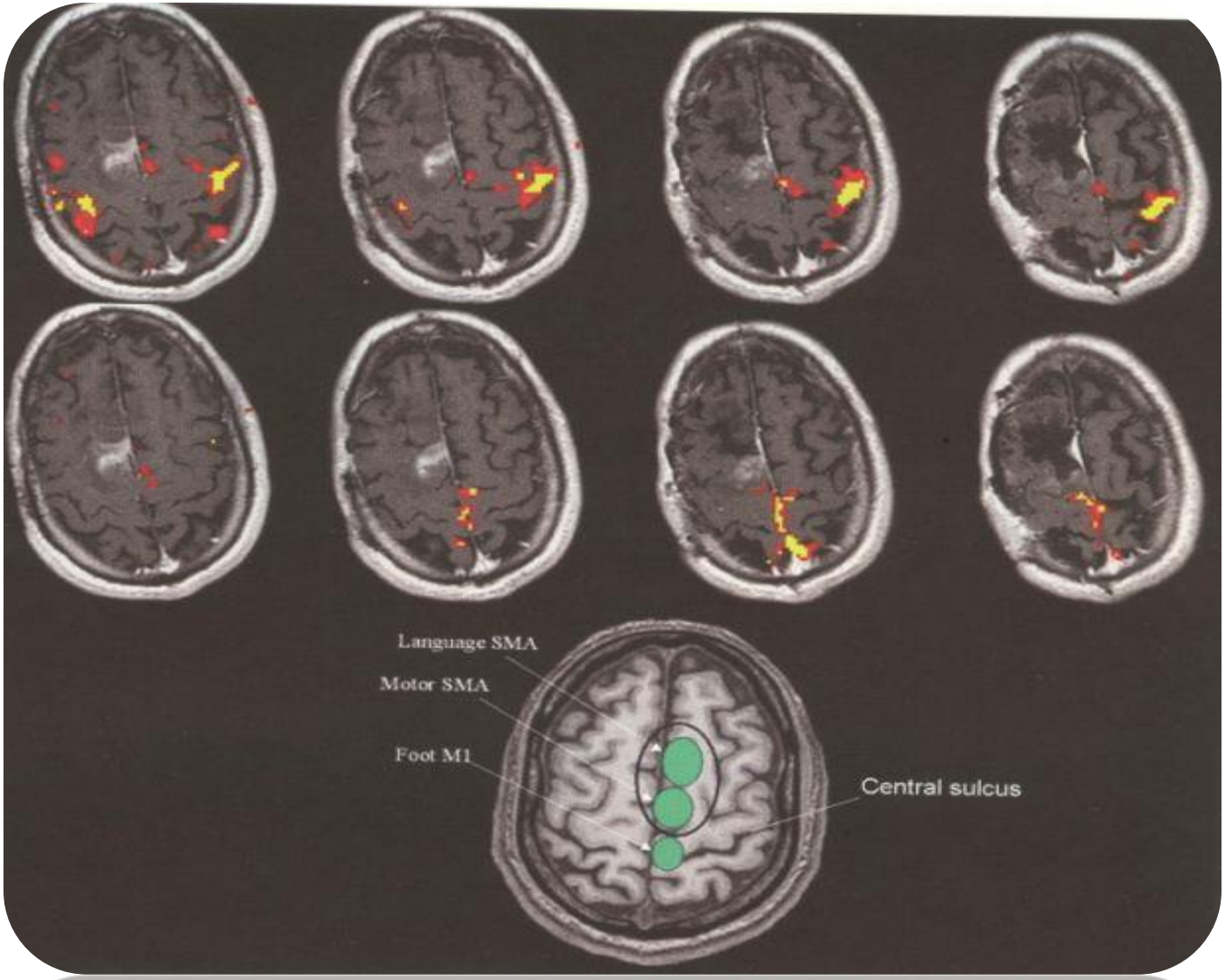


FMRI pitfalls

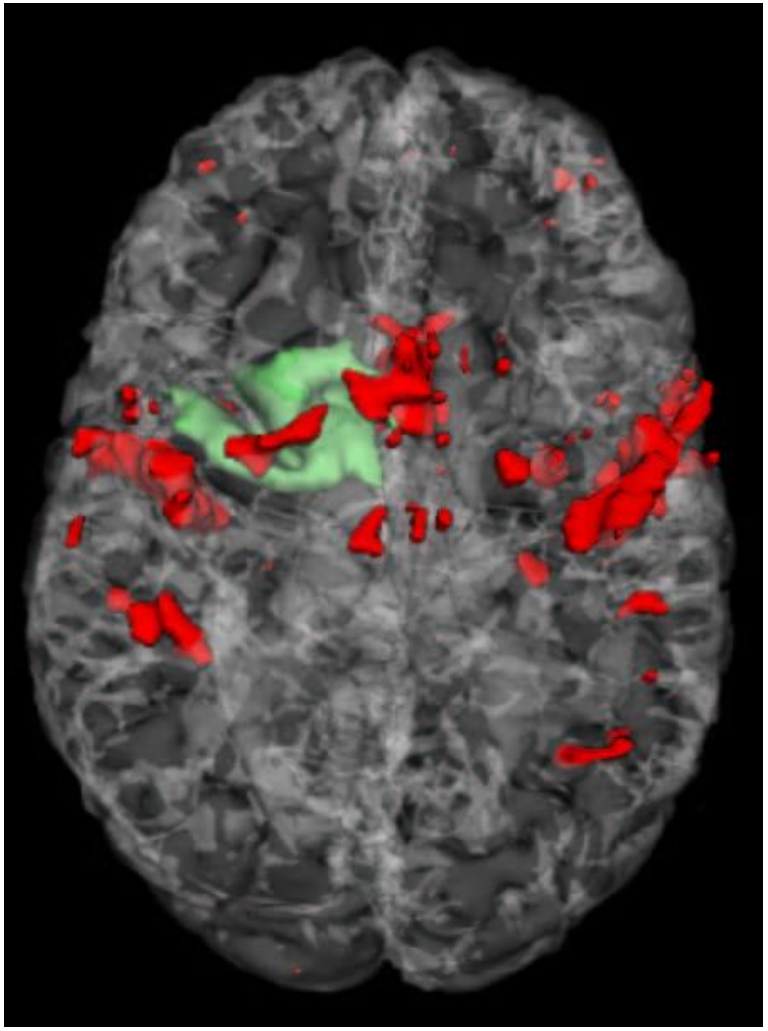
fMRI activation during bilateral finger tapping overlaid on two contagious T2 weighted images in a patient with a glioma in the leg/foot portion of the motor gyrus. Central sulcus? Reverse omega?



Anatomical boundaries of dorso-medial functional regions are poorly defined



Preoperative fMRI, Motor Experiment



F. Talos

Frontal

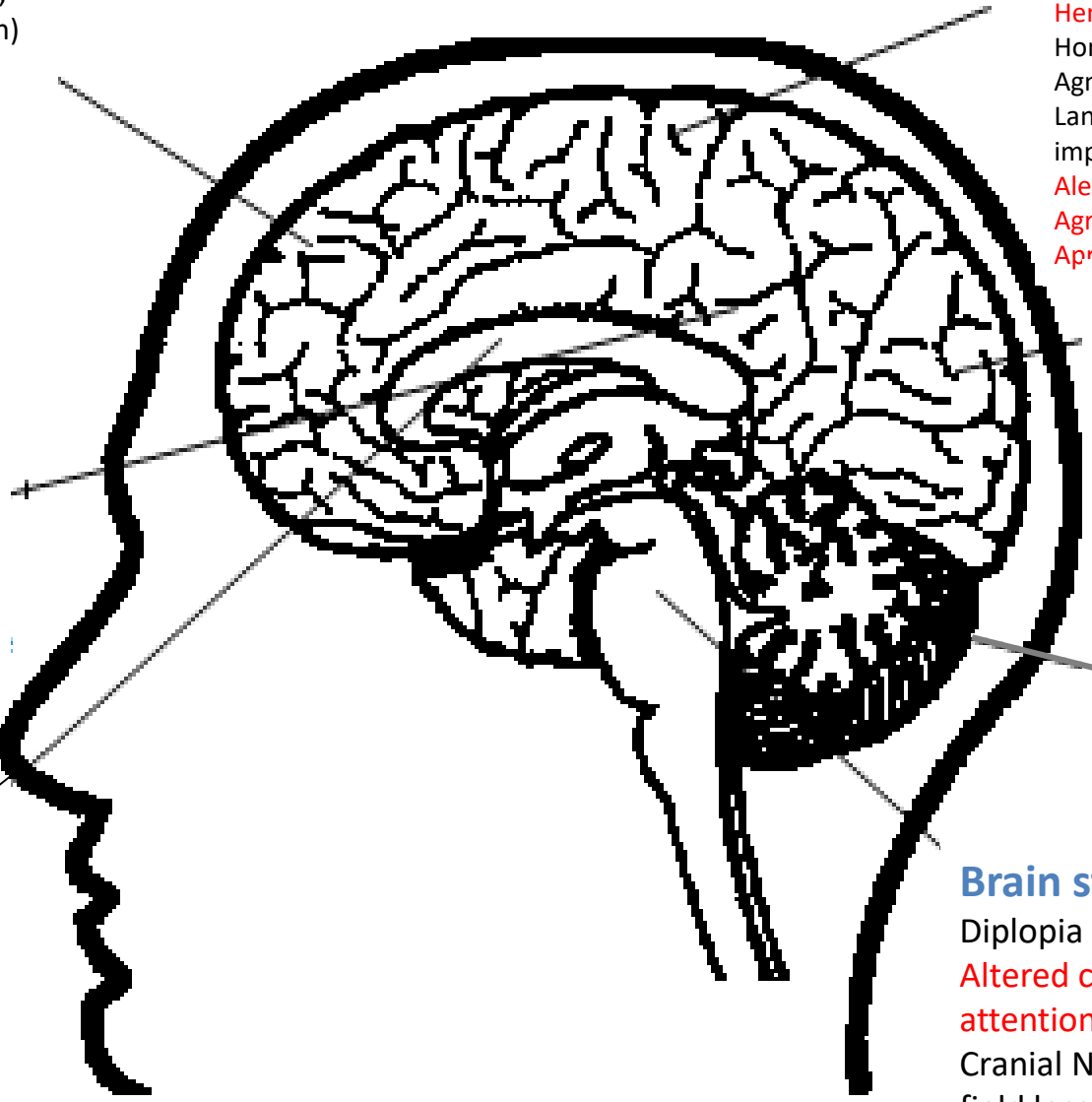
•Personality changes(impulsivity, lack of inhibition, lack of concern)
•Executive dysfunction
•Diminished self awareness of impaired neurologic or neuropsychological functioning (anasognosia)
•Language deficits

Temporal

•Auditory and perceptual changes
•Memory and learning impairment
•Aphasia and other language disorders

Corpus callosum

•Transmission of visual information
•Integration of sensory inputs
•Transmission of somatosensory information



Parietal

Somatosensory changes
Impaired spatial relations
Hemispatial neglect
Homonymous visual defects
Agnosia
Language comprehetion impairment
Alexia
Agraphia
Apraxia

Occipital

Alexia (disorders of reading)
Homonymous hemi anopsia
Impaired extra occular muscle movements
Color anomia
Achromatopsia

Cerebellum

Ataxia

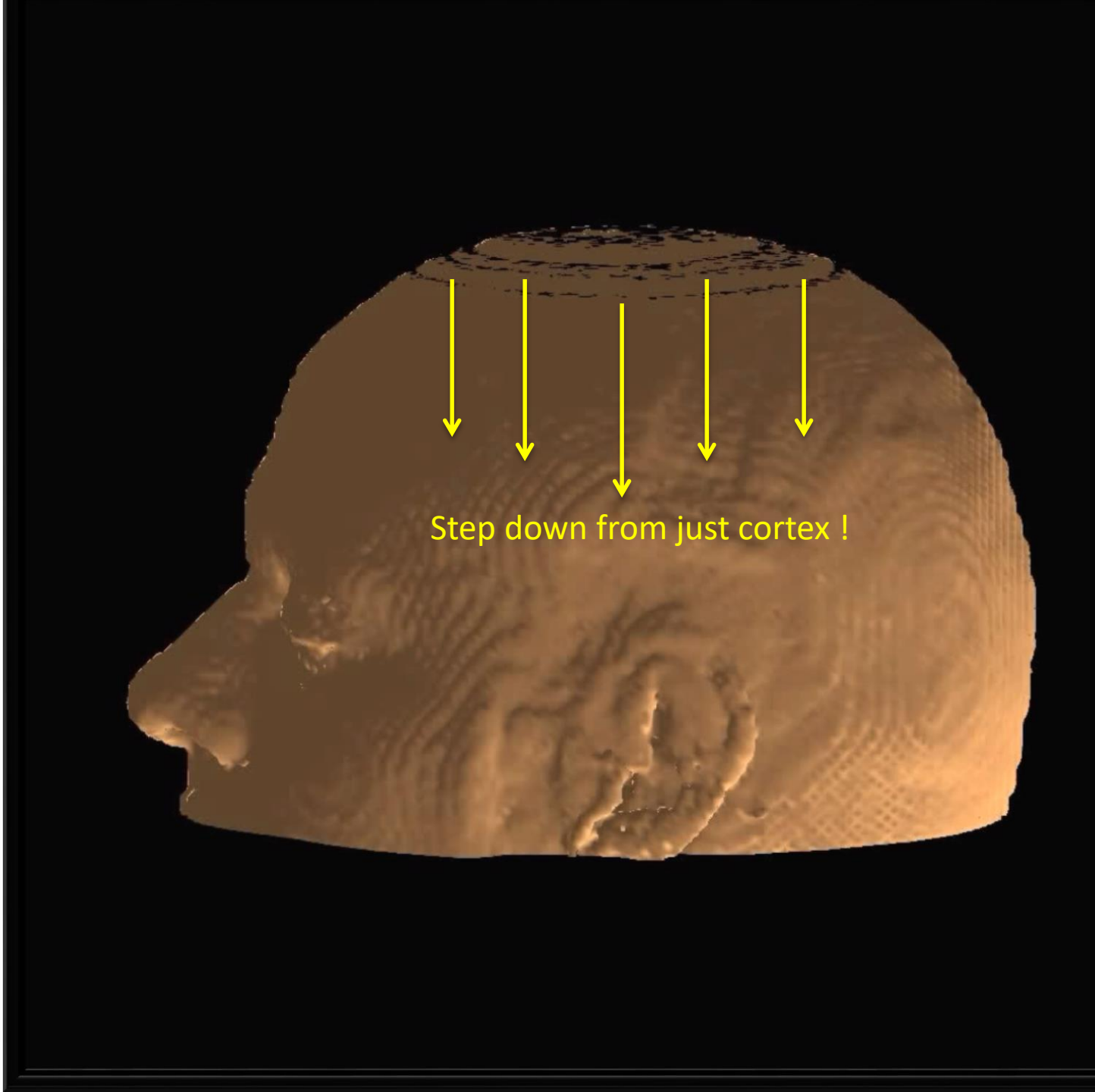
Brain stem

Diplopia
Altered consciousness and attention
Cranial Neuropathies(visual field loss, dysartheria, impaired extra ocular muscle movement

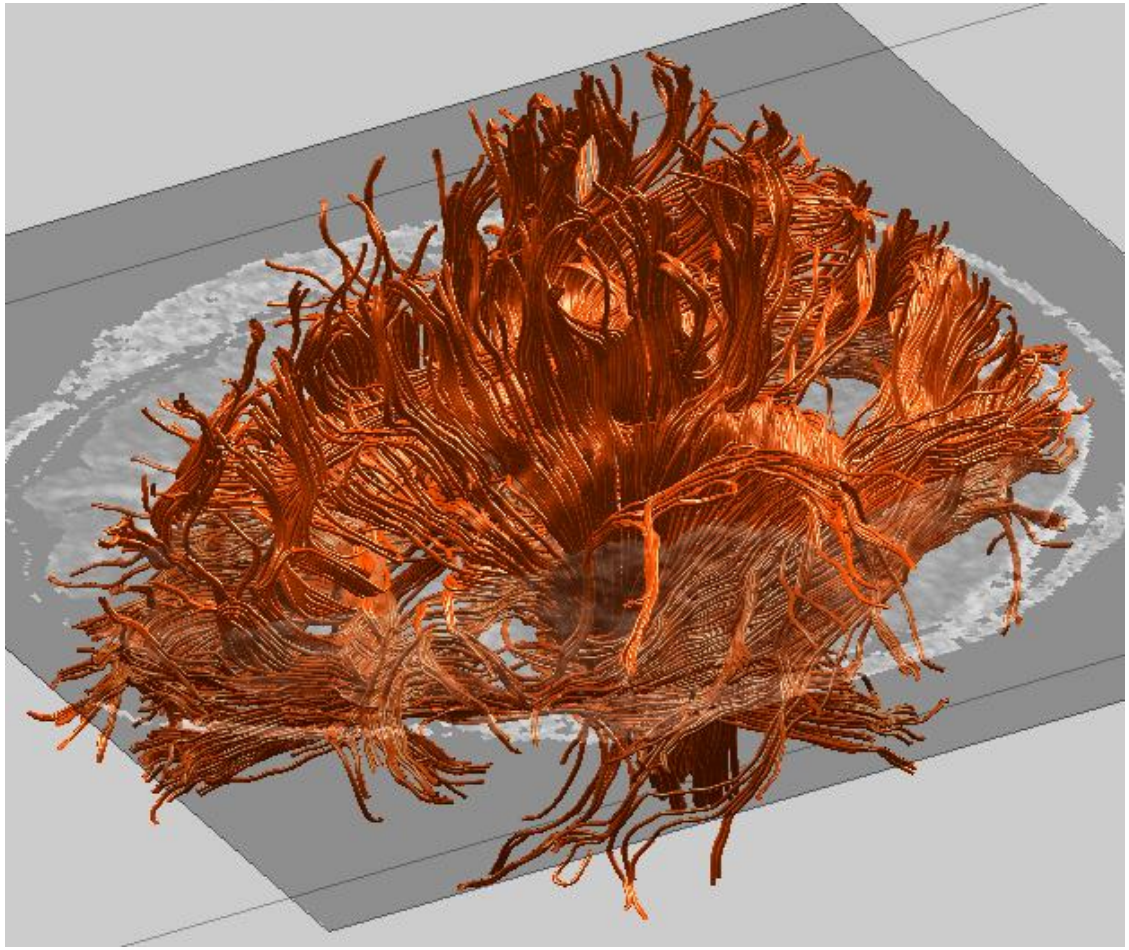
DTI

Diffusion Tensor Imaging

for imaging tracts

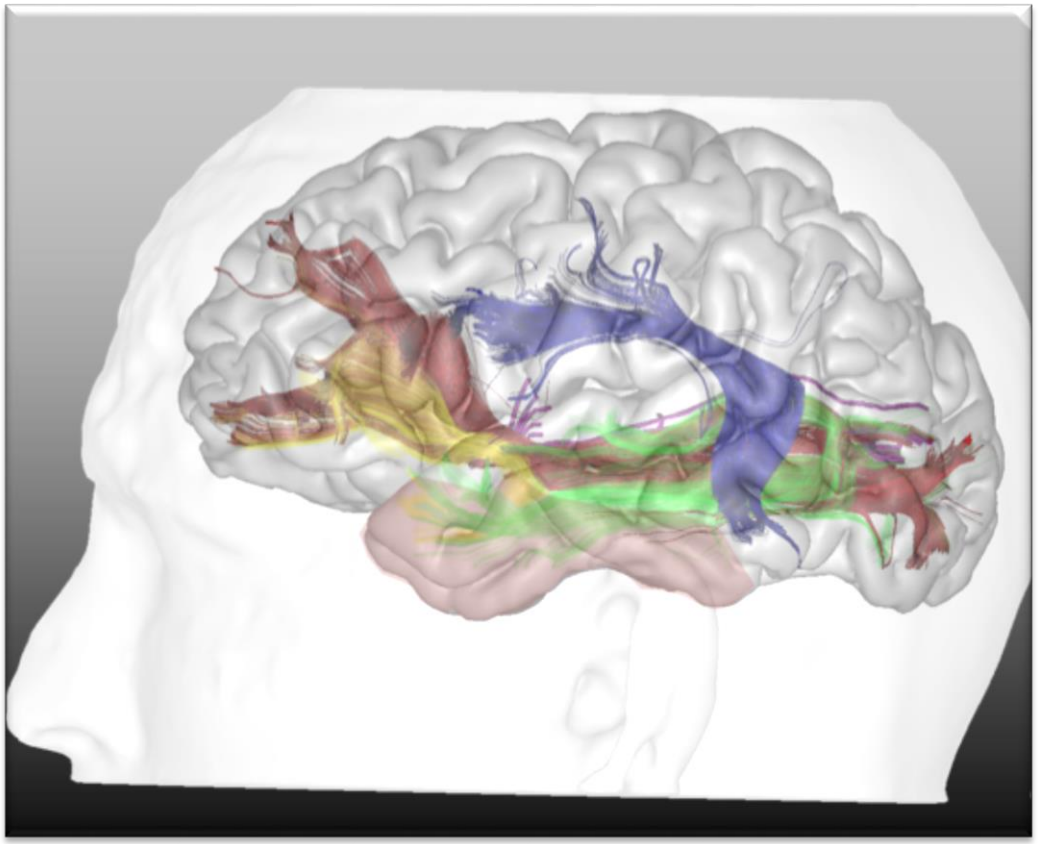


DT-MRI Tractography



H.J. Park, M.E. Shenton, C.-F. Westin

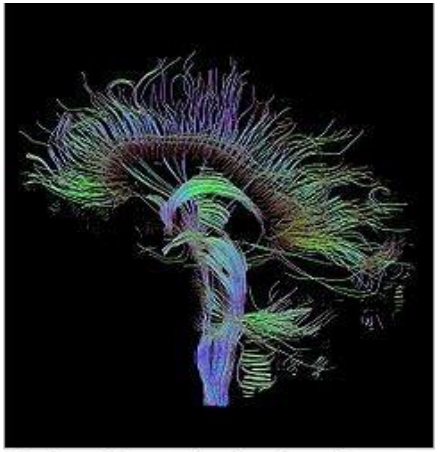
Subcortical tracts



- Monitoring the cortex is not enough
- The tracts need to be respected also

DTI

- In neuroscience , **tractography** is a procedure to demonstrate the neural tracts



Tractographic reconstruction of neural connections via Diffusion tensor imaging (DTI).

- MRI
- 3D network for short connections, both cortical and sub-cortical

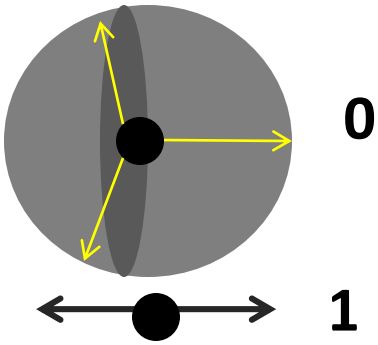
DTI- Tractography

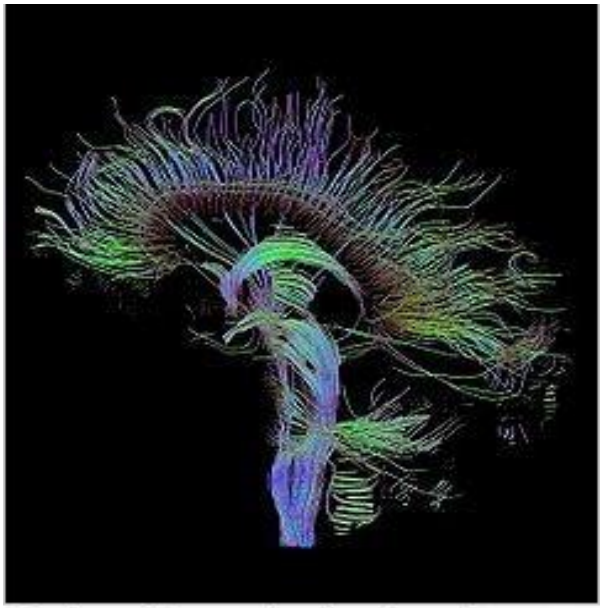
- **D**iffusion: water diffuses symmetrically
- **T**ensor: Bundles of fiber tracts make the water diffuse asymmetrically in a tensor
- **I**maging :MRI sequence image spherical vs linear diffusion of water

- Barriers: axon, cell membrane, and myelin
  (in white matter: myelin sheath of axons)

Anisotropy?

- Isotropy
- Anisotropy





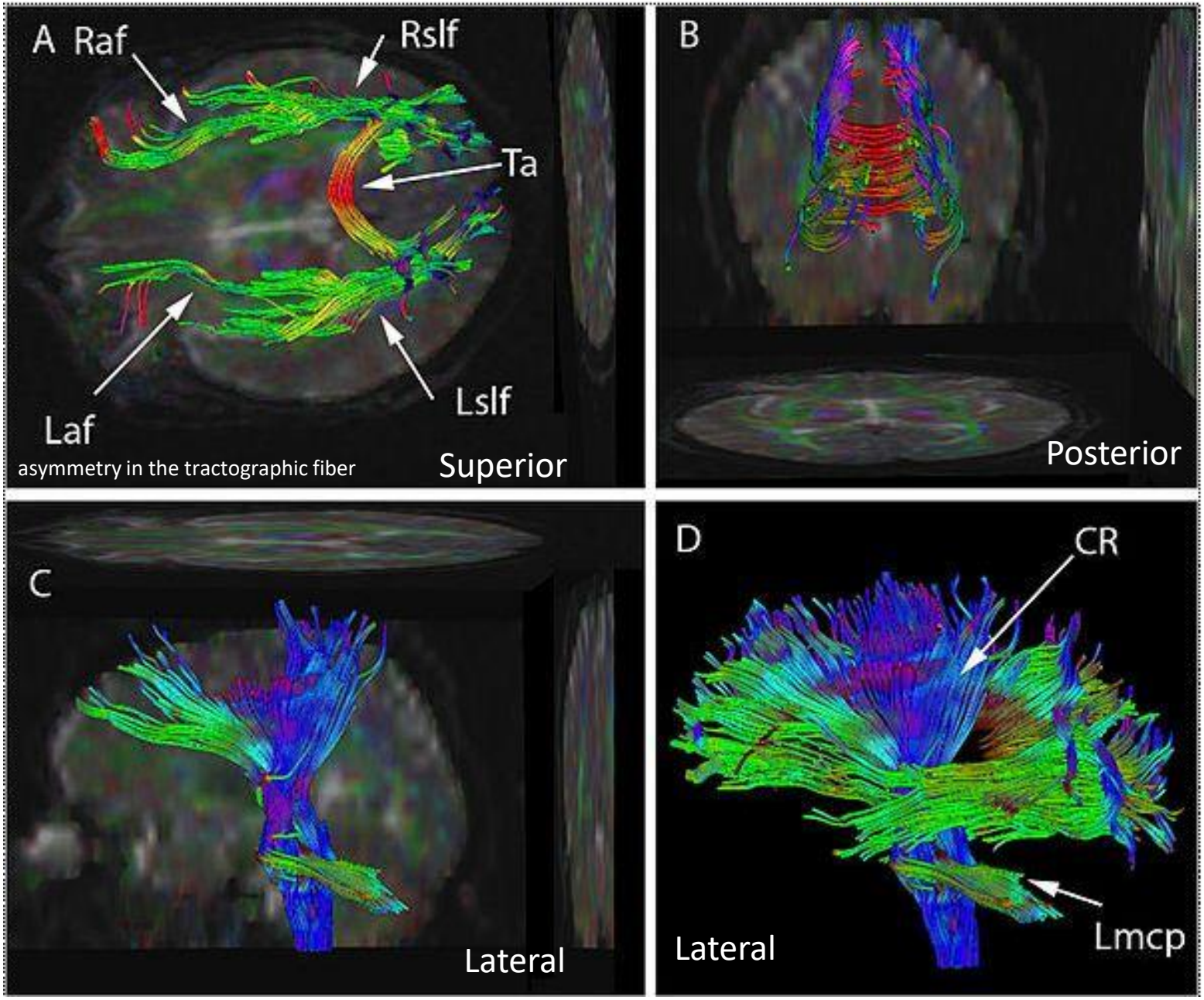
Tractographic reconstruction of neural connections via Diffusion tensor imaging (DTI).

- Fractional anisotropy (FA)

- Well defined tracts: FA≥ 0.2
- Few regions have FA larger than 0.90.
- The number gives information of how spherical the diffusion is but says nothing of the direction.

Post processing programs: extract these directions

- **Red** indicates directions in the X axis: right to left or left to right.
- **Green** indicates directions in the Y axis: posterior to anterior or from anterior to posterior.
- **Blue** indicates directions in the Z axis: foot-to-head direction or vice versa


A
Raf
Rslf
Ta
Laf
Lslf
asymmetry in the tractographic fiber
Superior
B
Posterior
C
Lateral
D
CR
Lmcp
Lateral

Diffusion Tensor Imaging

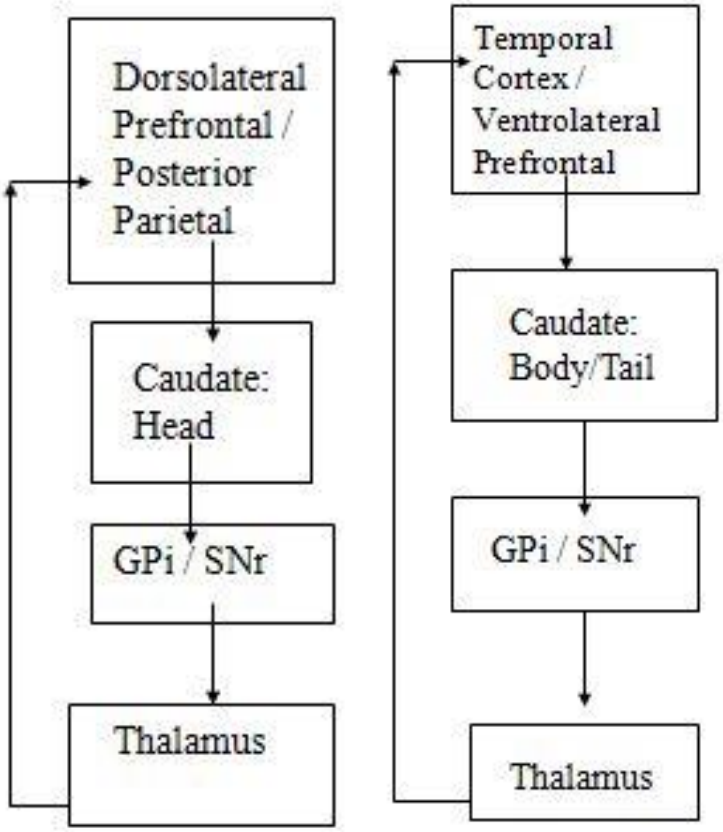
White matter

myelinated axons connecting brain regions.

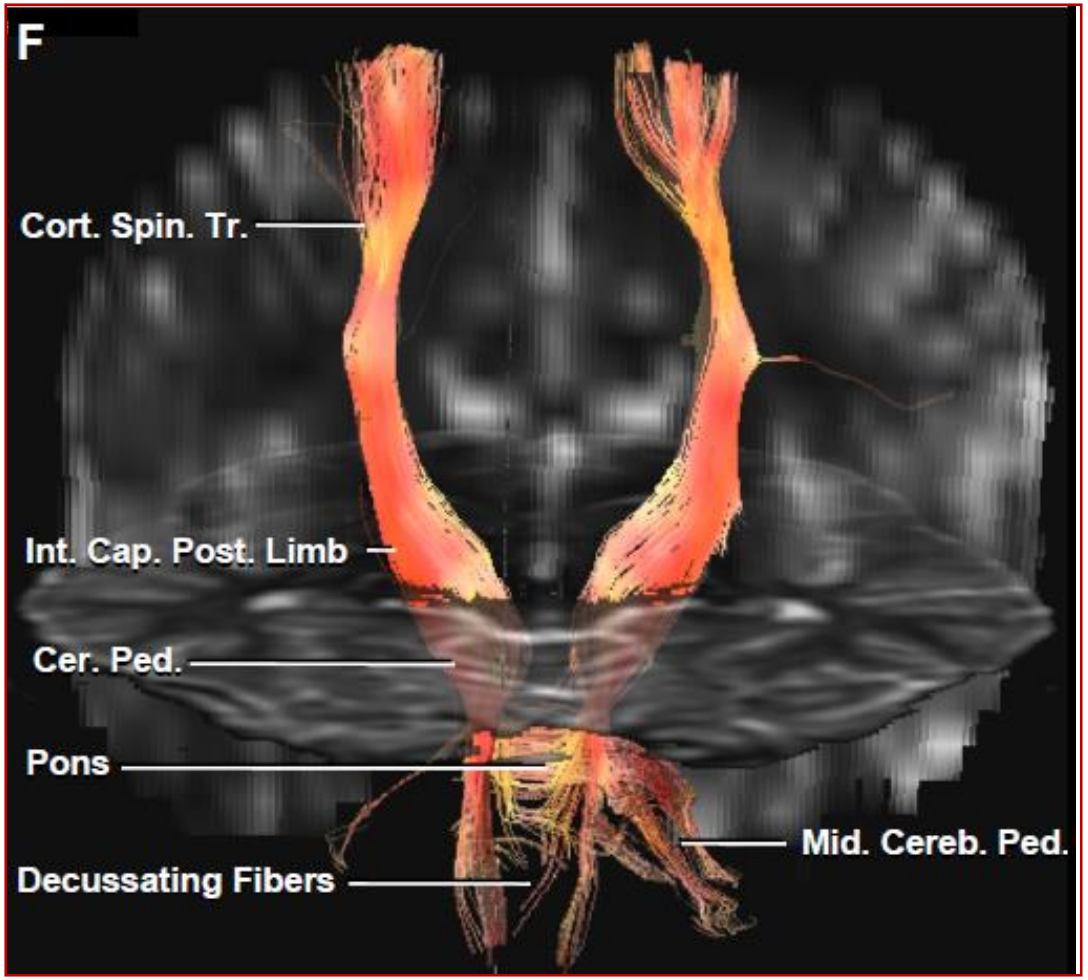
Basal ganglia:

Verifying corticostriatal loop anatomy in humans

Examine individual differences in anatomical connectivity

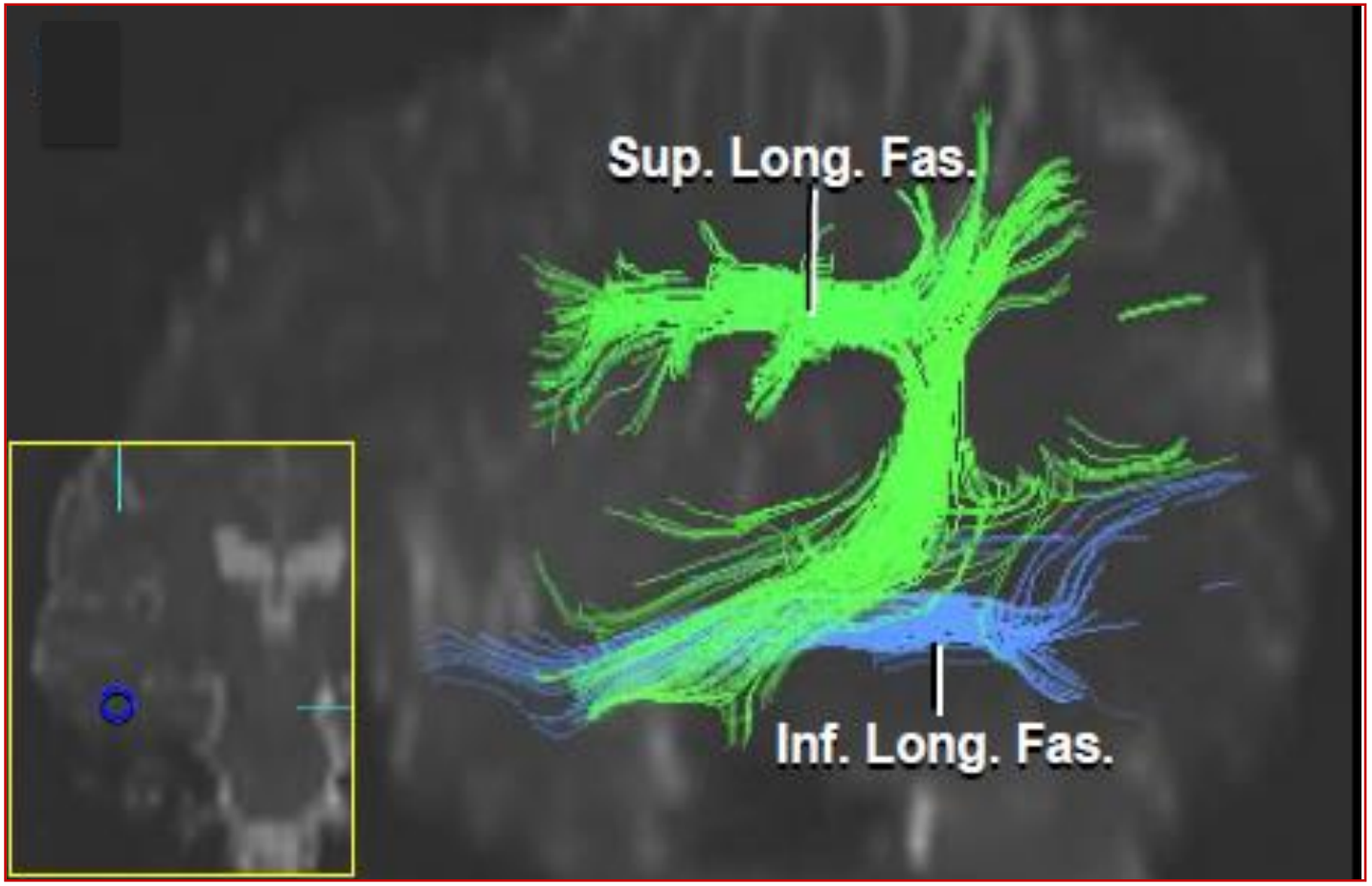


Pyramidal tract:



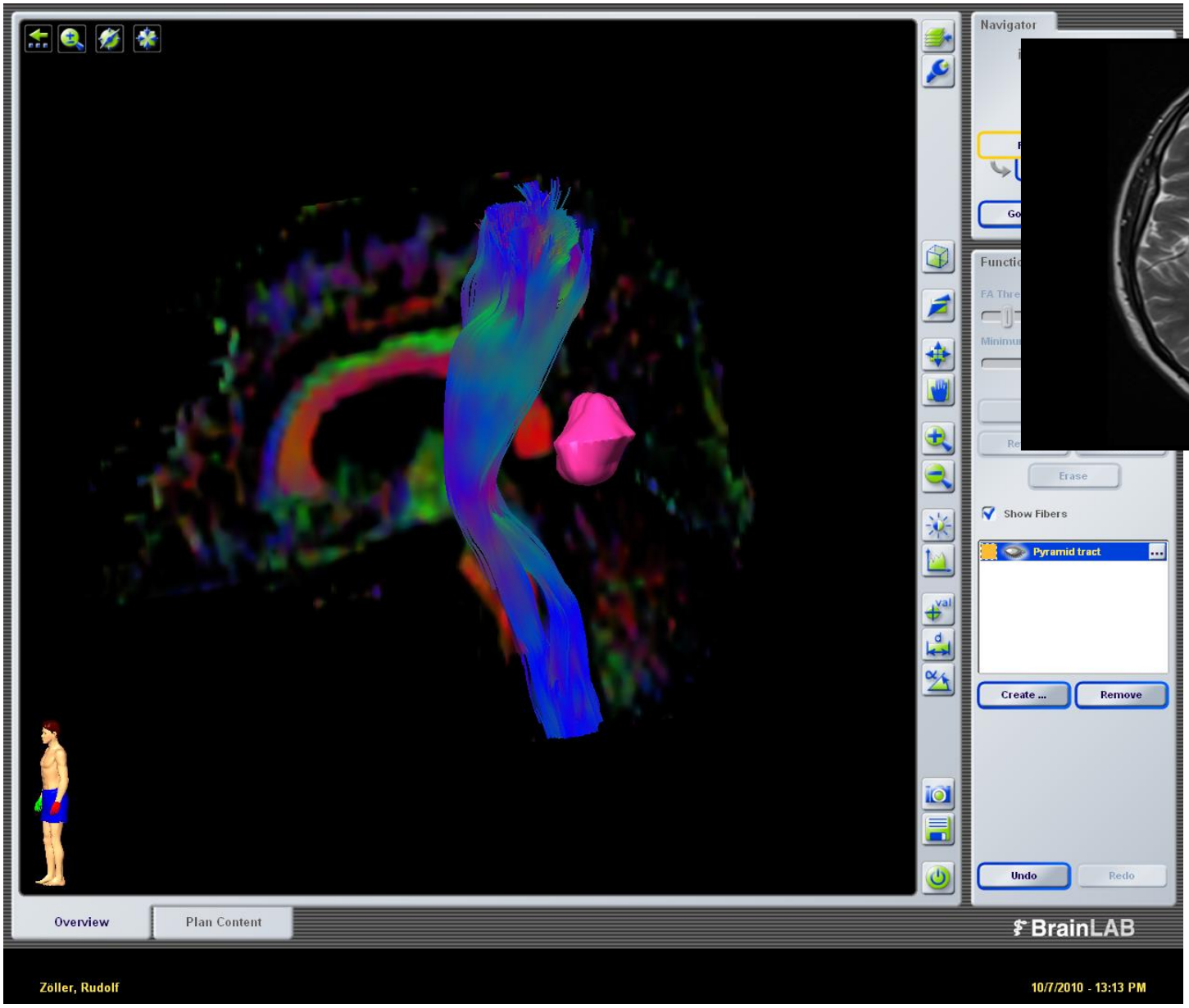
J.C. Fernandez-Miranda 2008

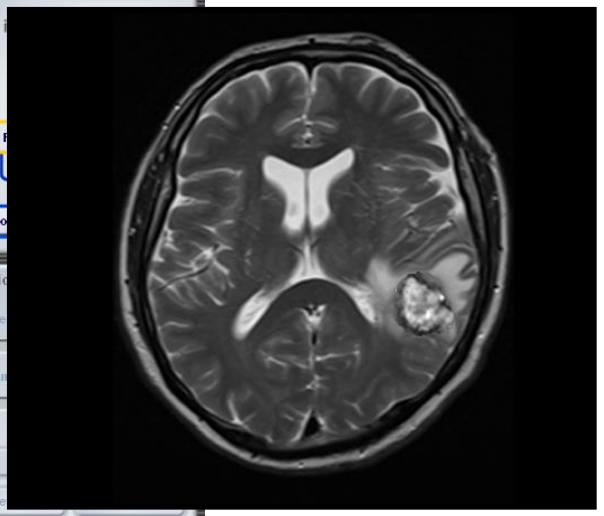
Sup. Longitudinal fasciculus
Fasciculus arcuatus (language)



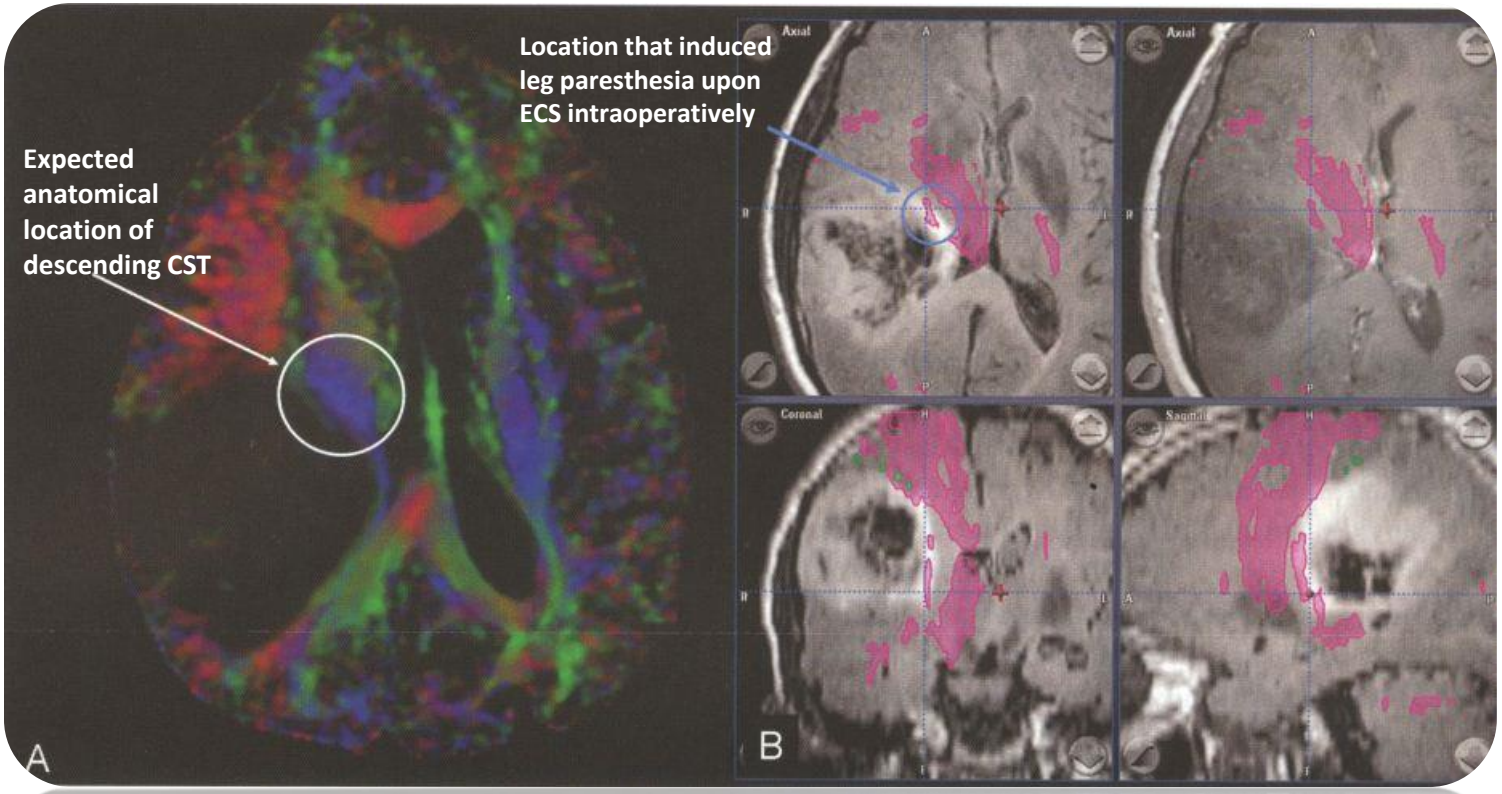
J.C. Fernandez-Miranda 2008

Practical use

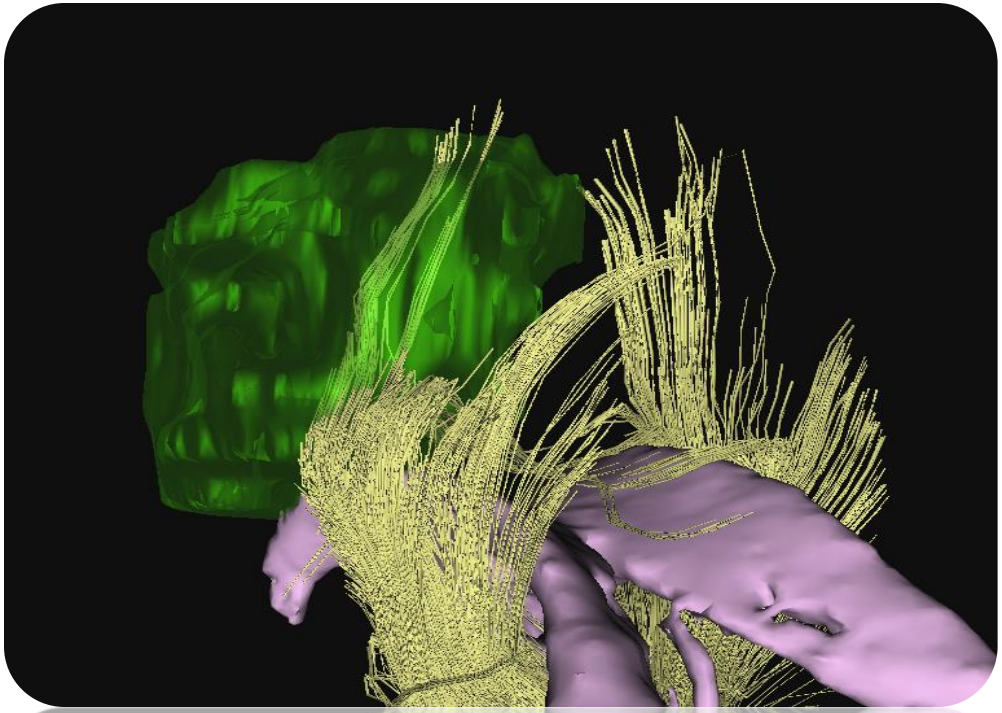


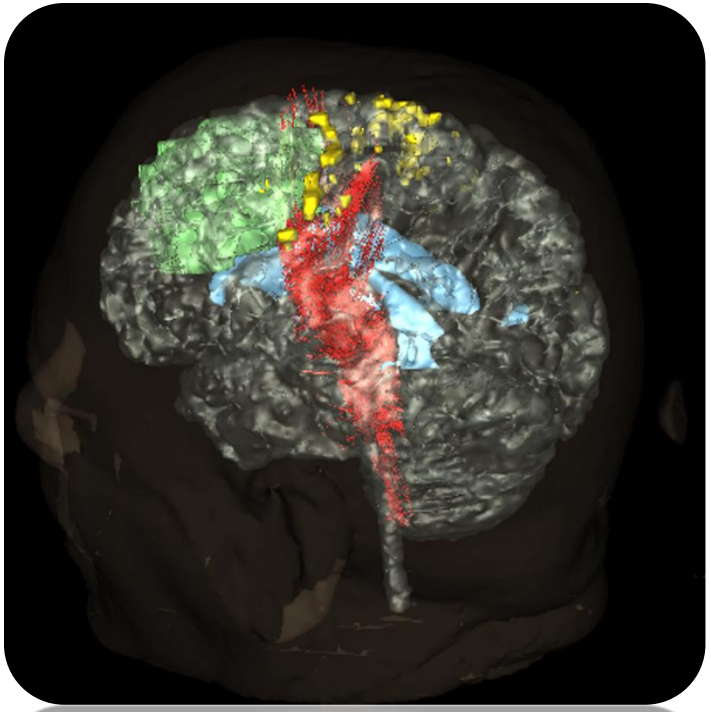


Color fractional anisotropy map (A) an intra-operative neuro-navigational image (B) in a patient with a GBM



Oligodendroglioma – DT-Tractography + fMRI





F. Talos

(PET) Positron Emission Tomography

- A PET scan is a radionuclide scan that produces a 3-D image or map of functional processes such as blood flow, oxygen use and blood sugar (glucose) metabolism.

- Glucose is often combined with a radioactive substance (radiotracer) fluorodeoxyglucose (FDG), that's injected into the patient

- Different tissues in our body take up different radionuclides at different rates.

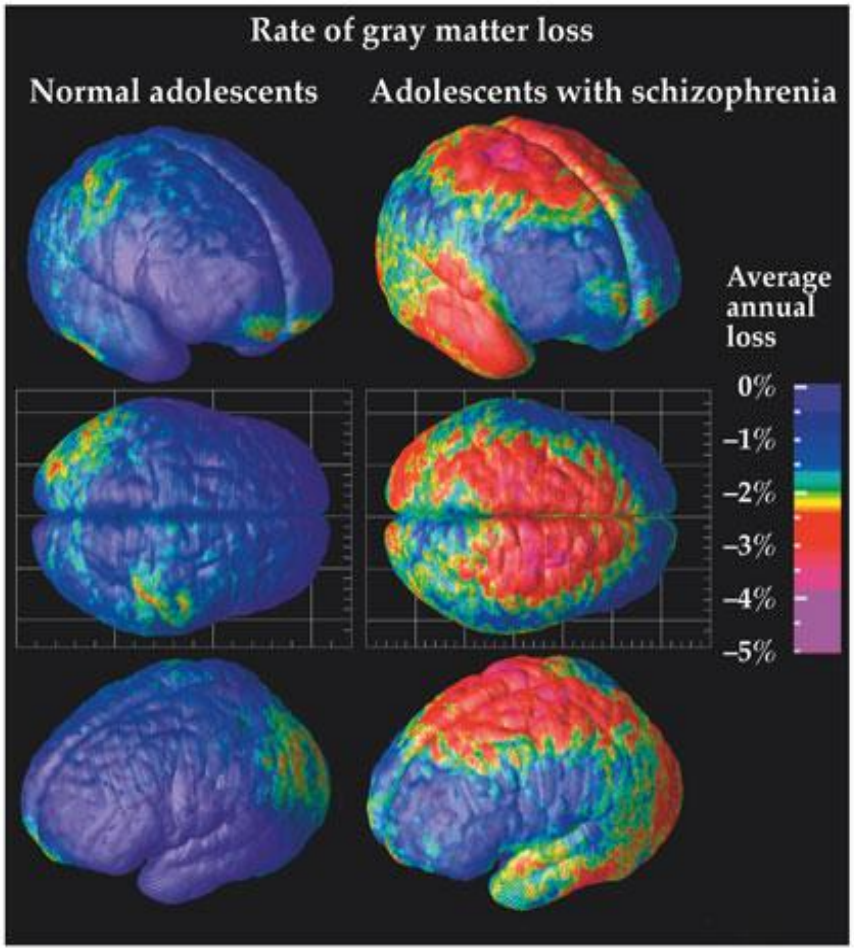
- The number of positrons emitted by an organ or area of tissue indicates the amount of radioactive substance

- Intense color = high uptake = hot spots
- Less intense color = low uptake of radioactive substance = cold spots.

PET Radiotracers other than FDG

- **Dopamine**
- **Benzodiazepine**
- **Serotonin**
- **Histamine**
- **Muscarinic cholinergic**
- **Amyloid**
- **Protein kinase C**
- **Monoamine oxidase**

PET scan



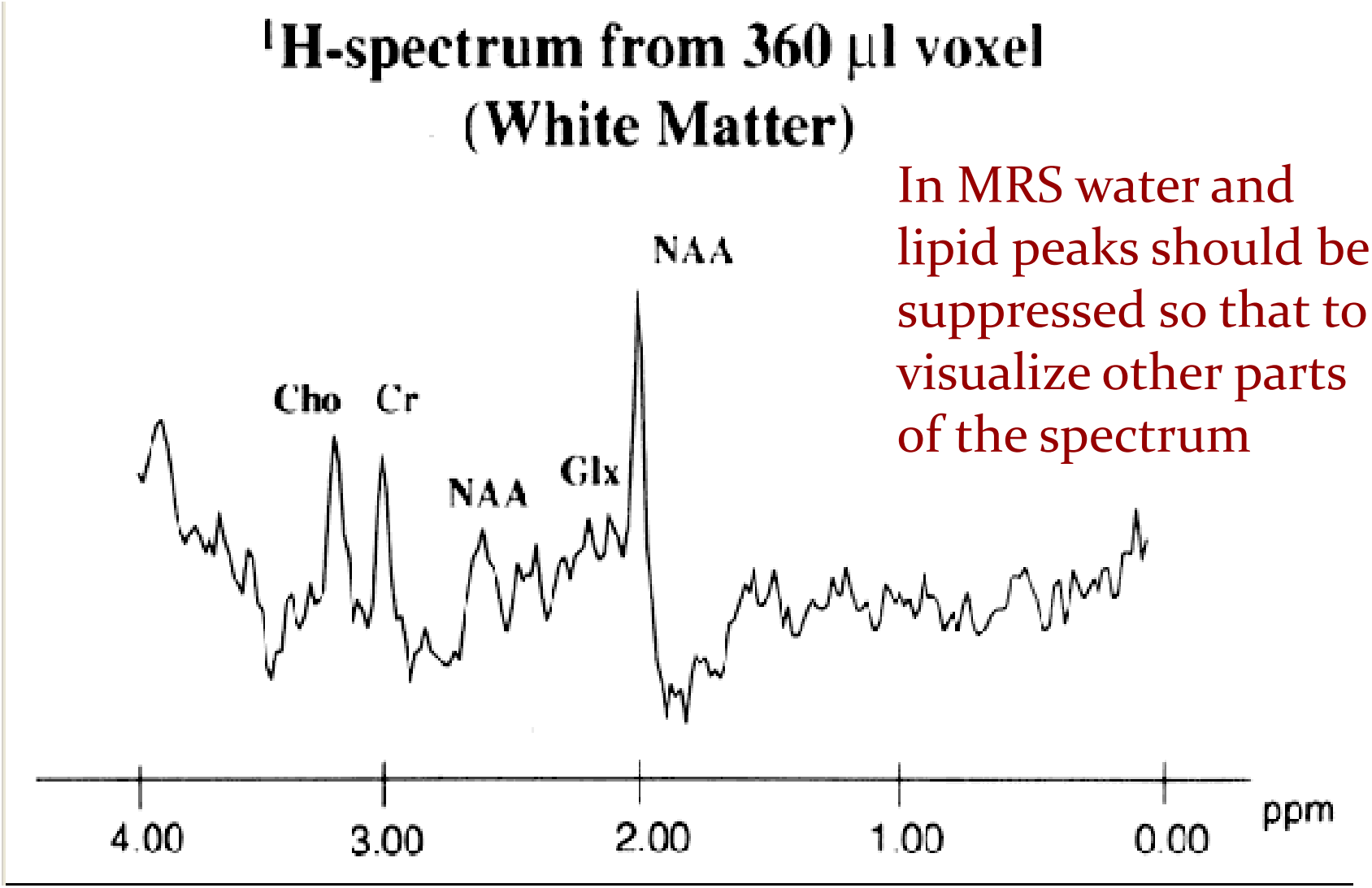
BIOLOGICAL PSYCHOLOGY, Fourth Edition, Figure 16.6 © 2004 Sinauer Associates

Single photon emission computed tomography (SPECT)

- SPECT is very similar to PET
- Uses a radioactive tracer material and detects gamma rays.
- In contrast to PET, the tracer used emits gamma radiation that is measured directly.
- Perfusion rather that metabolism.
- SPECT has lower resolution than a PET scan.
- SPECT scans are significantly less expensive.

MRS

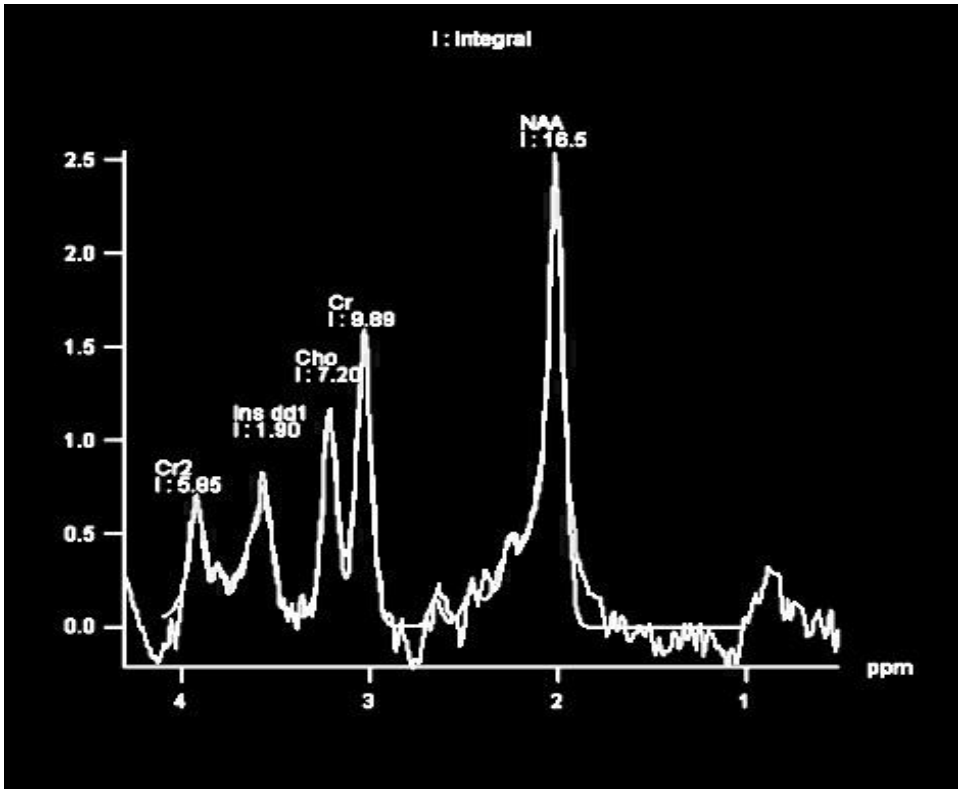
We have MRS available …

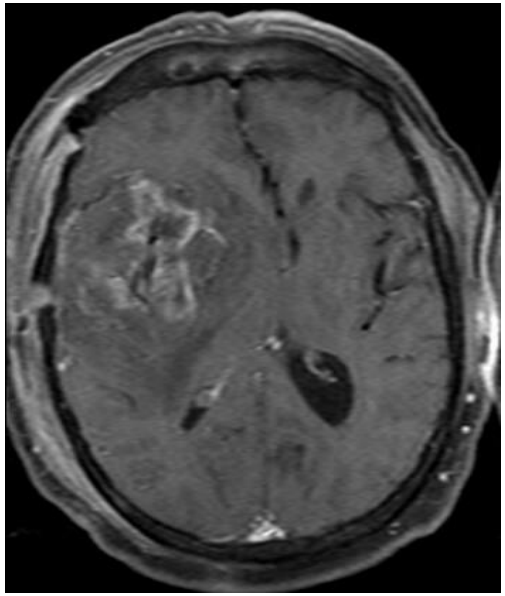


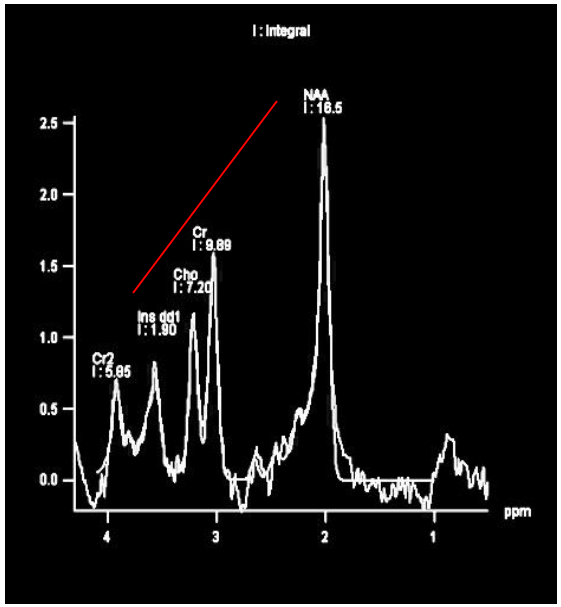
In MRS water and lipid peaks should be suppressed so that to visualize other parts of the spectrum

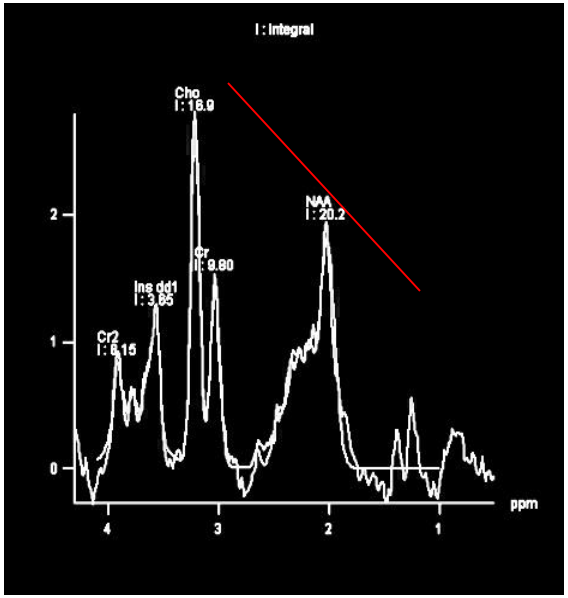
Detectable peaks in MRS

- (Cr)
- (Cho)
- (NAA)
- Lactate
- Lipids









Cho- Cr-NAA line is an upstroke in normal condition

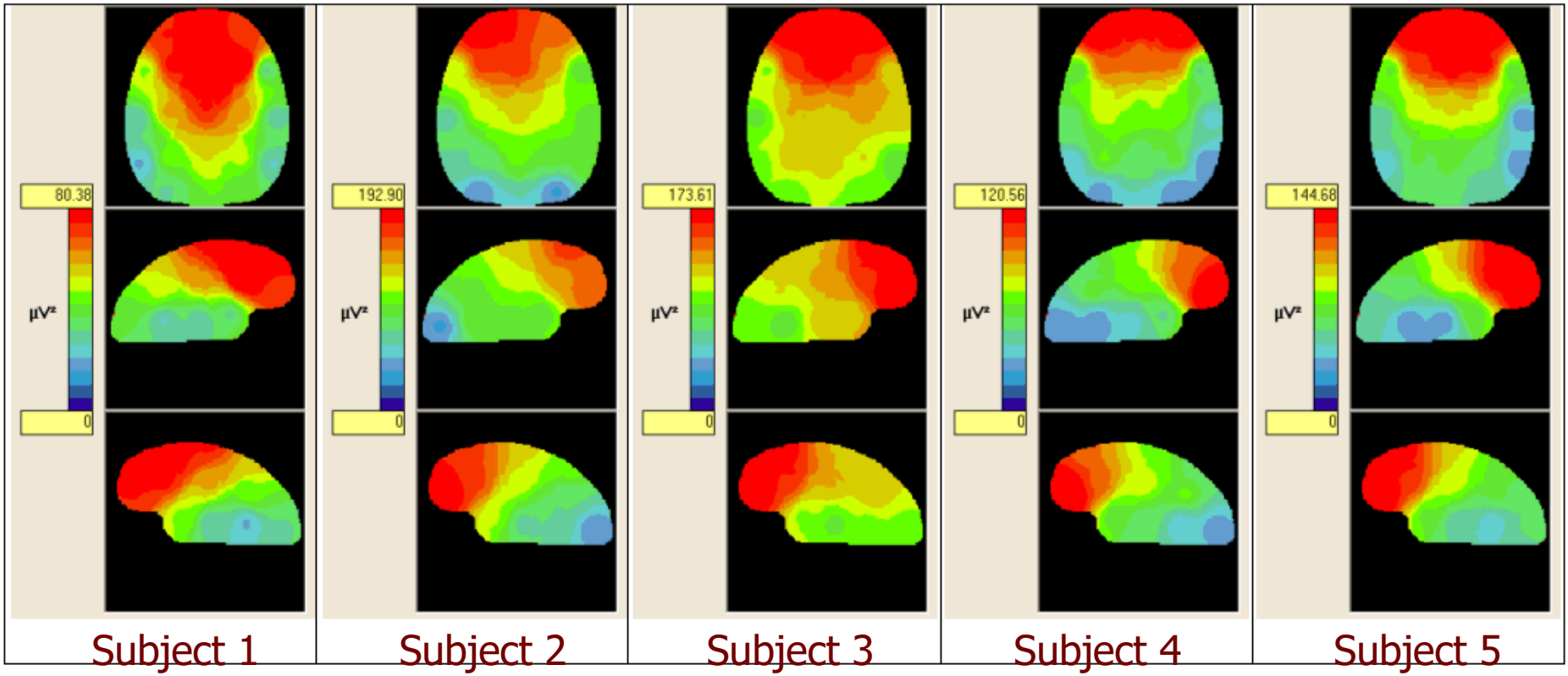
In brain tumors this will be reversed

This line's slope is known as Hunter's angle

QEEG

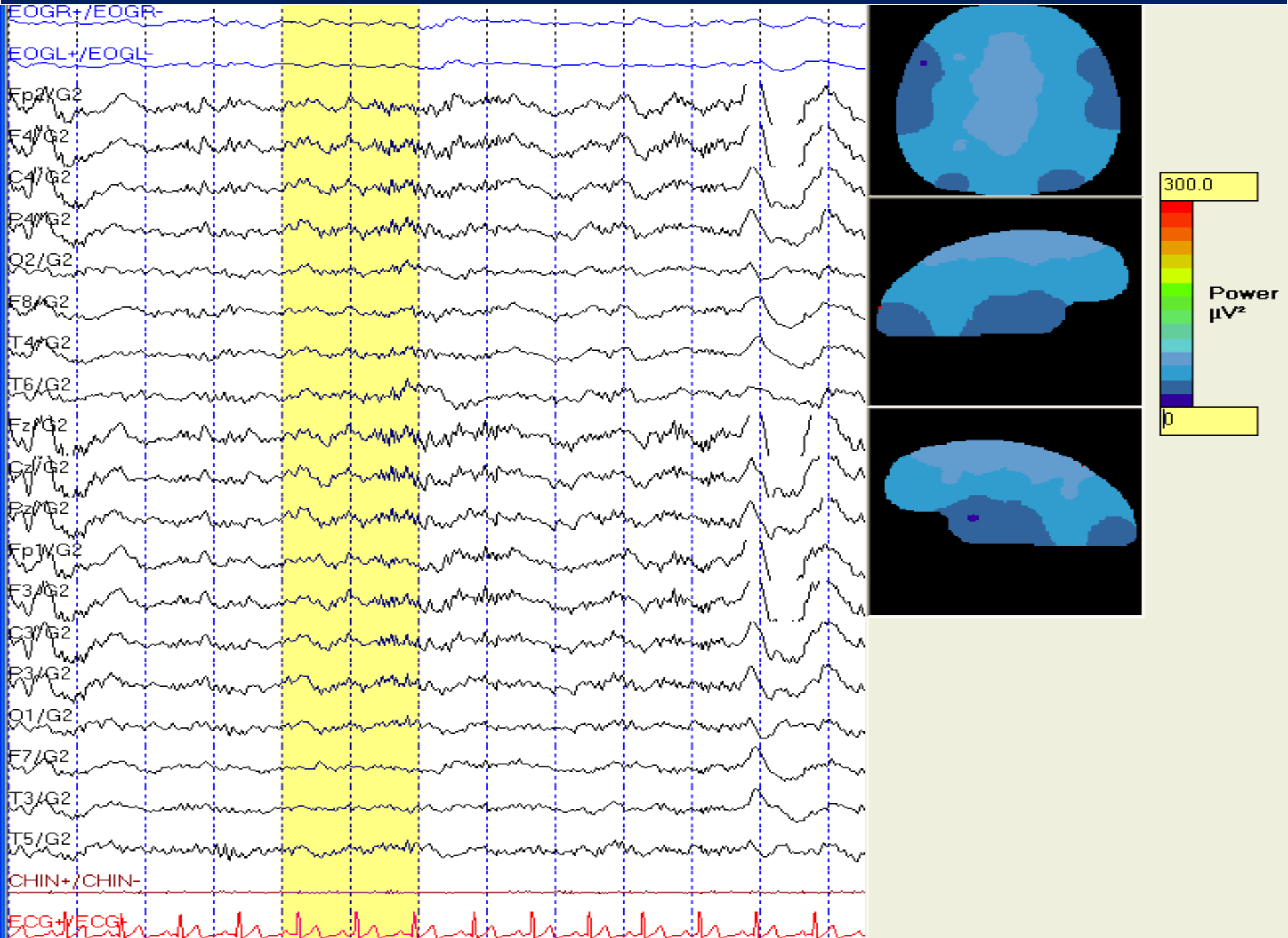
Scalp topographic mapping

of the slow component (0.25-2.5 Hz) of CAP



Functionally event results in:

ERP (Event-related potentials)	ERS (Event-related synchronization)	ERD (Event-related desynchronization)
phase-locked	not phase-locked	not phase-locked
	Closing eyes and relaxation: **increase** in alpha (9-12 Hz)	Hand movement: **decrease** in Mu rhythm (9-13 Hz)


EOGR+/EOGR-
EOGL+/EOGL-
Fp2/G2
F4/G2
C4/G2
P4/G2
O2/G2
F8/G2
T4/G2
T6/G2
Fz/G2
Cz/G2
Pz/G2
Fp1/G2
F3/G2
C3/G2
P3/G2
O1/G2
F7/G2
T3/G2
T5/G2
CHIN+/CHIN-
ECG+/ECG-
300.0
Power
µV²
0

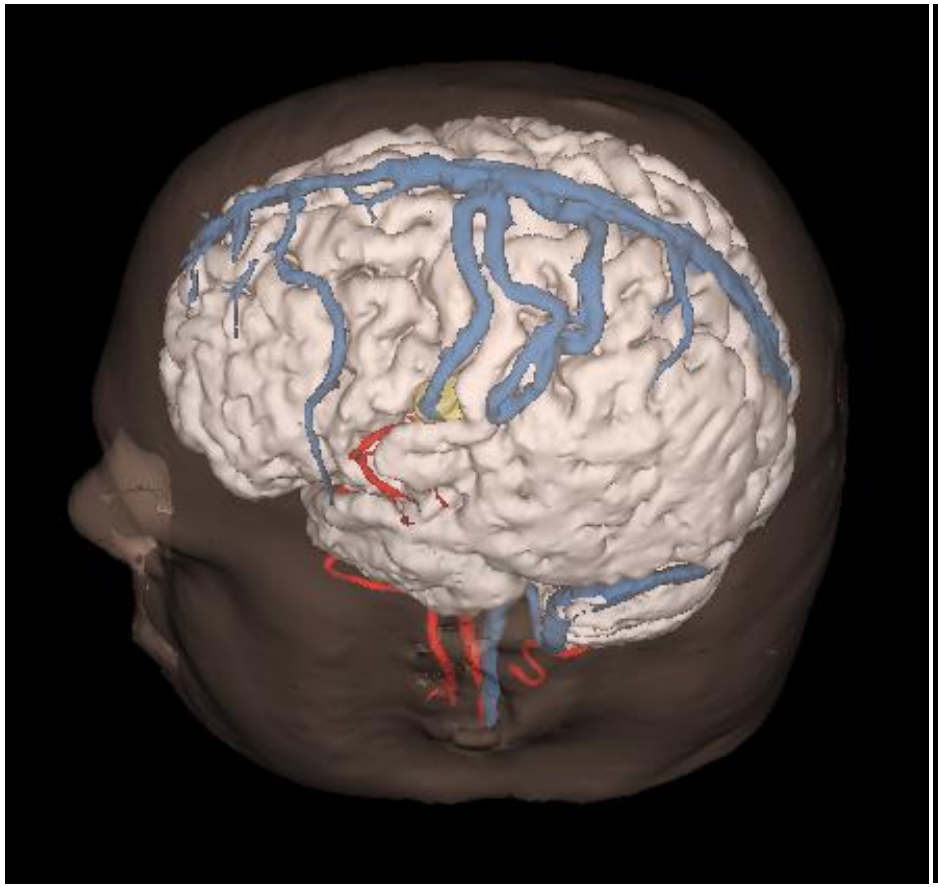
Goal: Assist Surgeons

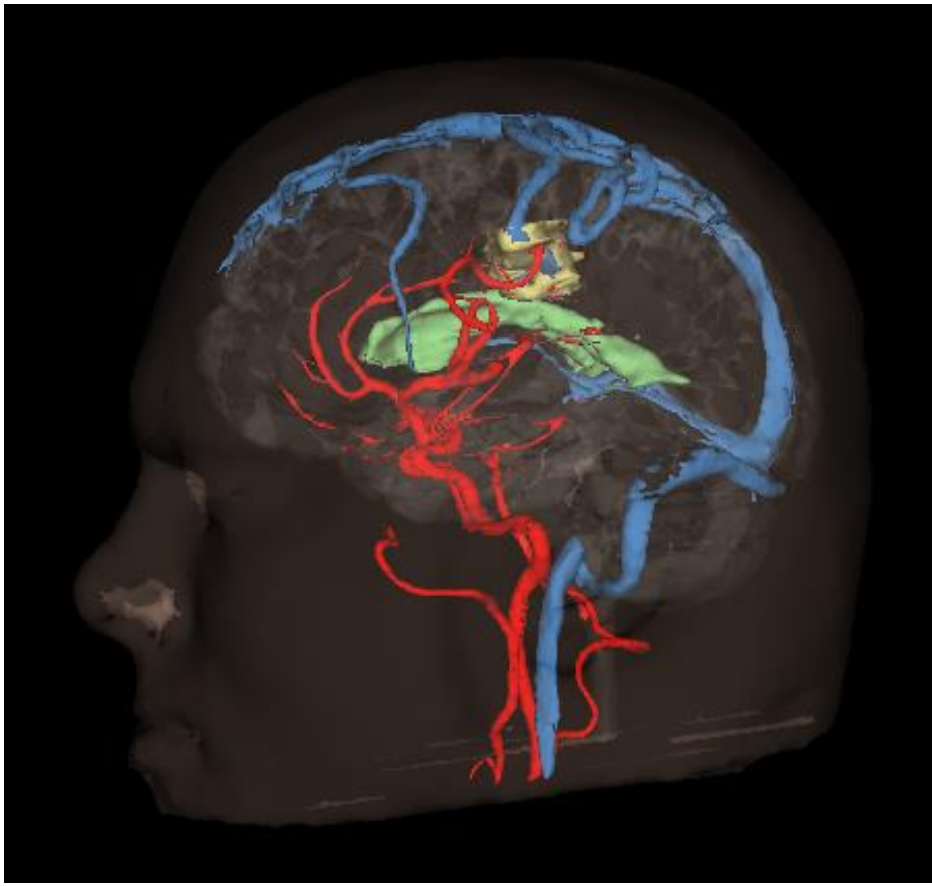
- Surgical Planning & Simulation
  - Maximize Tumor Removal
  - Minimize Damage to Critical Structures
- Intraoperative Visualizations via 3D Slicer

Pre-Operative Image Processing

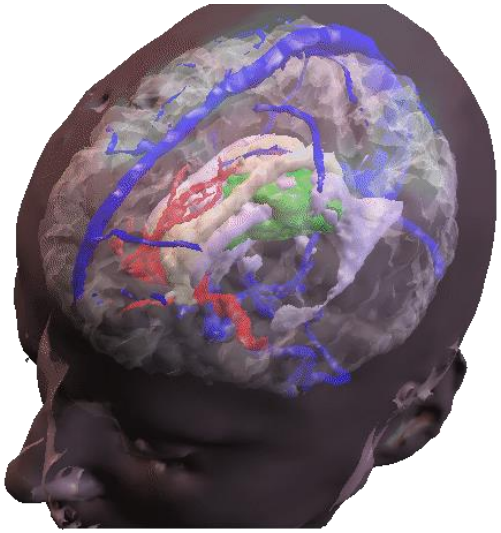
- Construct 3D Models
  - Semi-Automated Segmentation
  - DTMRI Tract Tracing
- Register all pre-operative data

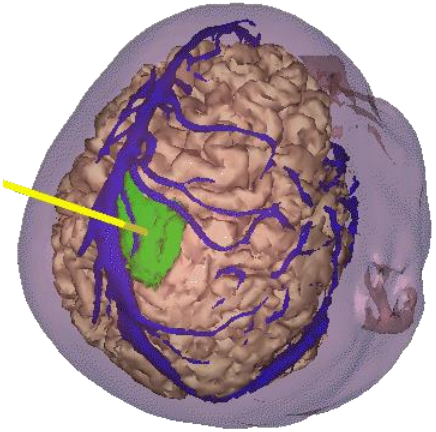
Integrated Preoperative Data

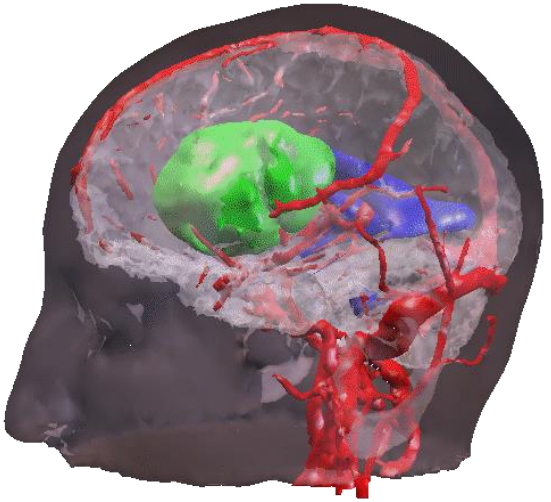


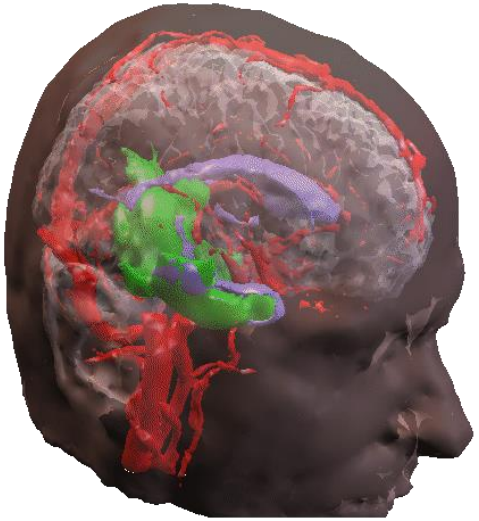


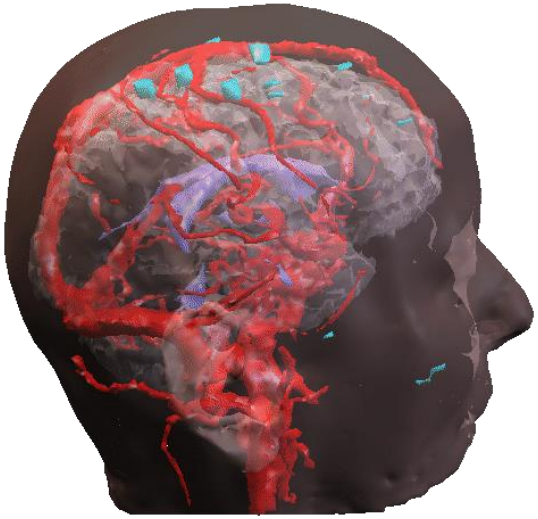
Patient-specific models





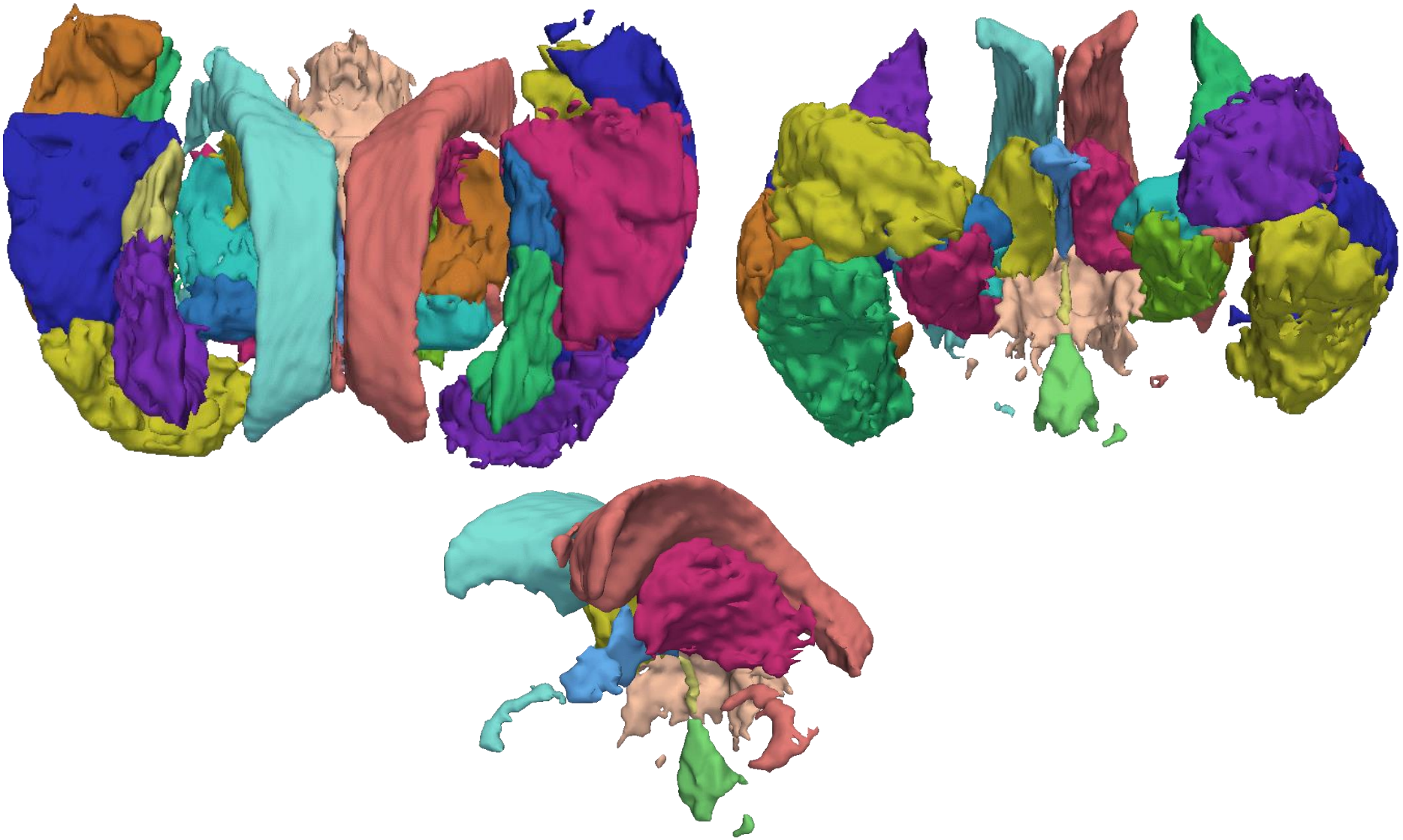






•Gering_fmri

Segmentation of Neural Structures

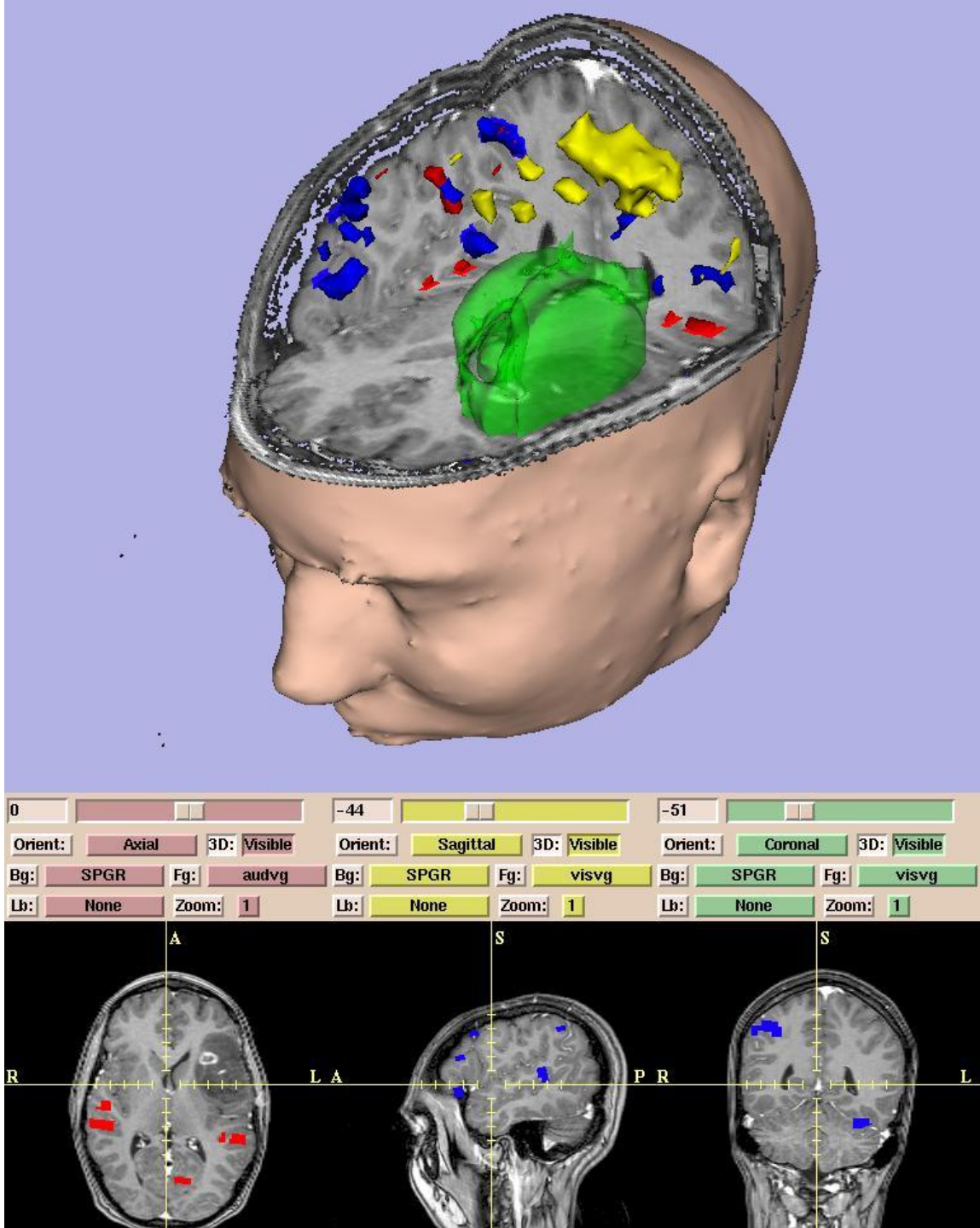


Construct Intraoperative Visualization

- transmit image data and 3D models thru volumetric deformation
- integrate with iMRI images and models
- display with 3D Slicer
- LCD screen in front of surgeon in iMRI
  - coordinate visualization with intraoperative instruments

3D Slicer: tool for

- Visualization
- Registration
- Segmentation
- Measurements
- Realtime Integration



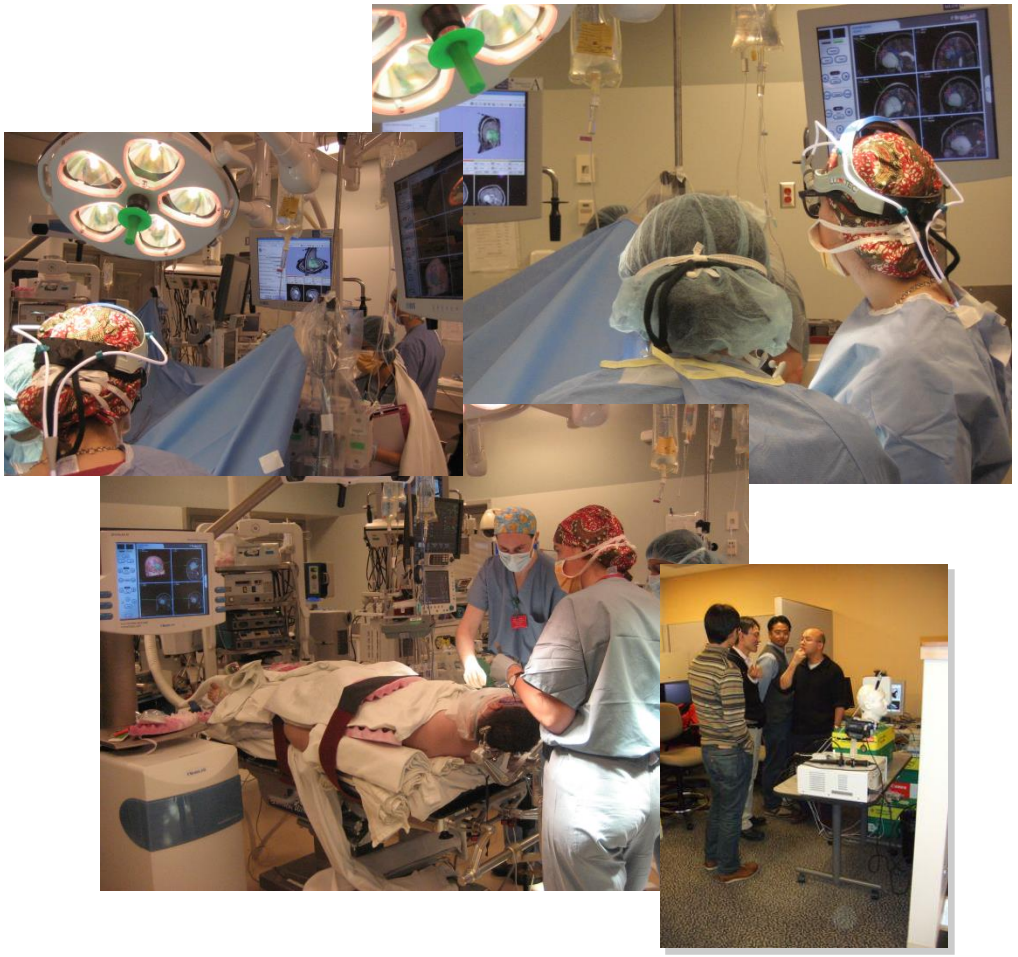
Provided by D. Gering

- Invasive vs Non-invasive brain mapping (EcoG)
- Awake craniotomy

Open Image Guided Therapy

- December 2007: Concept
- January 2008: Prototype and Name
- July 2008: BrainLab VVLink with Yale (Papademetrios)
- December 2008: Real Time MR Control
- February 11, 2009: Initial Clinical Application with Dr. Alex Golby

- March 2011, multi center collaboration

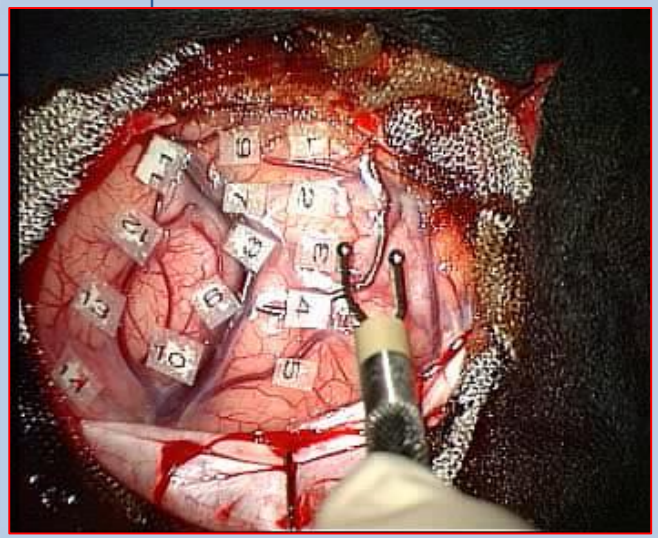


„Awake“-Craniotomy: Minimizing risk

Neuronavigation, functional monitoring

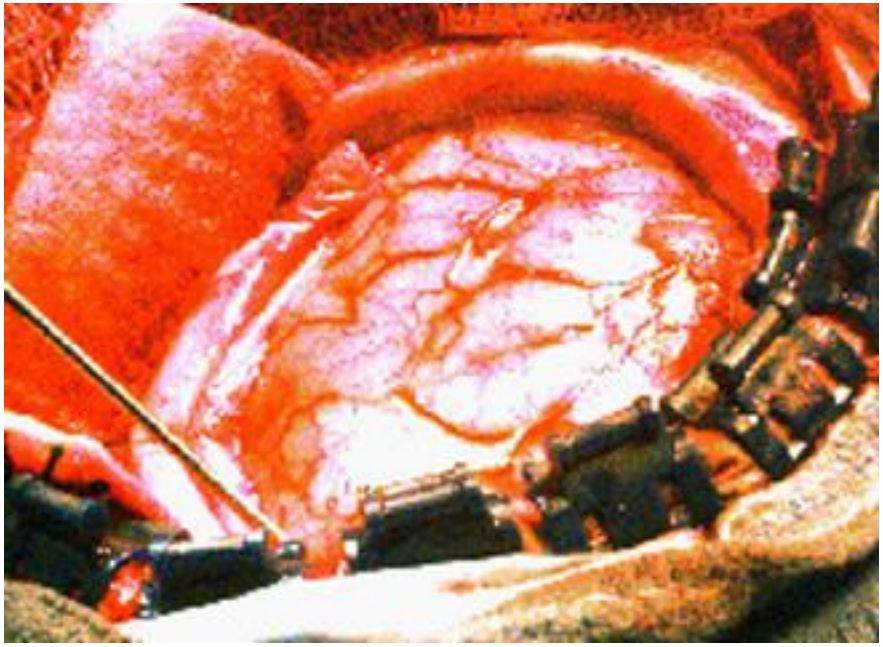
Intraoperative mapping and stimulation

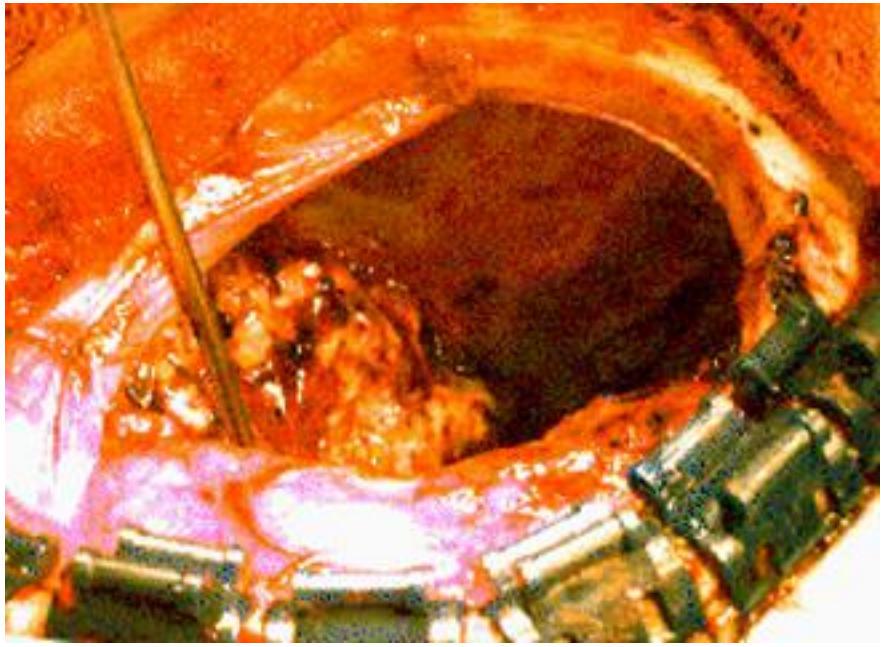
- Local anesthesia (except for motor mapping)
- Asleep / Awake / Asleep
- laryngeal mask, propofol, remifentanyl



- **Methodology**
  - Bipolar stimulation (Ojemann)
  - Cortical and subcortical
  - Biphasic current (1ms, 60 Hz, 2-18 mA)
- **Principles**
  - Motor mapping: induction of unvoluntary movements
  - Sensory mapping: induction of paresthesias
  - Mapping of cognitive functions: transient disturbances (language, calculation, comprehension, memory, writing…)

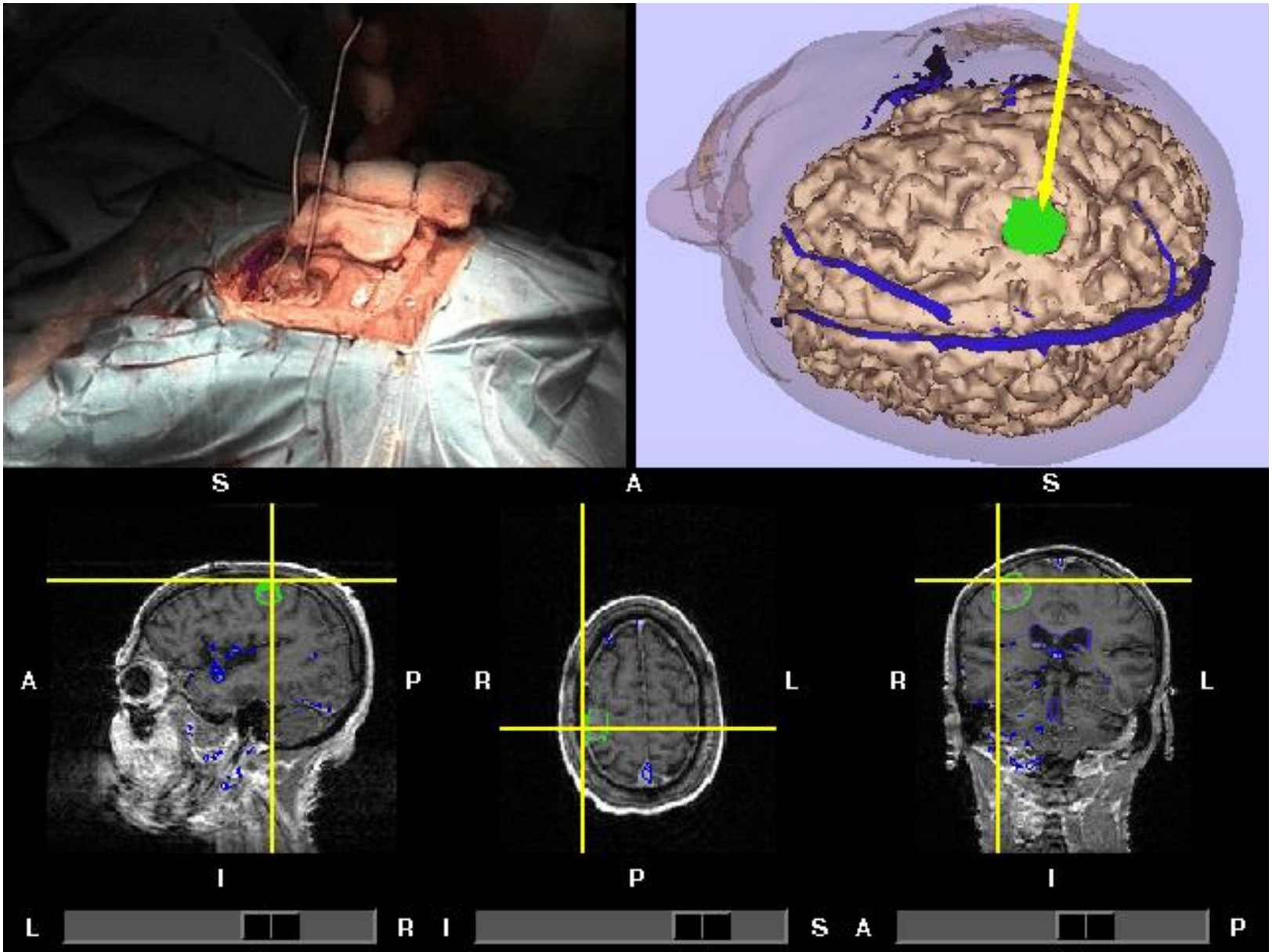
Conventional Surgery: Seeing surfaces





Provided by Nakajima, Atsumi et al.

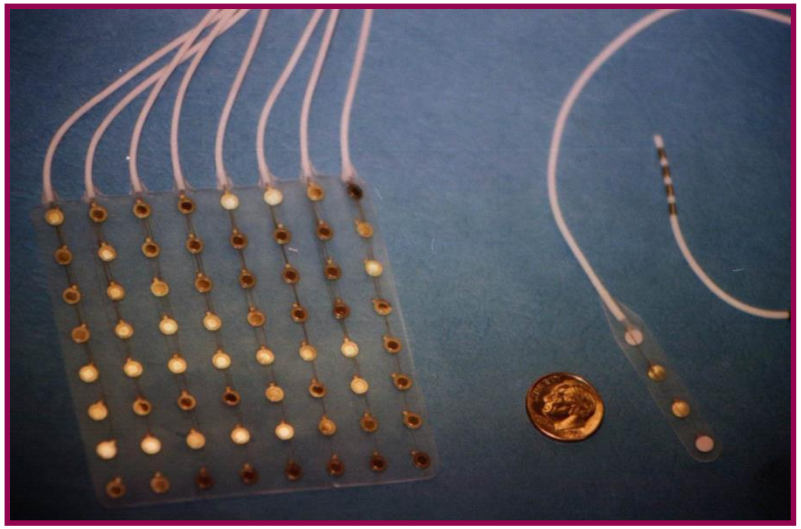
Computer Assisted Surgery: seeing through surfaces

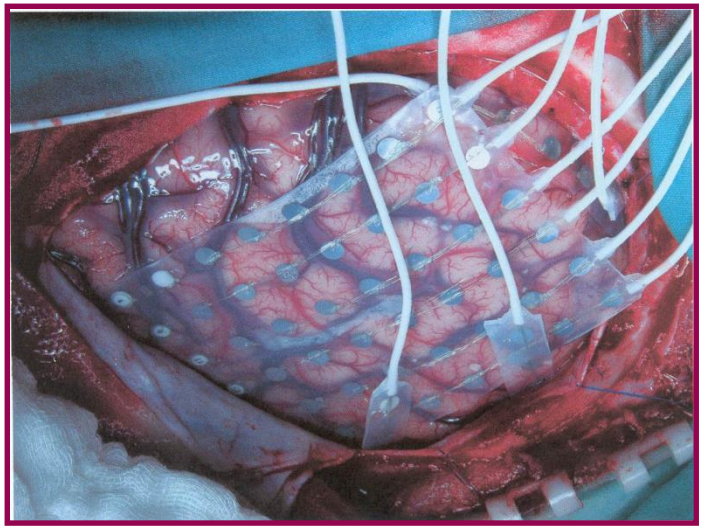


Functional Brain mapping using ECoG (electrocorticography)

Use of ECoG for identification of functional brain areas

- ECoG stimulations: determine critical location by disrupting the function.
- ECoG recordings: mapping endogenous cortical function, reflecting normal cortical function.

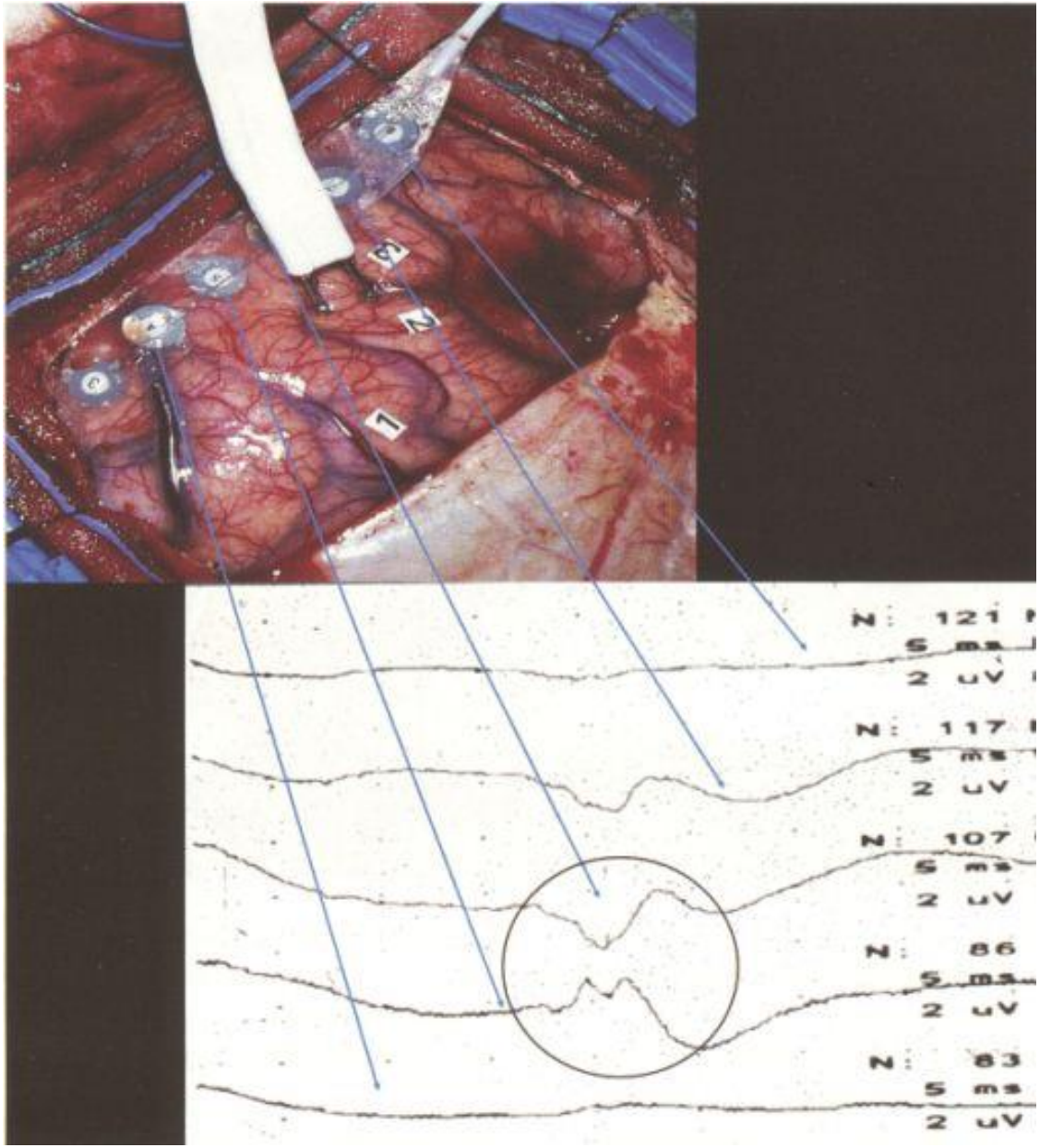




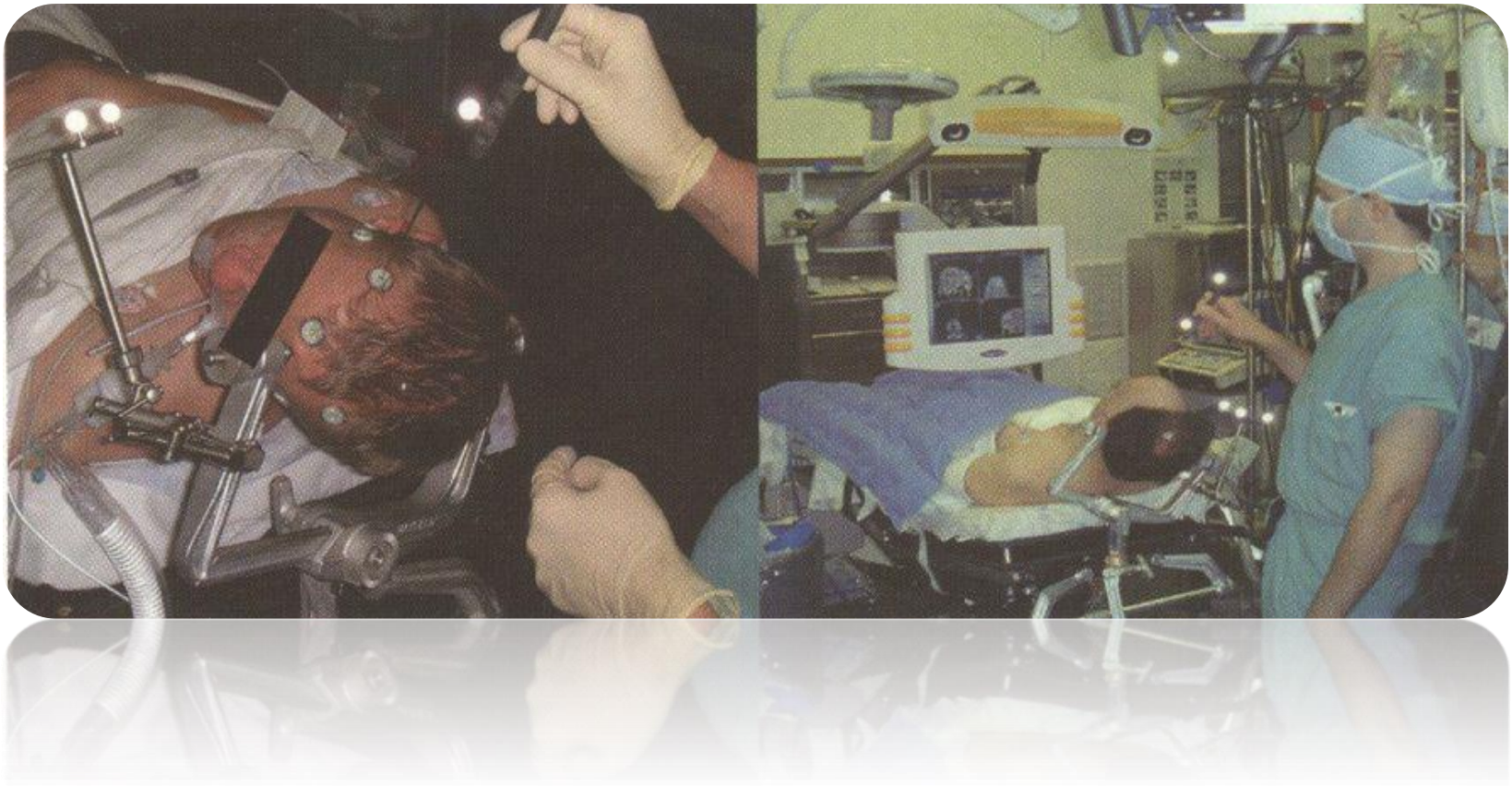
Intra operative mapping by SSEP and ECS

ES of median nerve caused EP measured by the recording electrode.

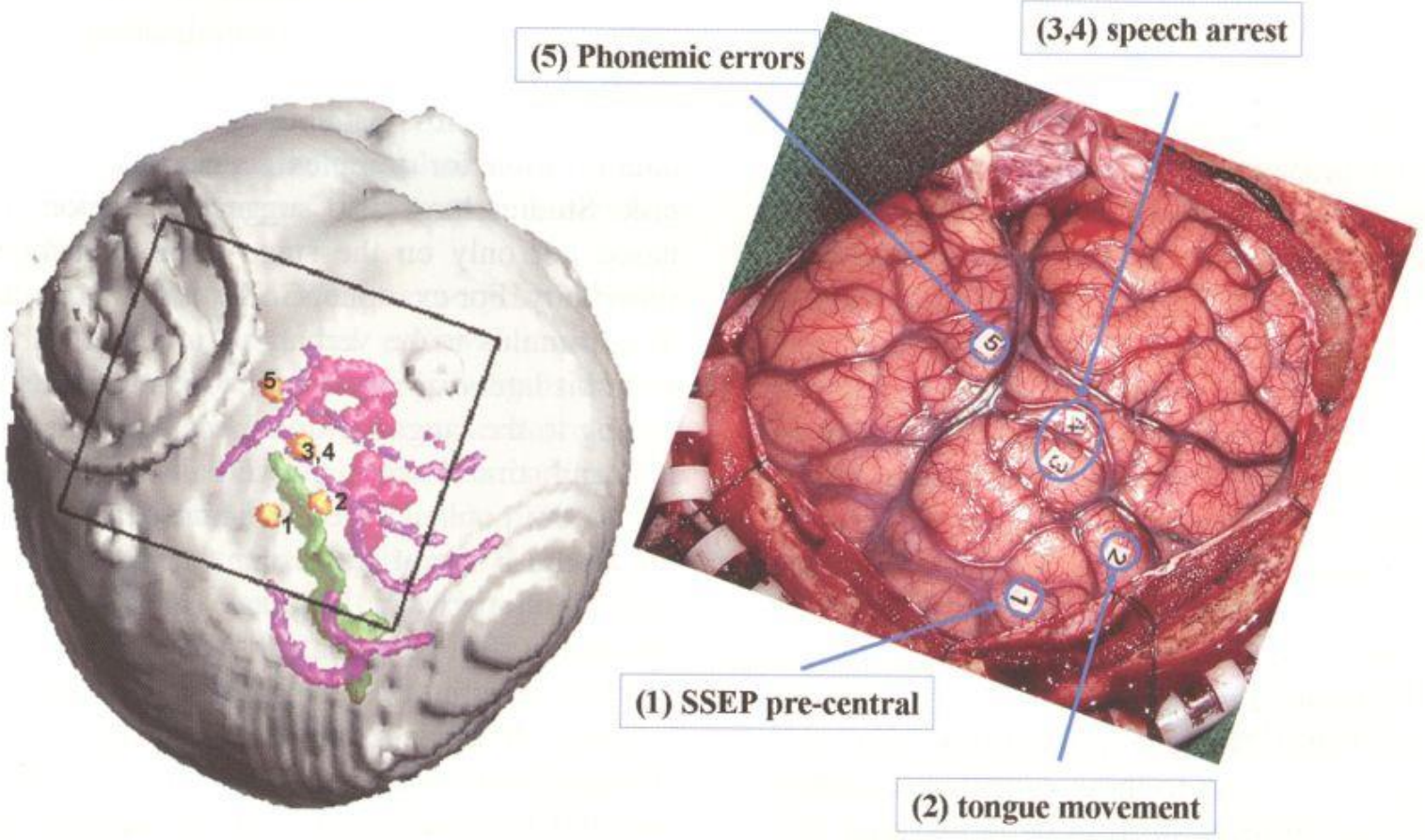
Elecrographic phase reversal in the EP tracing marks the boundary between motor and sensory cortex



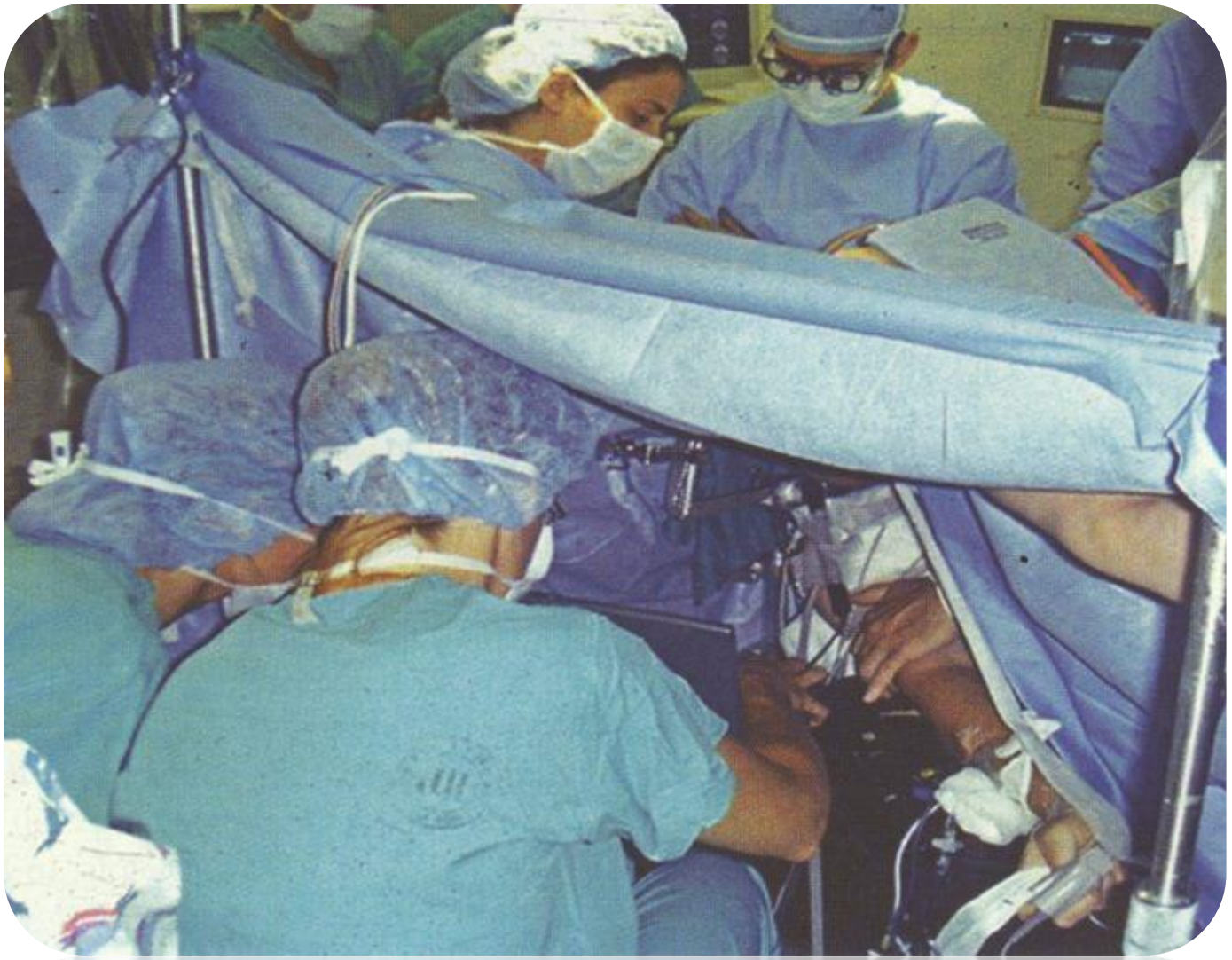
Intra-operative navigation by frameless stereotaxy



Speech fMRI integrated for navigation



Intra-operative assessment of the awake patient during functional mapping by ECS



“Brain mappnig is a giant leap forward to reduce the risk and maximize the favourable outcome when doing brain surgery”. Dr.Alex Golby UC Davis