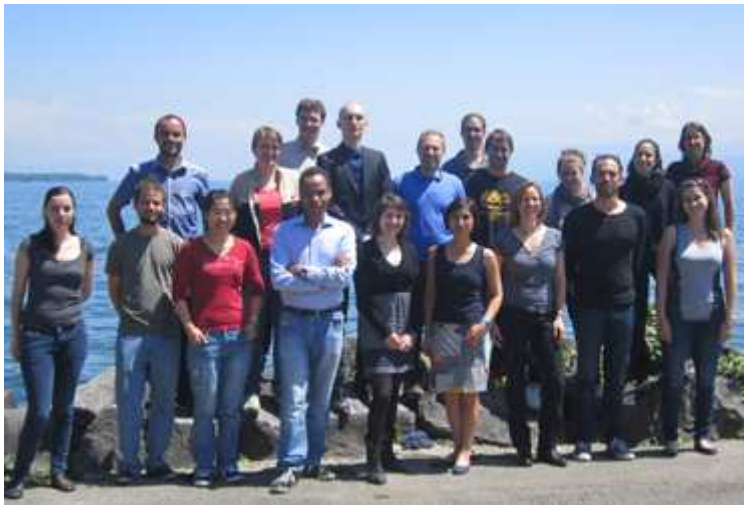


Functional MRI

SPM course - 04/2014

Laboratoire de Recherche En Neuroimagerie (LREN)

Antoine Lutti - antoine.lutti@chuv.ch

Outline

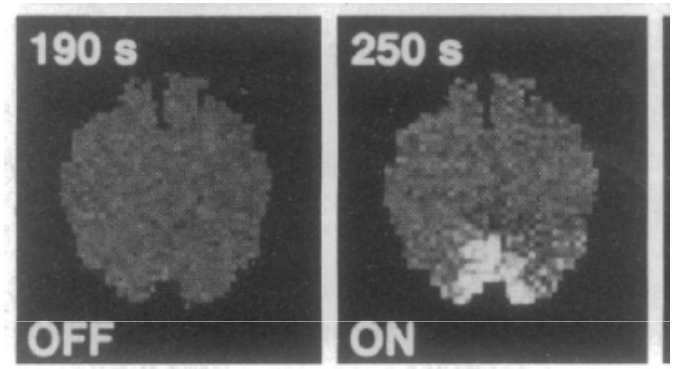
- BOLD effect
- Image encoding for fMRI
- Limitations of EPI
- Advanced fMRI

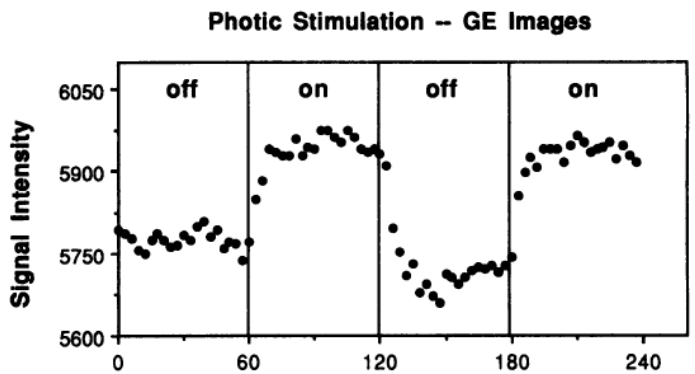
Outline

- **BOLD effect**
- Image encoding for fMRI
- Limitations of EPI
- Advanced fMRI

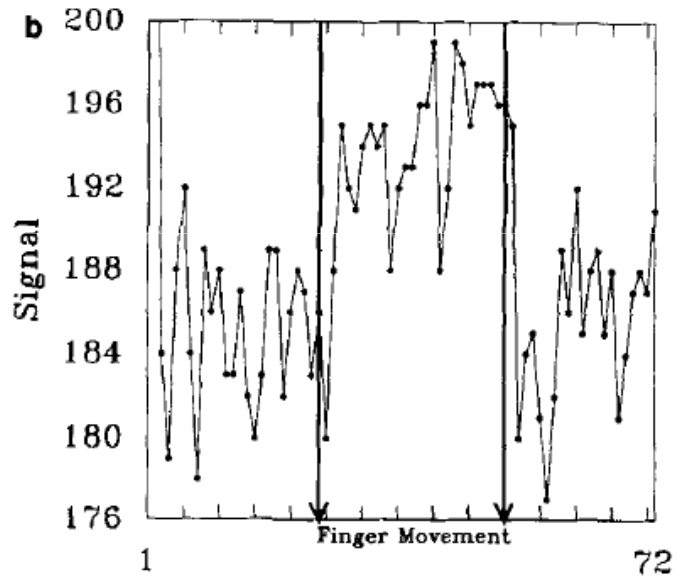
Blood Oxygen Level Dependent (BOLD) effect

BOLD: localized signal change during activation





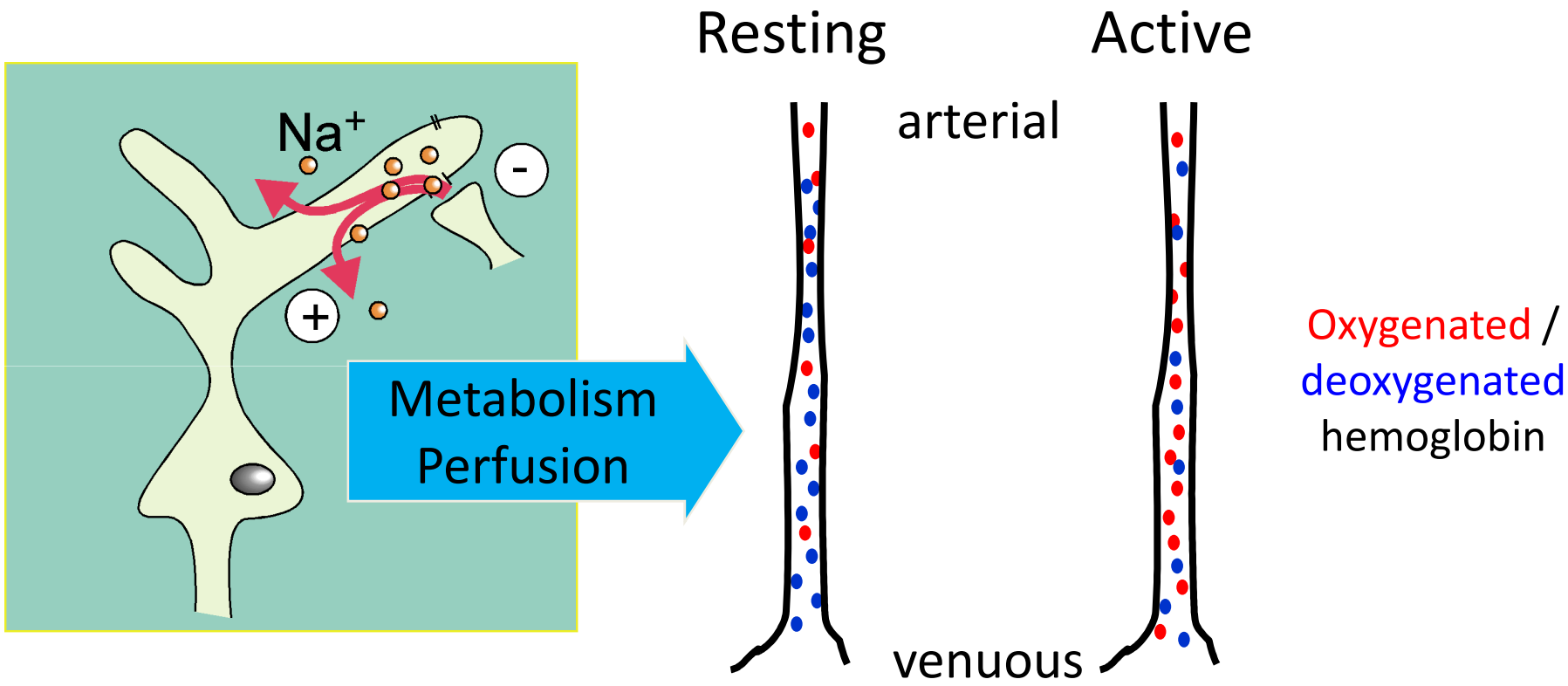
Kwong et al., PNAS 1992



Bandettini et al., MRM 1992

Ogawa et al., 1990: “static” BOLD effect in rat brain
Kwong et al., Bandettini et al., Ogawa et al., 1992:
BOLD fMRI in human

Blood Oxygen Level Dependent (BOLD) effect

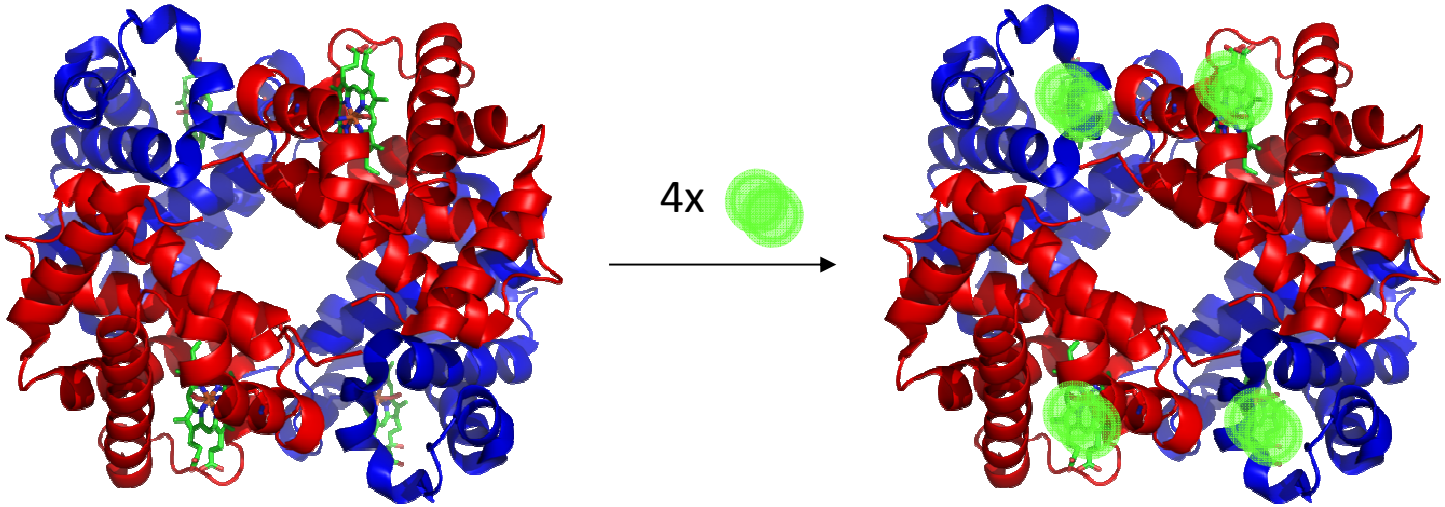


Increased activity leads to increased concentration in oxyhemoglobin

Change in oxy/deoxy hemoglobin concentration detectable in MRI

Magnetic susceptibility of hemoglobin

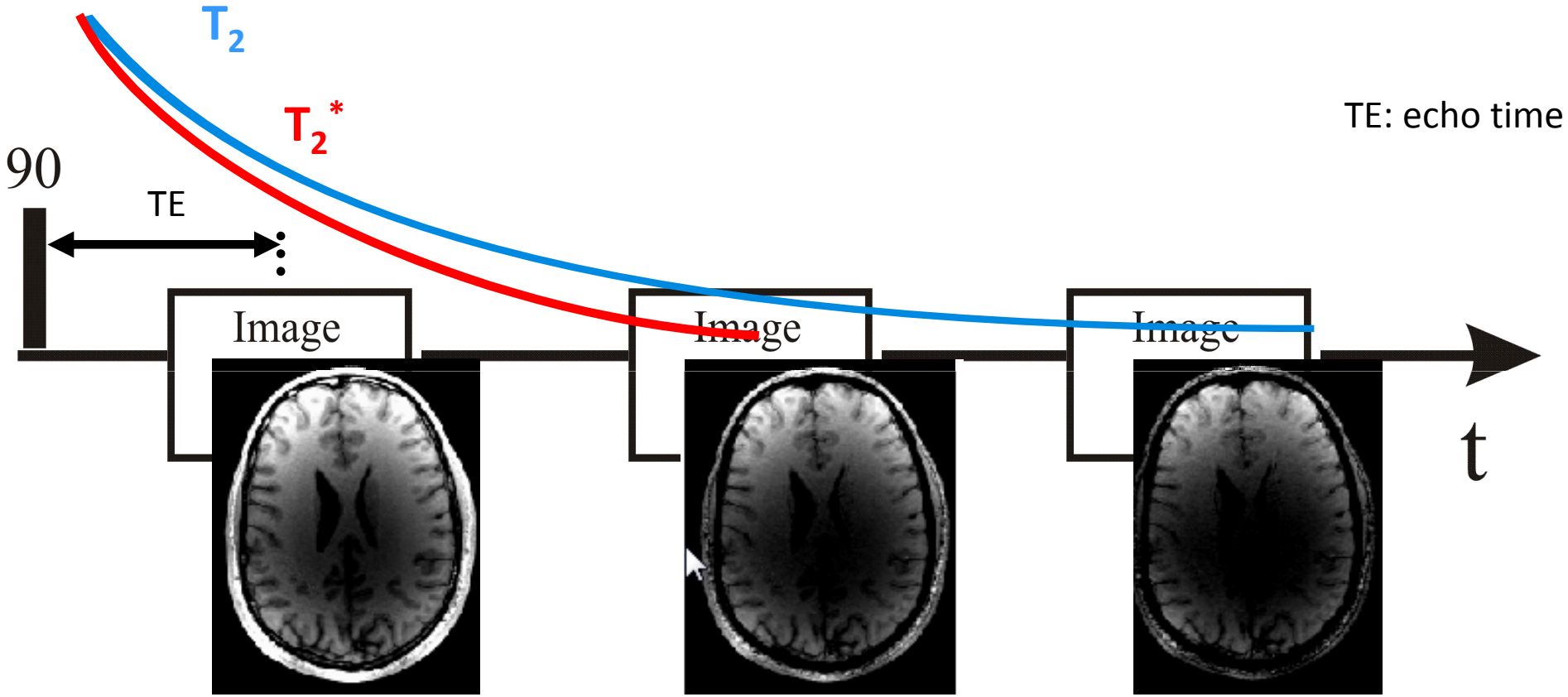
Pauling and Coryell, PNAS 1937



Deoxygenated hemoglobin (Hb)
- paramagnetic
- different to tissue (H_2O)
- creates local B0 inhomogeneities

Oxygenated Hb:
- diamagnetic
- same as tissue (H_2O)
- does not perturb B0 homogeneity

T2* decay

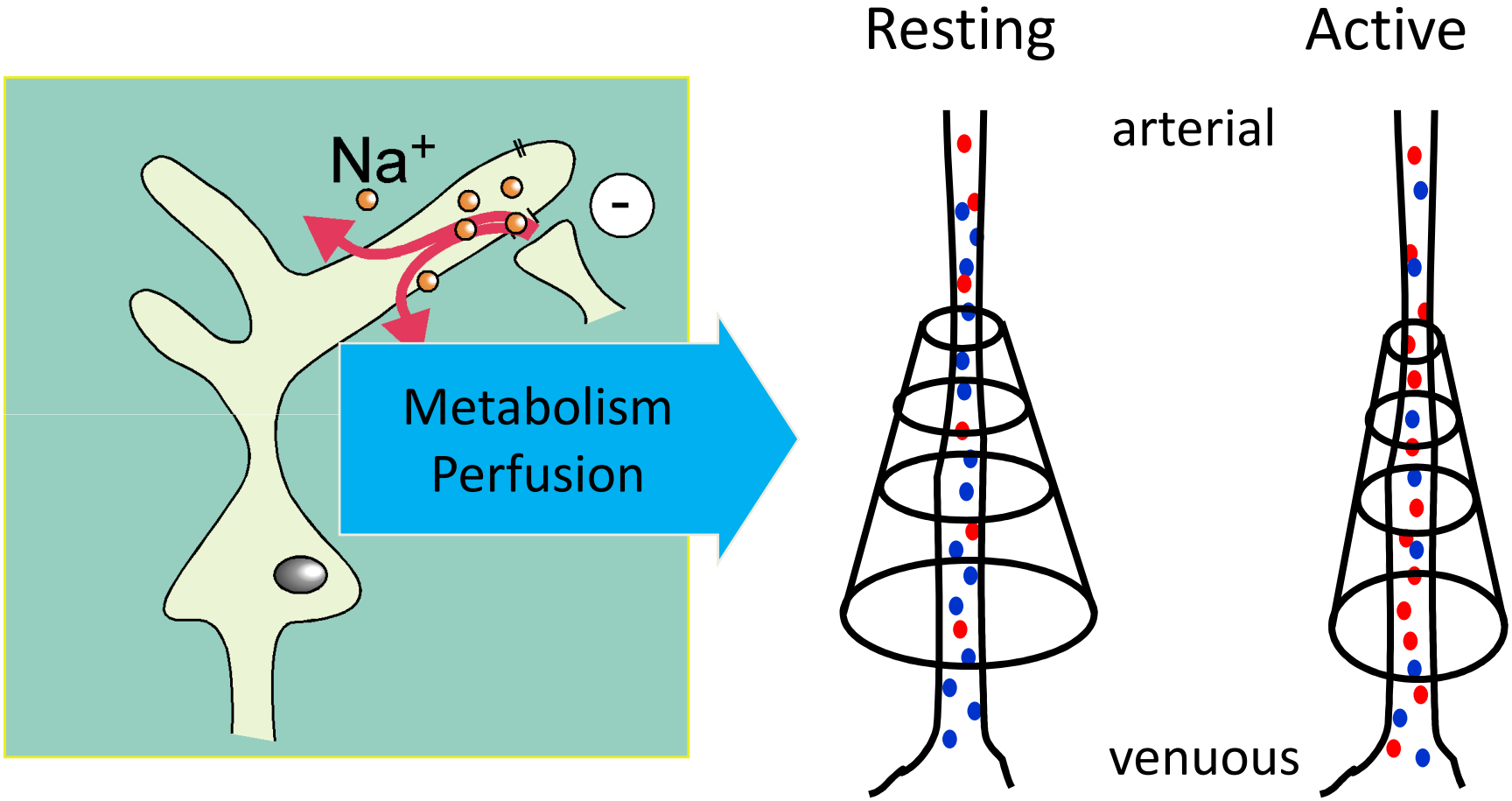


T2* contrast: - sensitive to local B0 inhomogeneities effects

- T2*<T2

Anatomical lecture
Principals of image encoding

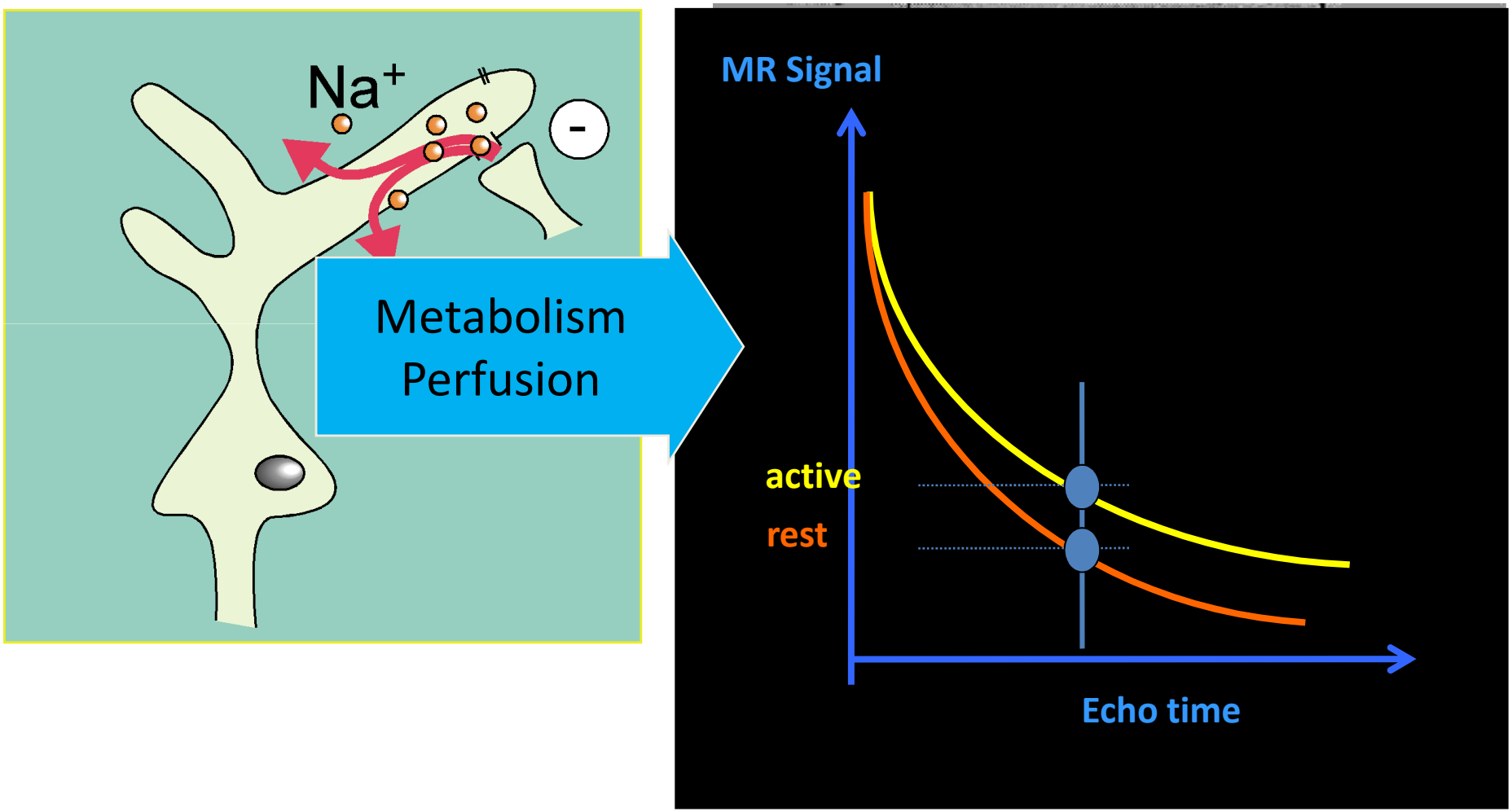
Blood Oxygen Level Dependent (BOLD) effect



Oxygenated / deoxygenated hemoglobin

- Impact signal intensities in T2* images
- endogenous contrast agent

BOLD effect and MR imaging



BOLD activation leads to a signal change in T2*-weighted images

Outline

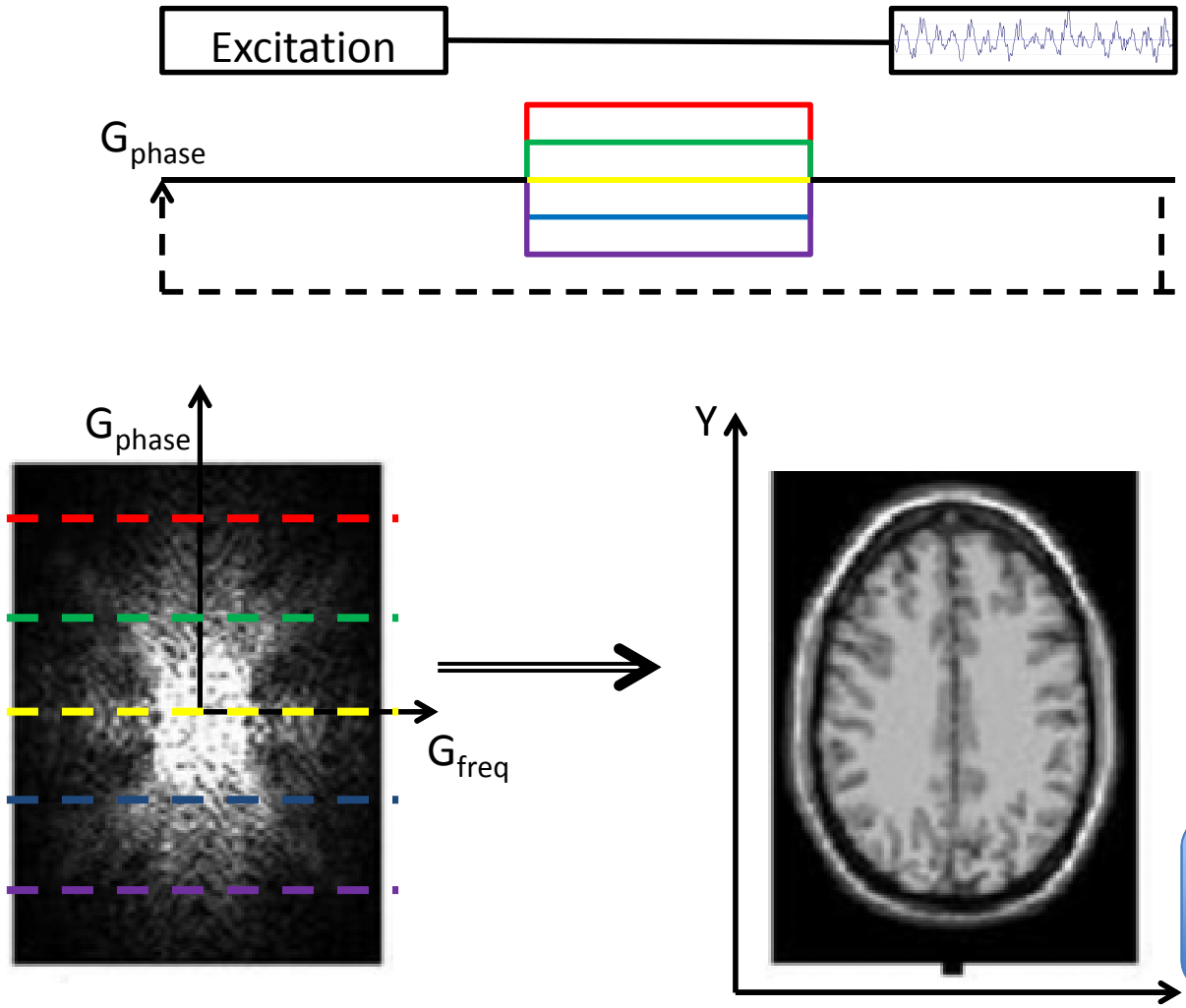
- BOLD effect
- **Image encoding for fMRI**
- Limitations of EPI
- Advanced fMRI

Image encoding for fMRI - requirements

- High-frequency sampling of the BOLD response
  -> high acquisition speed (~s/volume)

- Maximal BOLD sensitivity over the entire brain

Reminder: image encoding for anatomical imaging



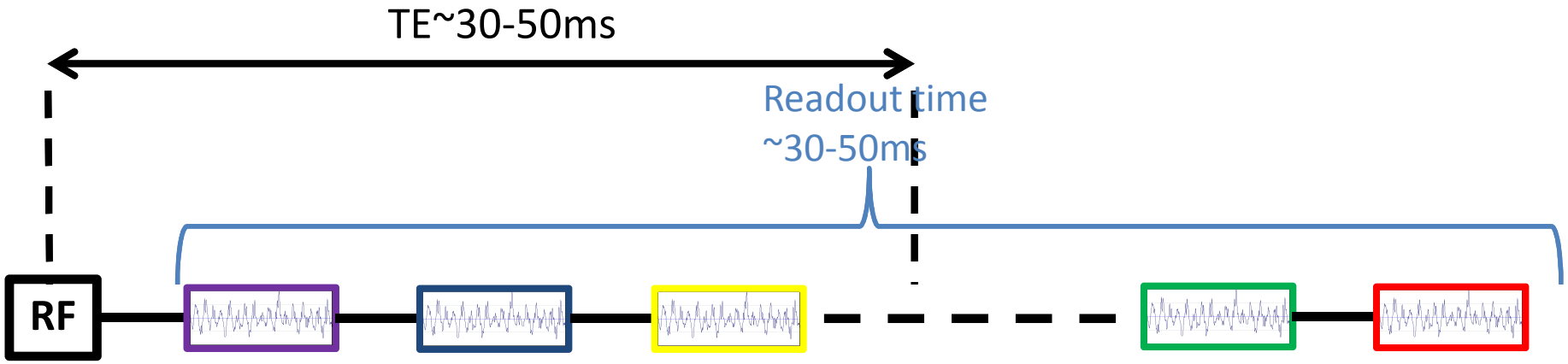
http://iopscience.iop.org/0031-9155/52/7/R01/fulltext/

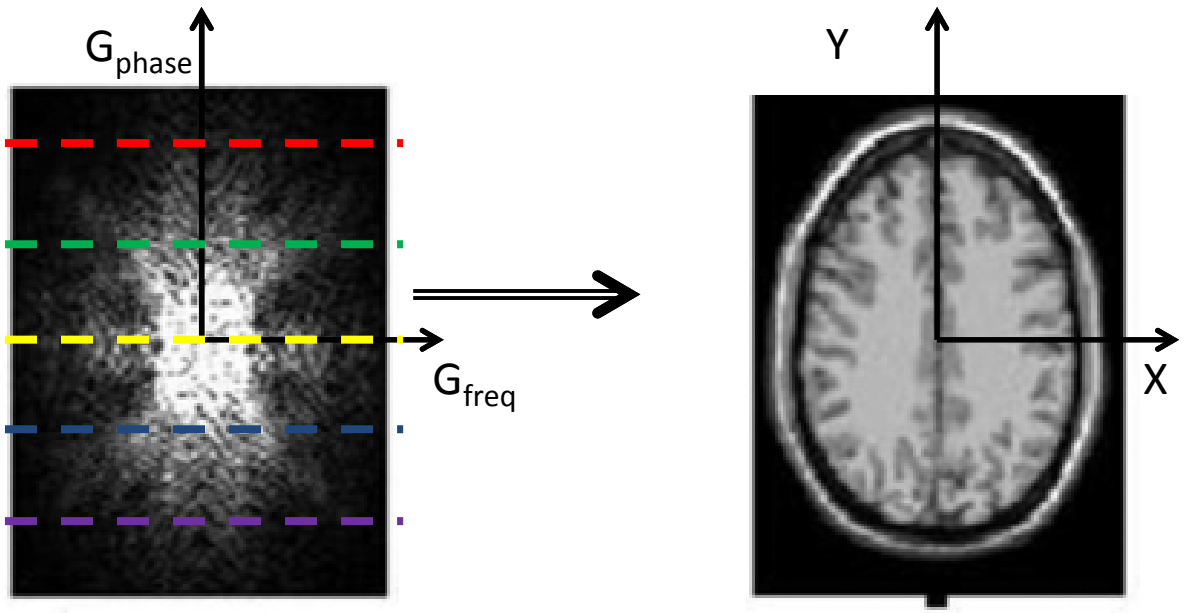
Acquisition time: ~mins

Too slow for fMRI

Anatomical lecture
Principals of image encoding

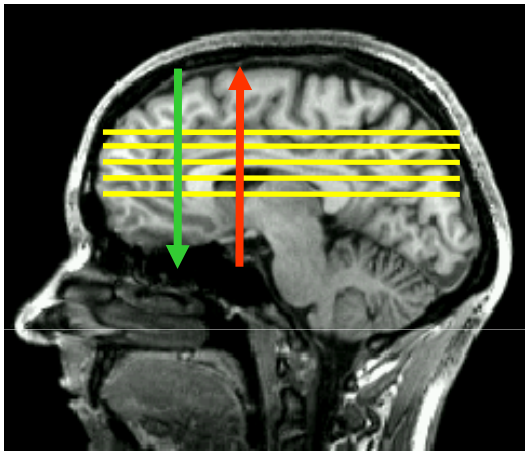
Image encoding for fMRI
Echo Planar Imaging





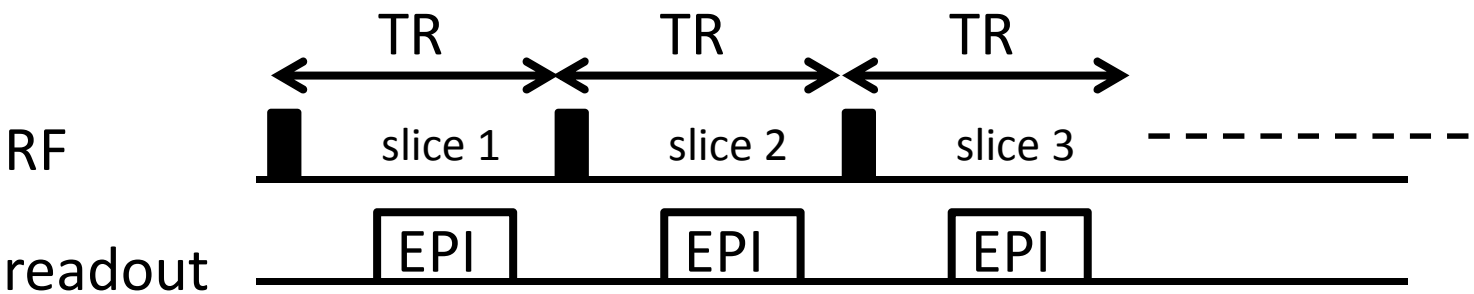
2D image after one RF excitation

Image encoding for fMRI



Neighboring slices are acquired successively

in ascending (↑) or descending (↓) order

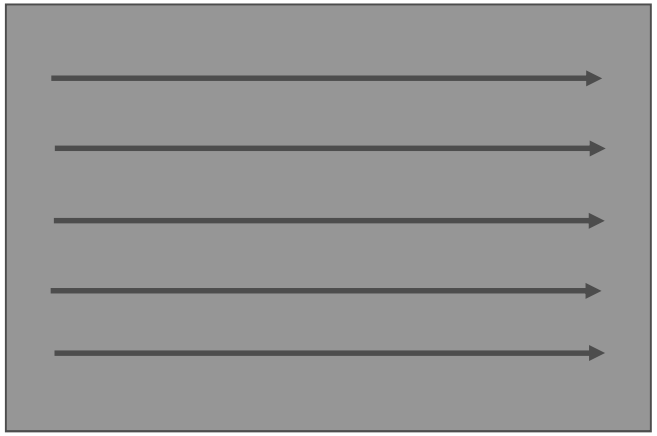


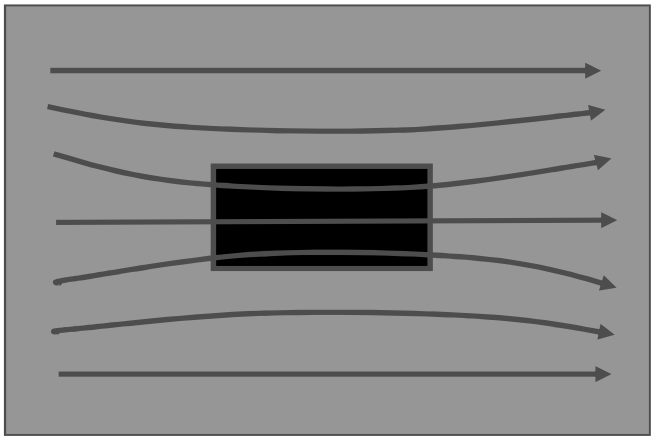
TR~50-100ms

Outline

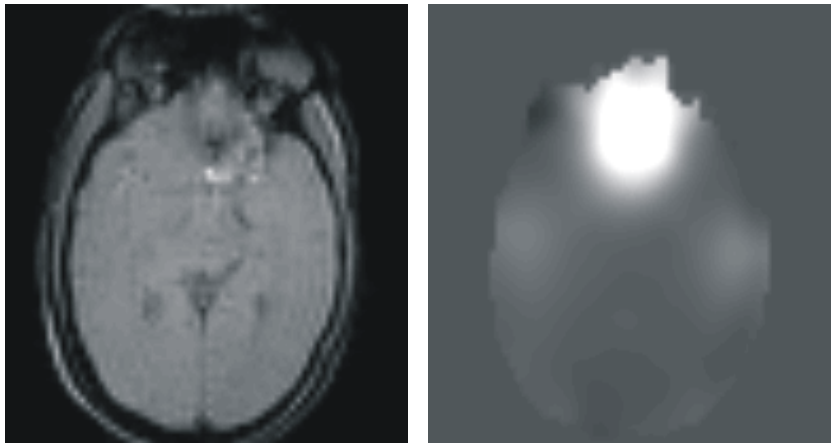
- BOLD effect
- Image encoding for fMRI
- **Limitations of EPI**
- Advanced fMRI

Susceptibility effects in EPI





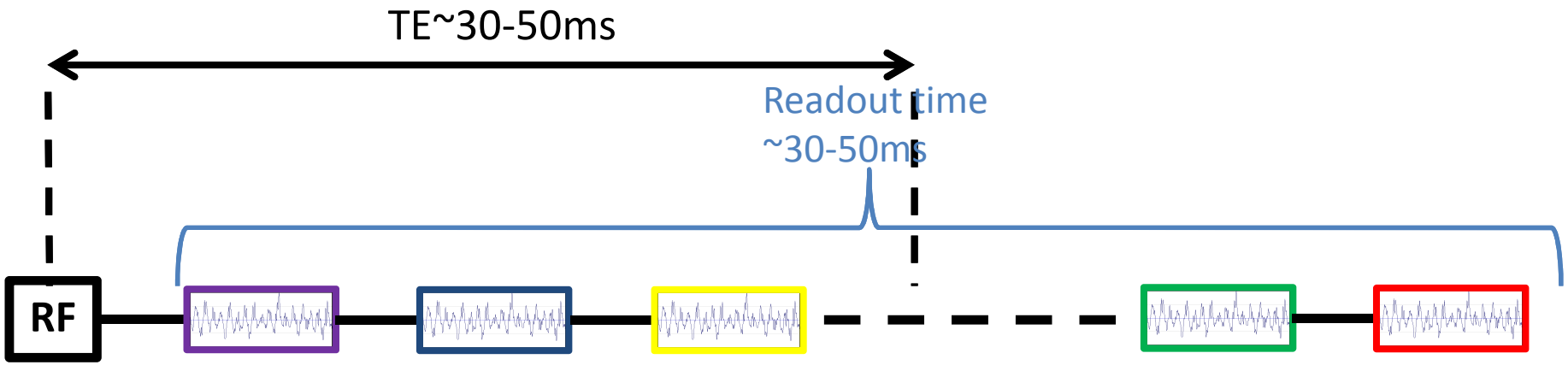
Variation in magnetic susceptibility distorts the static magnetic field (B0)

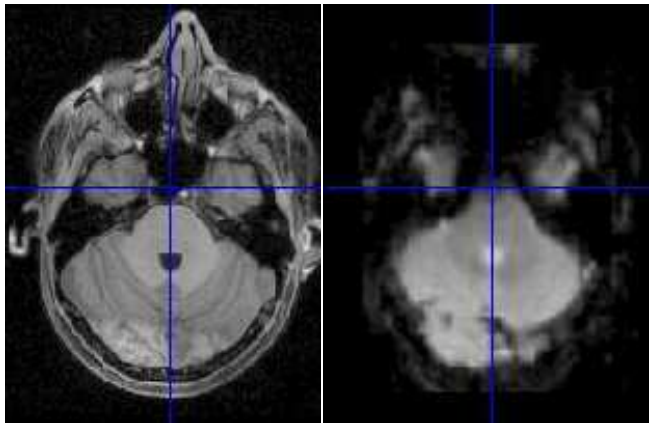


B0 inhomogeneities at the air/tissue interface

e.g. Orbito Frontal Cortex, Amygdala, temporal lobes,…

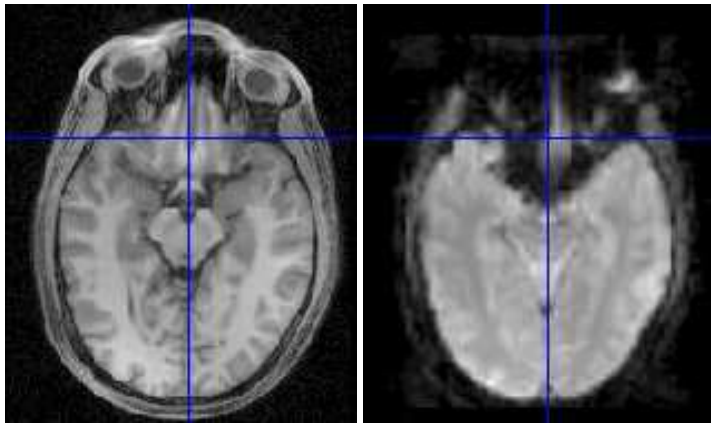
Susceptibility effects in EPI





Anatomical EPI

Long EPI readout -> distortions

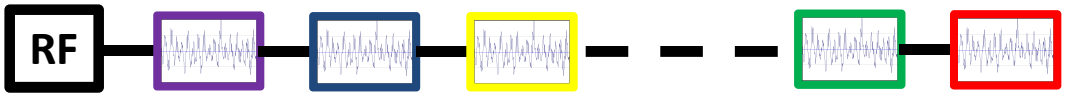


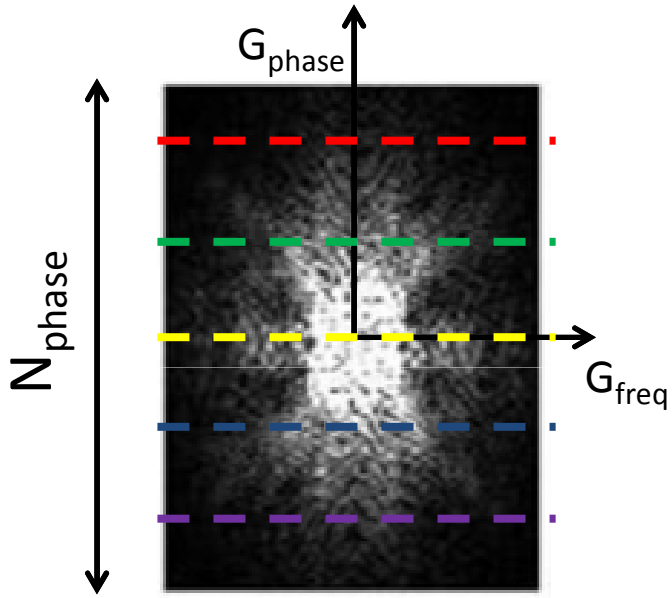
Anatomical EPI

Long EPI echo-time -> dropouts

Anatomical lecture
Effects of field gradients on signal intensities

EPI artefacts – image distortions



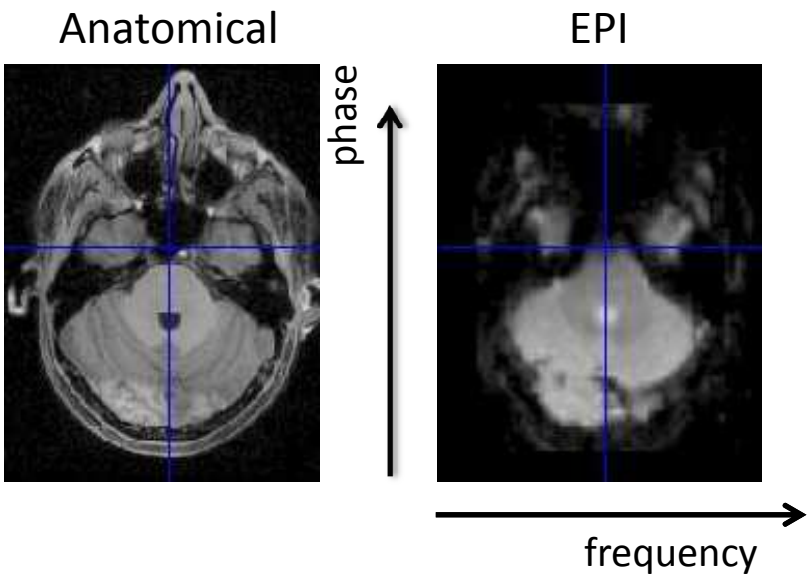


Frequency direction
Sampling time = readout duration
Frequency direction is fast

Phase direction
Sampling time = Nphase * readout duration
Phase direction is slow

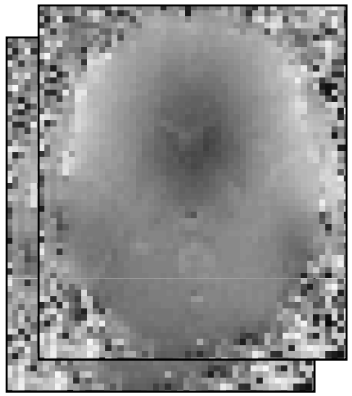
EPI artefacts – image distortions

- Distortions take place along the slow 'phase' direction
- Orienting 'phase' direction anterior-posterior preserves brain symmetry
- Distortions increase with readout duration (high image resolution)

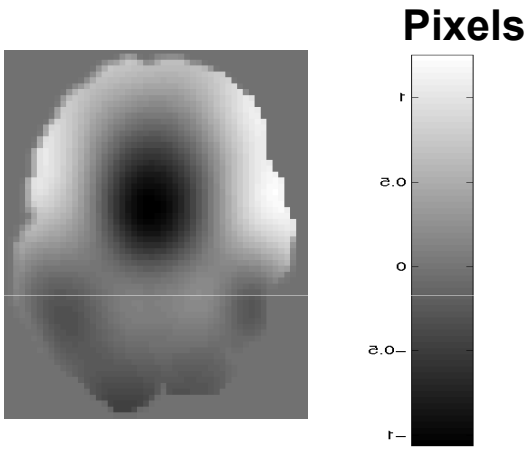


EPI image distortion correction

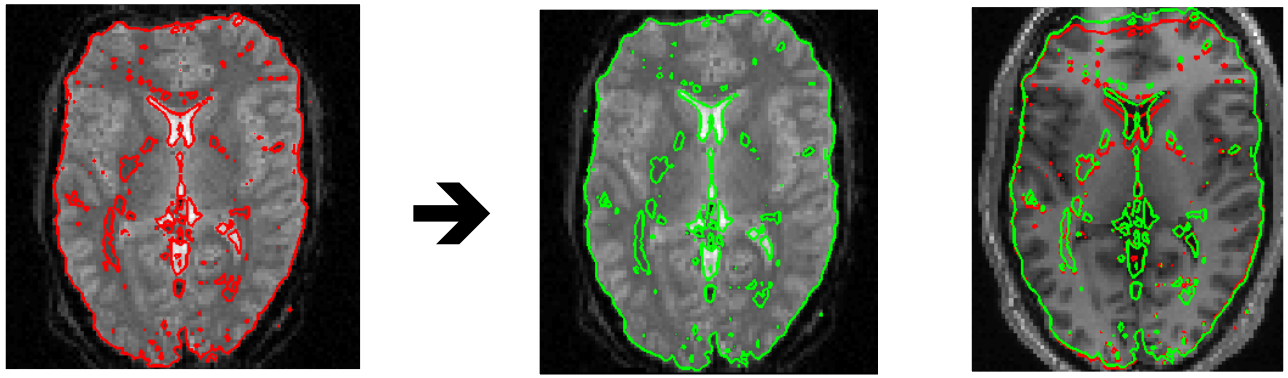
Measure phase evolution in head using a separate scan



Calculate map of pixel shift

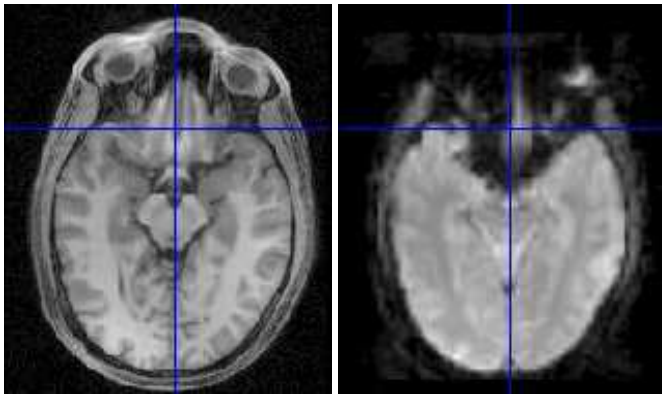


Use pixel shift map to unwarp image



Jezzard and Balaban, 1995, MRM, 34(1);65-73; Hutton et al, 2002, Neuroimage, 16(1);217-240

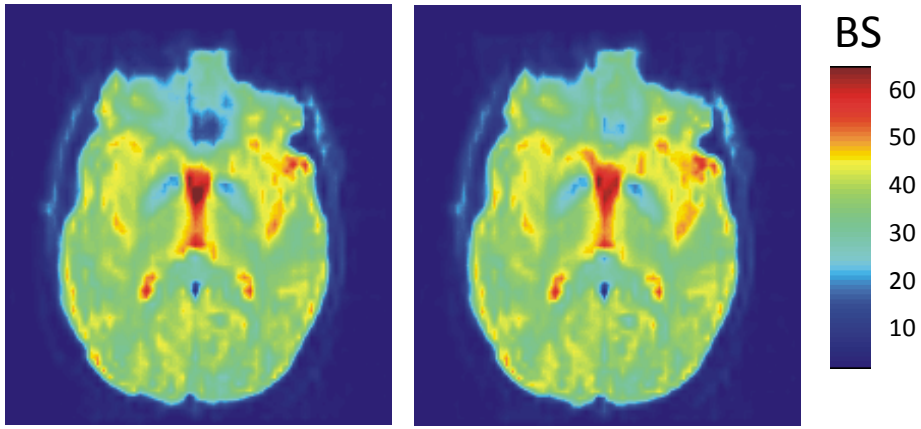
EPI artefacts - dropouts



Anatomical EPI

Pulse sequences can be modified to optimize BOLD sensitivity in dropout areas

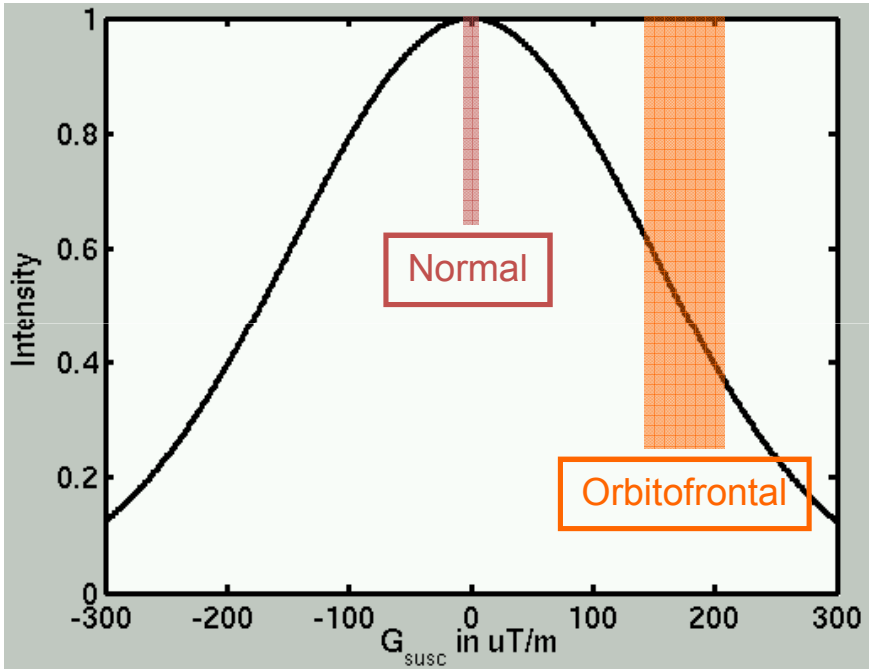
Standard EPI Optimized EPI



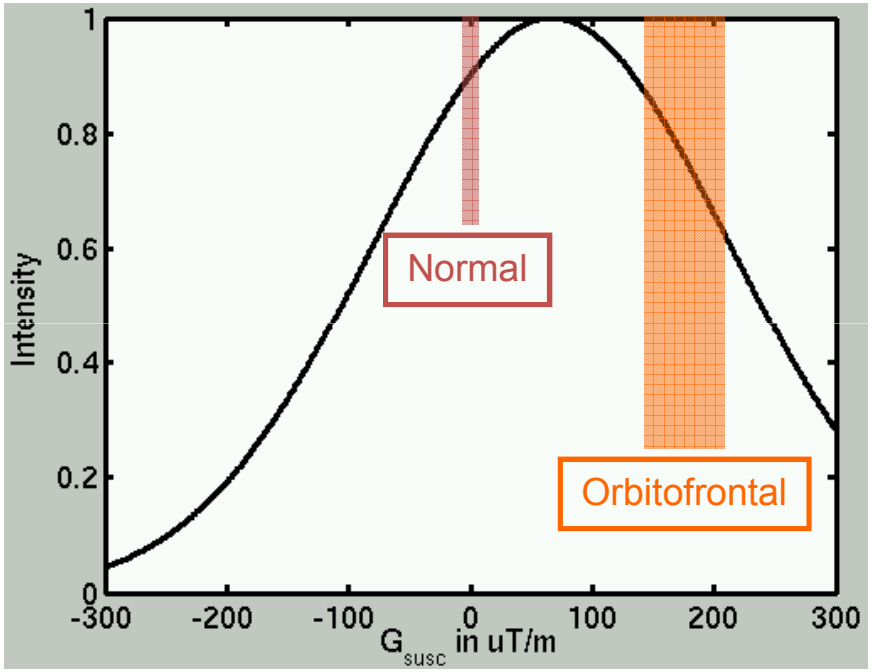
Deichmann et al., Neuroimage 2003; Weiskopf et al., Neuroimage 2006; Weiskopf et al., MAGMA 2007

EPI artefacts - dropouts

(Simulation for slice thickness of 2 mm)



No dropout compensation



Dropout compensation

- Dropout compensation minimally impact unaffected areas
- Optimal dropout compensations vary with brain region

Deichmann et al., Neuroimage 2003

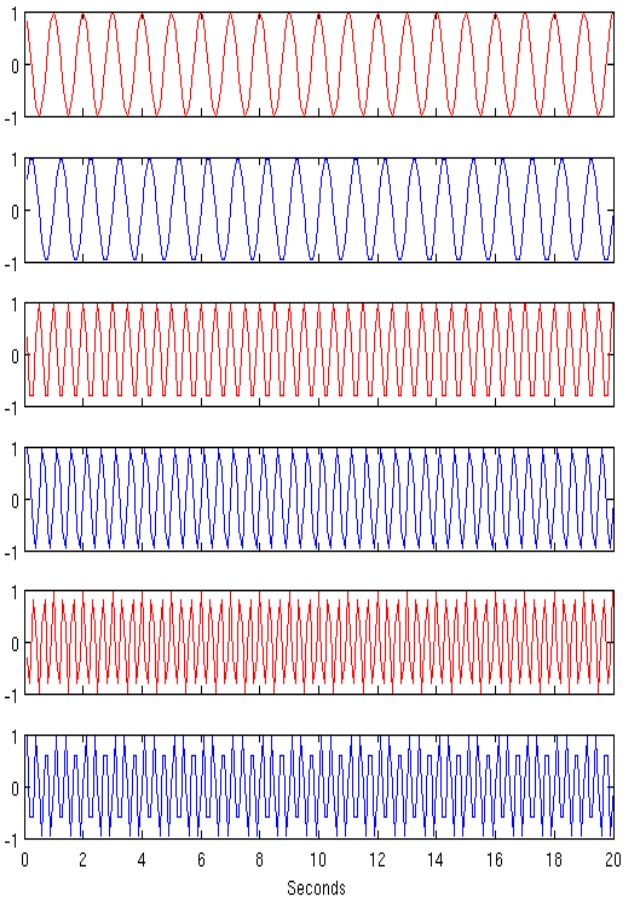
Physiological effects

- Physiological effects reduce stability of fMRI time-series
- Physiological correction based on peripheral measurements:

Pulse oximeter

Respiration belt

Physiological effects



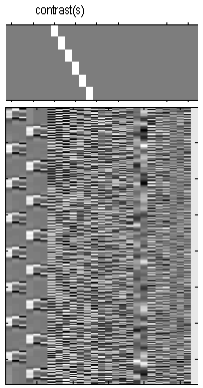
- Measured cardiac and respiratory phase can be modelled using a sum of periodic functions e.g. sines and cosine of increasing frequency (Fourier set)

- Modelled effects can be
  - removed from original fMRI signal
  - or included in fMRI statistical model

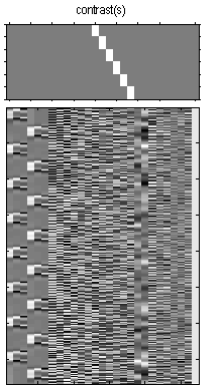
Glover G.H. Et al MRM 2000, Hutton et al., Neuroimage 2011

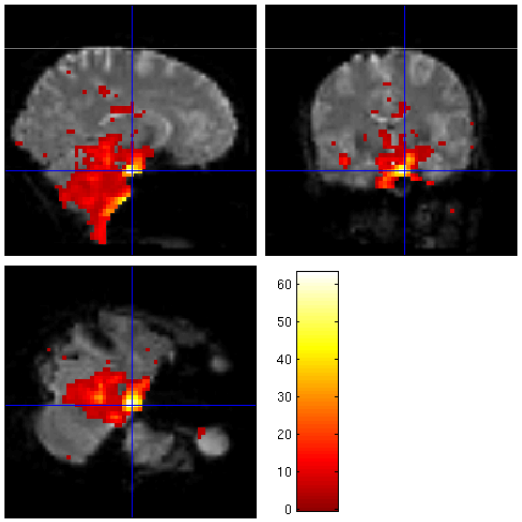
Physiological effects

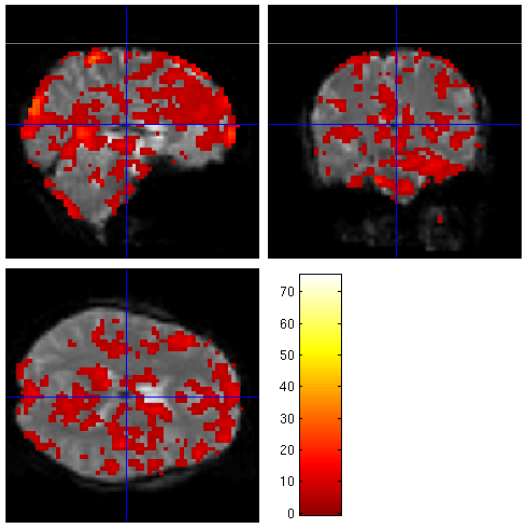
cardiac



respiration





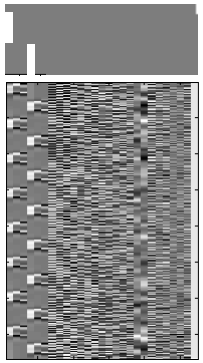


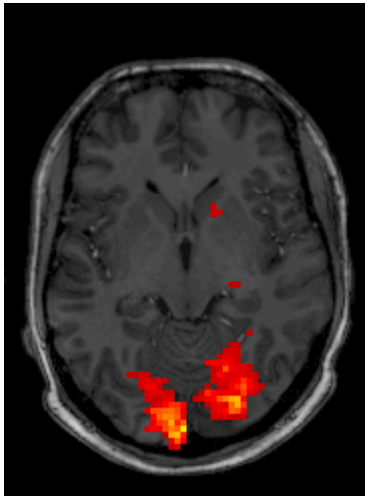
Cardiac effects observed in vessels

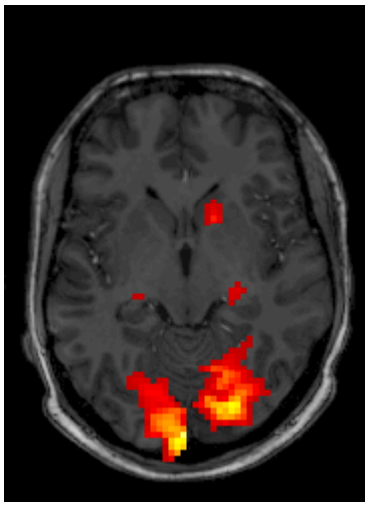
Respiratory effects observed globally

Physiological correction enhances BOLD sensitivity

Visual task:







Hutton et al., Neuroimage 2011

BOLD sensitivity – practical considerations

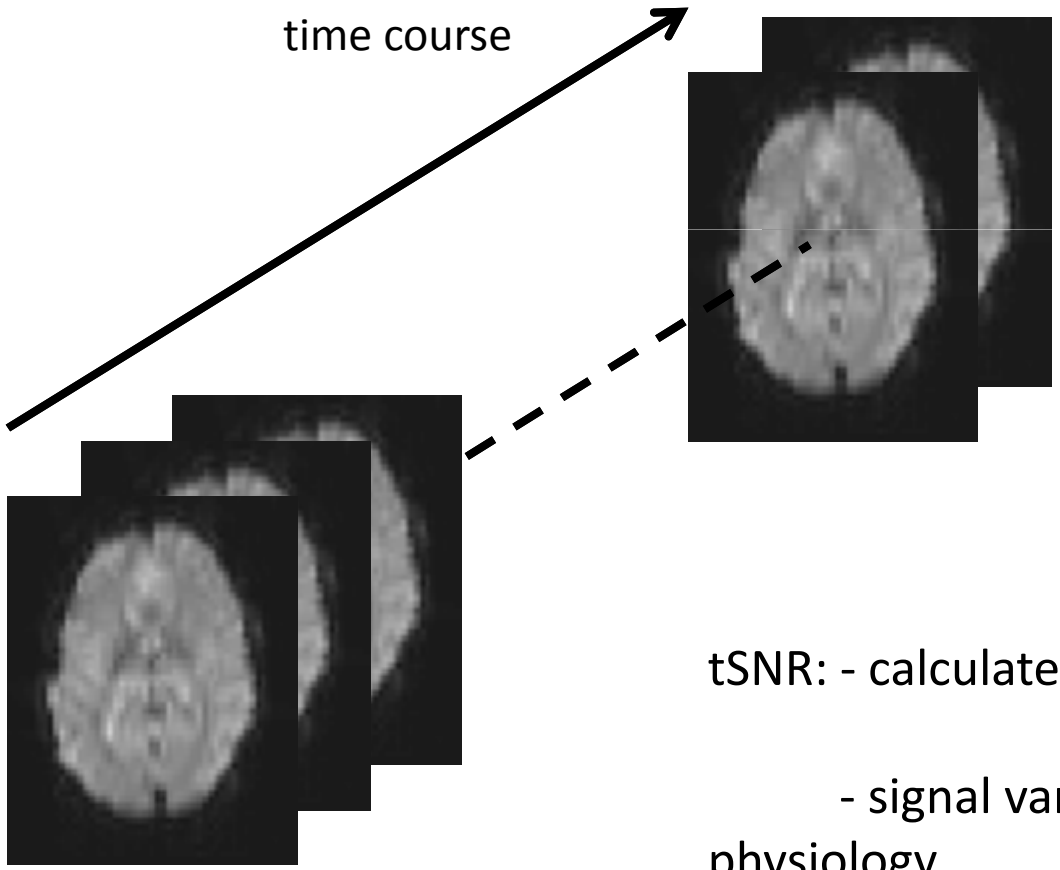
What acquisition parameters should I use for my fMRI study?

- Given my ROIs, do I need dropout compensation?

Weiskopf et al., Neuroimage 2006

- What's the impact of image resolution on BOLD sensitivity?

BOLD sensitivity and tSNR



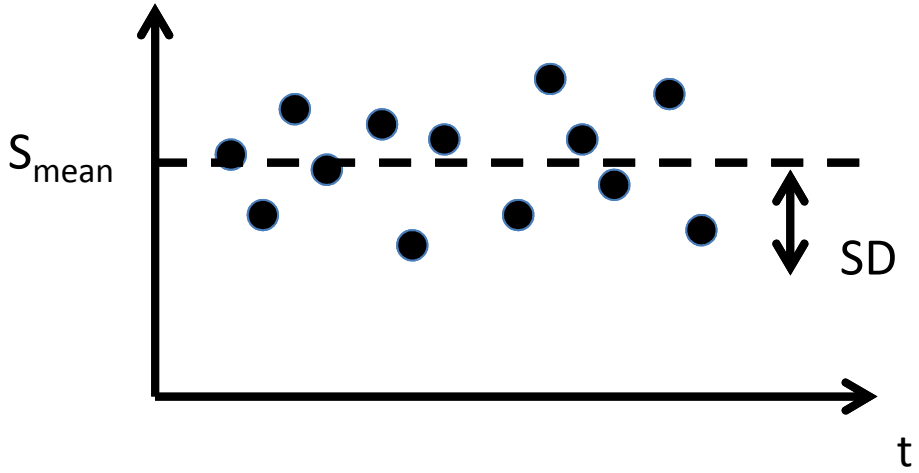
$$tSNR = \frac{mean(Signal)_{timecourse}}{SD(Signal)_{timecourse}}$$

tSNR: - calculated over the time-course

- signal variance: from thermal noise and physiology

BOLD sensitivity and tSNR

$tSNR = S_{mean}/SD$

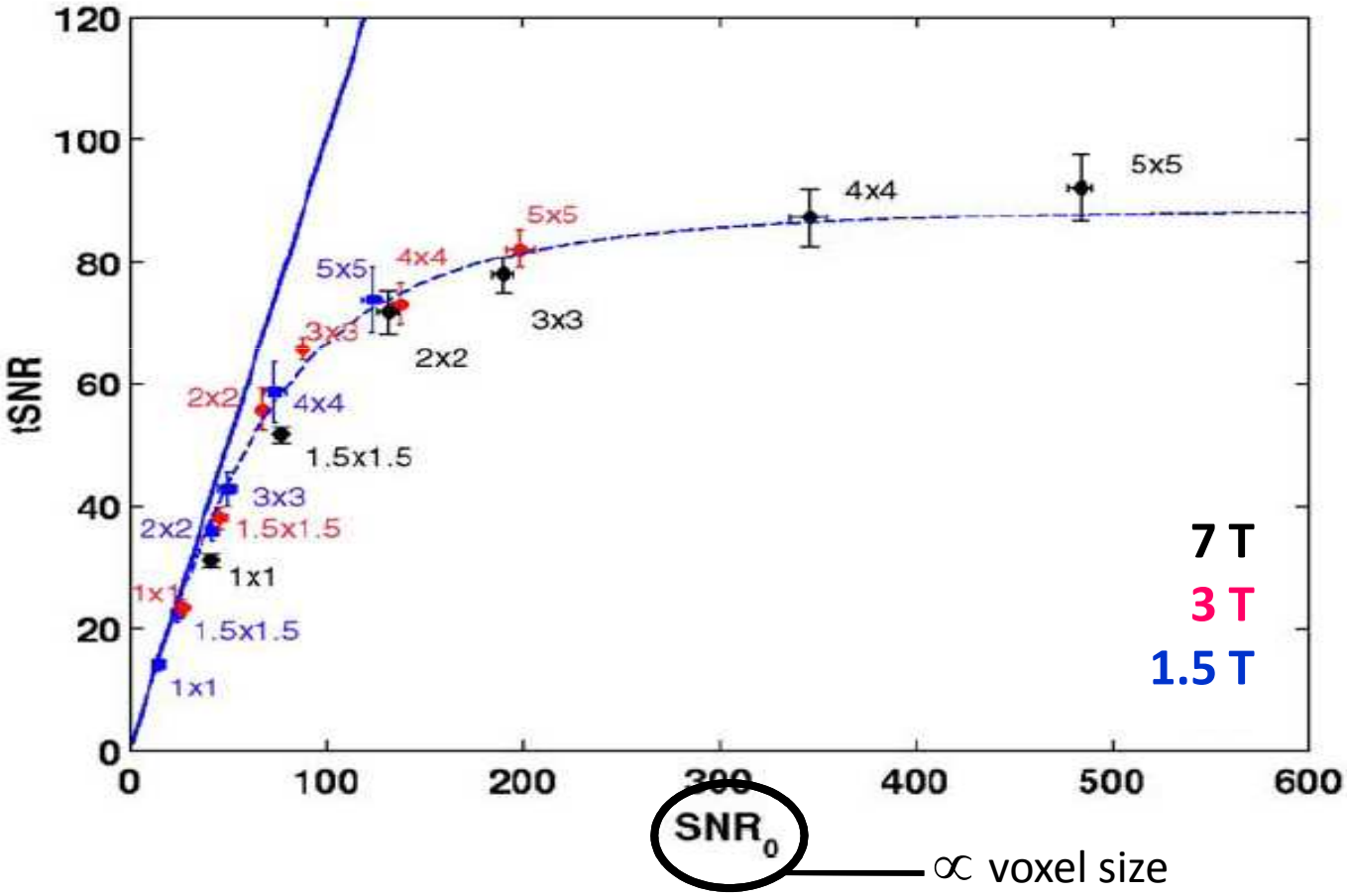


low tSNR

High tSNR

Temporal stability is a measure of BOLD sensitivity

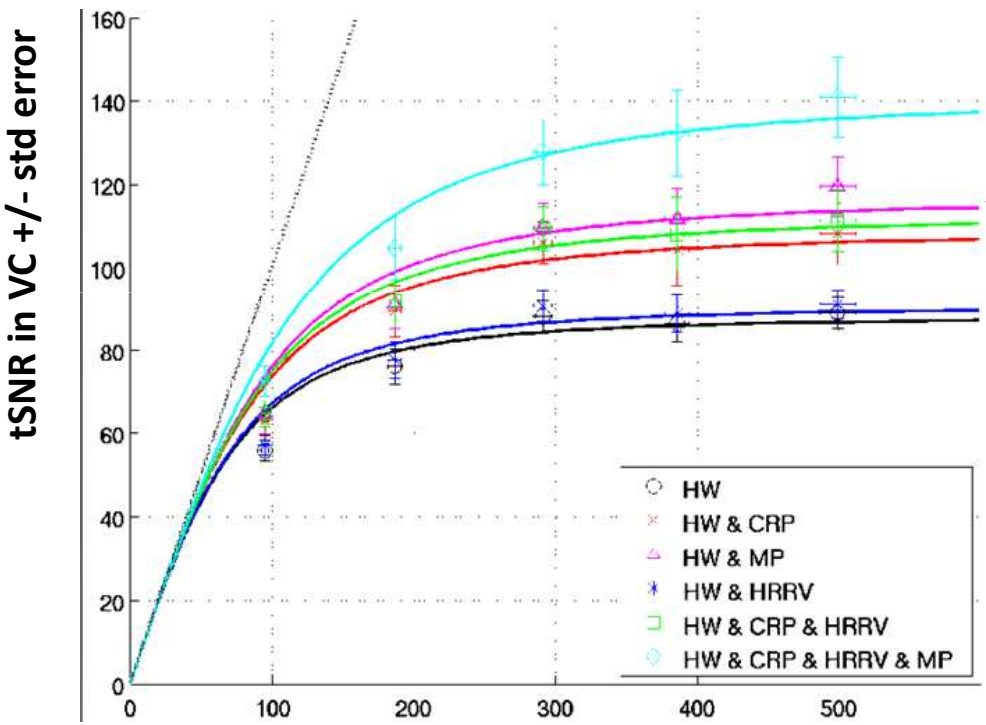
BOLD sensitivity depends on voxel size



∝ voxel size

Triantafyllou et al., Neuroimage 2005

Increasing temporal SNR with physiological noise correction



All cardio-respiratory effects and motion parameters

Motion parameters

All cardio-respiratory parameters

Correction for physiological effects increases BOLD sensitivity

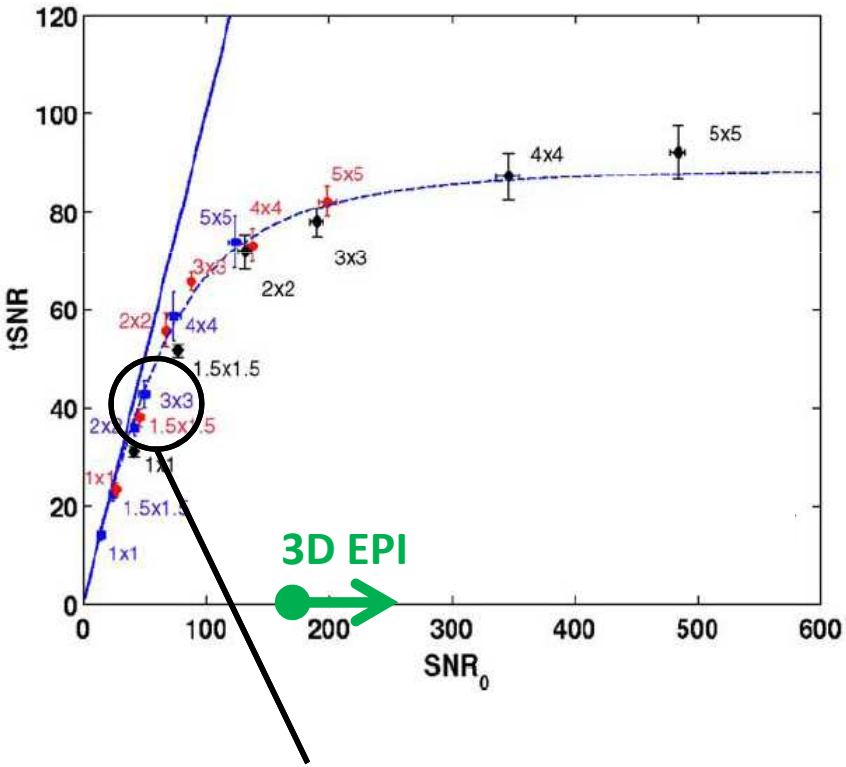
SNR_0 ∝ voxel size

Hutton et al., Neuroimage 2011

Outline

- BOLD effect
- Image encoding for fMRI
- Limitations of EPI
- Advanced fMRI

Advanced fMRI - High-resolution

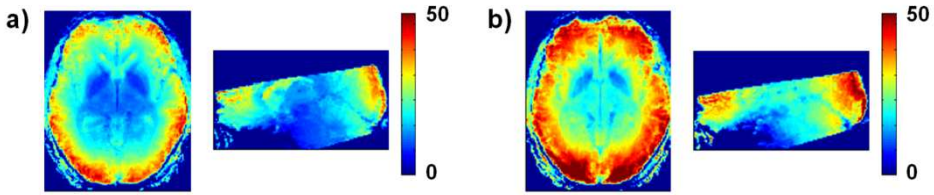


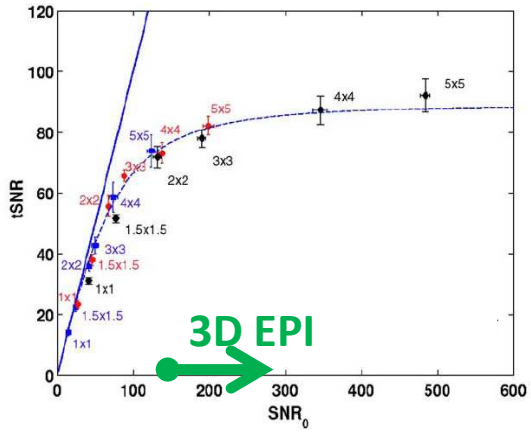
3D encoding increases SNR_0 (see anatomical lecture)

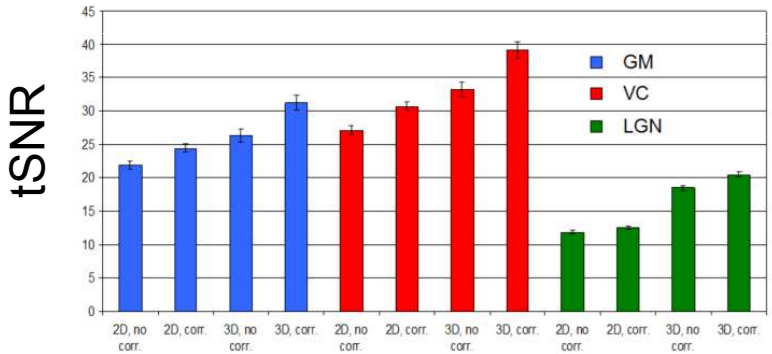
Advanced fMRI - High-resolution

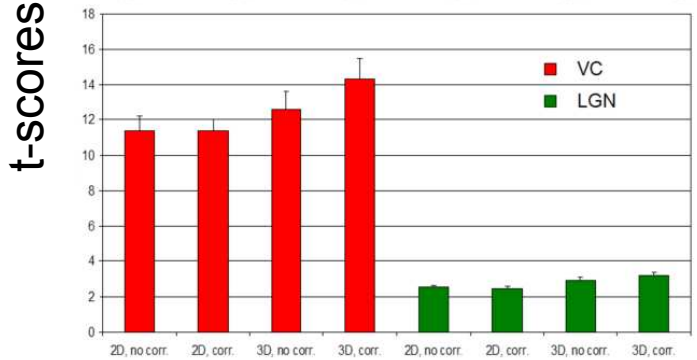
tSNR 2D EPI

tSNR 3D EPI









Anatomical lecture
3D Image Encoding

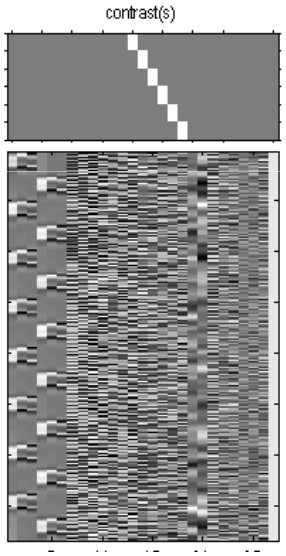
$tSNR_{3D}$ - 128% $tSNR_{2D}$ in VC
- 164% $tSNR_{2D}$ in LGN

Visual stimulation:
$tscores_{3D}$ - 125% $tscores_{2D}$ in VC
- 128% $tscores_{2D}$ in LGN

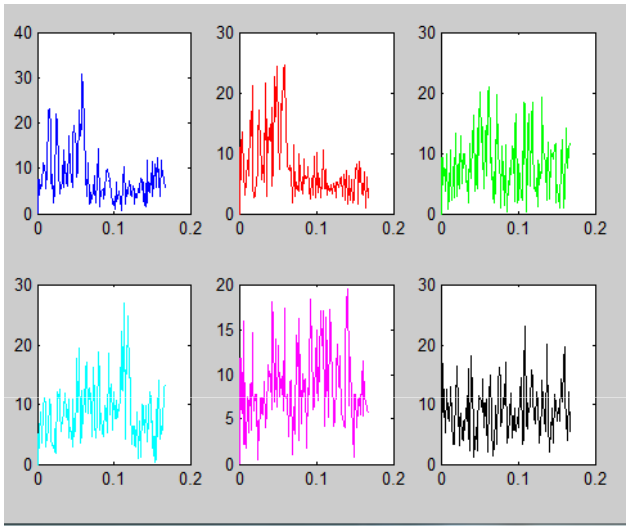
Lutti A. et al MRM 2013

Advanced fMRI - Ultra-fast fMRI

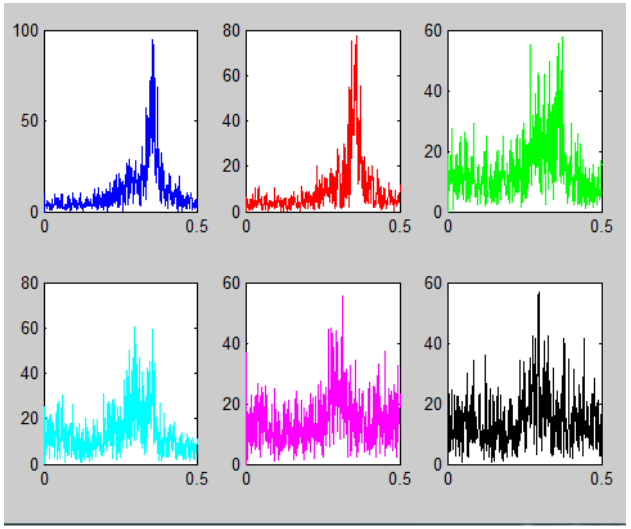
respiration



TR=3s



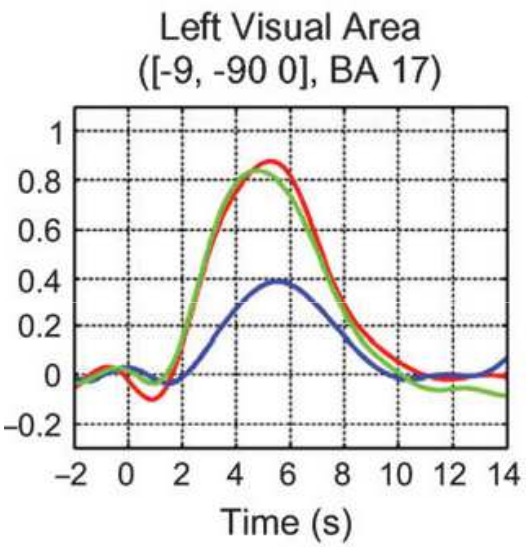
TR=1s

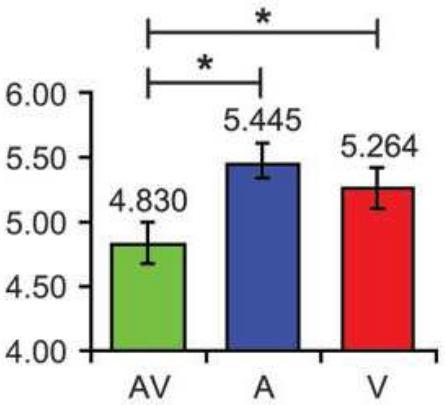


Short TR:

- Rapid sampling of physiological signal
- Improved physiological correction

Advanced fMRI - Ultra-fast fMRI



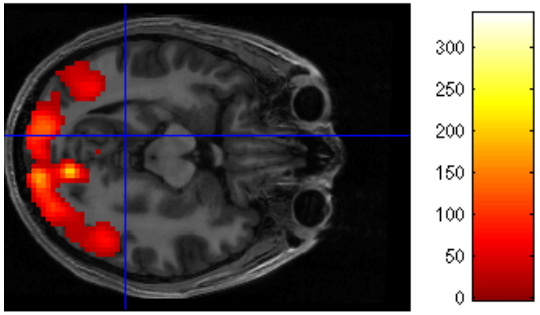


Study of the dynamics of the BOLD response

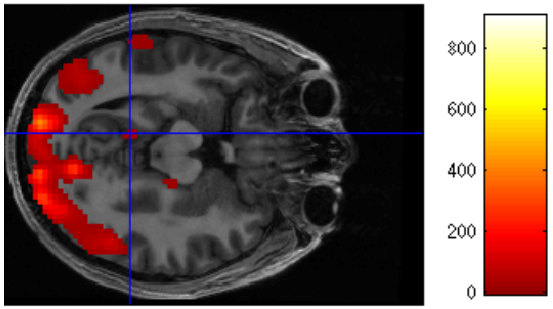
Martuzzi R. et al Cereb Cortex 2007

Advanced fMRI - Ultra-fast fMRI

TR = 3s



TR = 1s

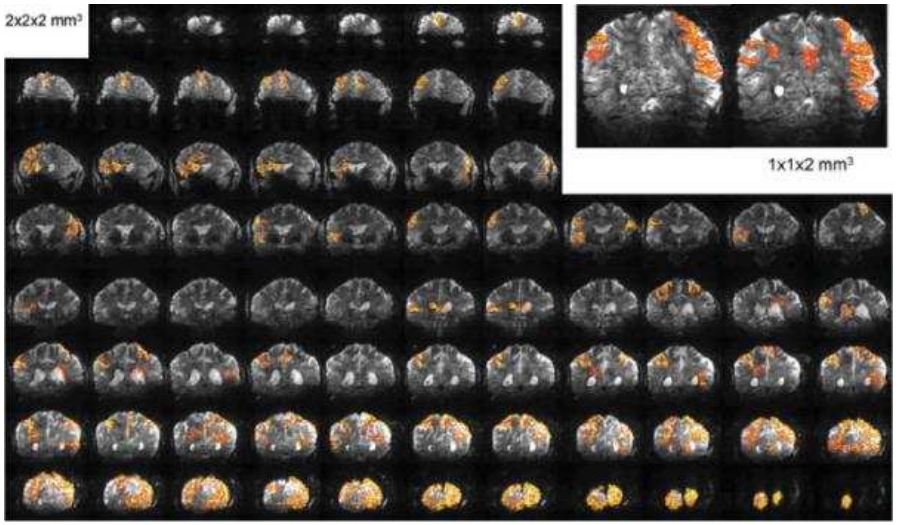


- 3D EPI acquisitions
+ parallel imaging

Lutti A. et al MRM 2013

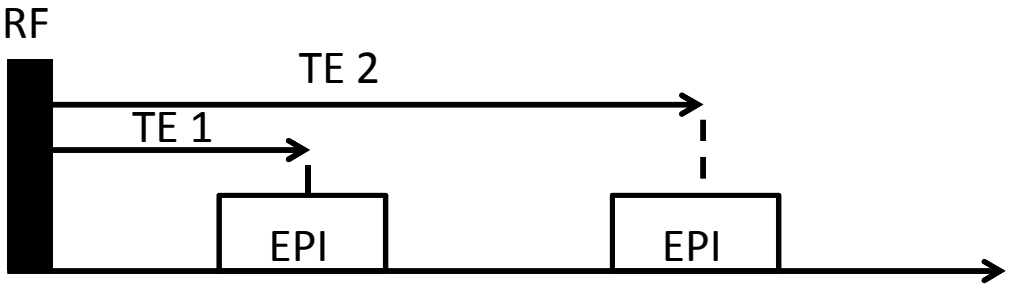
- Multi-band acquisitions

TR = 1.25s

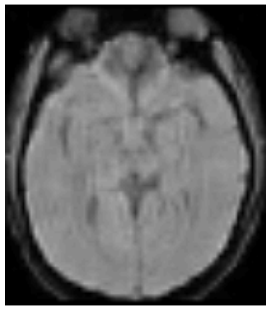


Moeller S et al. MRM 2010

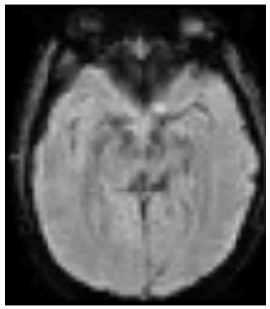
Advanced fMRI– multi echo acquisitions



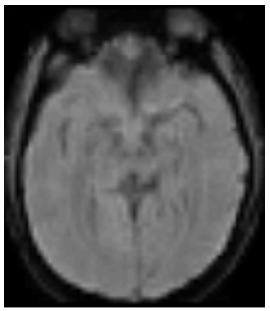
Echo1
TE=15.85ms



Echo2
TE=34.39ms



Echo1
+Echo2



EPI images free of signal dropout

Poser B.A., Norris D.G. Neuroimage 2009;

References

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  by F. Schmitt, M. K. Stehling, R. Turner and P. Mansfield

- Magnetic Resonance Imaging

  by Haacke *et al* - John Wiley and Sons, 1999