Functional MRI

SPM course - 04/2014

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Outline

• BOLD effect

• Image encoding for fMRI

• Limitations of EPI

• Advanced fMRI
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Blood Oxygen Level Dependent (BOLD) effect

BOLD: localized signal change during activation

Kwong et al., PNAS 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
Active Resting

arterial

Oxygenated / deoxygenated hemoglobin

Active

venous

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$_2$O)
- creates local B0 inhomogeneities

Oxygenated Hb:
- diamagnetic
- same as tissue (H$_2$O)
- does not perturb B0 homogeneity
T2* decay

T2* contrast: - sensitive to local B0 inhomogeneities effects
- T2*<T2

TE: echo time

Anatomical lecture
Principals of image encoding
**Blood Oxygen Level Dependent (BOLD) effect**

- **Metabolism**
- **Perfusion**

**Resting**
- arterial
- venuous

**Active**
- arterial
- venuous

**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

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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

Excitation

$G_{\text{phase}}$

Acquisition time: ~mins

Too slow for fMRI

Anatomical lecture
Principals of image encoding
Image encoding for fMRI
Echo Planar Imaging

Readout time
~30-50ms

2D image after one RF excitation
Image encoding for fMRI

Neighboring slices are acquired successively in ascending (↑) or descending (↓) order.

TR ~ 50-100ms
Outline

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• **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

Long EPI readout -> distortions
Long EPI echo-time -> dropouts
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

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

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)

- 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 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: - calculated over the time-course
- signal variance: from thermal noise and physiology

\[ tSNR = \frac{\text{mean}(\text{Signal})_{\text{timecourse}}}{\text{SD}(\text{Signal})_{\text{timecourse}}} \]
**BOLD sensitivity and tSNR**

\[
tSNR = \frac{S_{\text{mean}}}{\text{SD}}
\]

Temporal stability is a measure of BOLD sensitivity.
BOLD sensitivity depends on voxel size

\[ \propto \text{voxel size} \]

Triantafyllou et al., Neuroimage 2005
Increasing temporal SNR with physiological noise correction

Correction for physiological effects increases BOLD sensitivity

\( \text{SNR}_0 \propto \text{voxel size} \)

Hutton et al., Neuroimage 2011
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Advanced fMRI - High-resolution

3D encoding increases SNR₀ (see anatomical lecture)

1.5mm³ at 3T
**Advanced fMRI - High-resolution**

- **tSNR 2D EPI**
- **tSNR 3D EPI**

Visual stimulation:
- \( tSNR_{3D} \) - 128% \( tSNR_{2D} \) in VC
- 164% \( tSNR_{2D} \) in LGN

- **tscores\(_{3D}\)** - 125% \( tscores_{2D} \) in VC
- 128% \( tscores_{2D} \) in LGN

**Lutti A. et al MRM 2013**

**Anatomical lecture**

3D Image Encoding
Advanced fMRI - Ultra-fast fMRI

- 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

- 3D EPI acquisitions + parallel imaging

Lutti A. et al. MRM 2013

- Multi-band acquisitions

Moeller S et al. MRM 2010
Advanced fMRI– multi echo acquisitions

RF

TE 1

TE 2

EPI

EPI

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

• Echo-Planar Imaging: Theory, Technique and Application

• Magnetic Resonance Imaging
  by Haacke et al - John Wiley and Sons, 1999