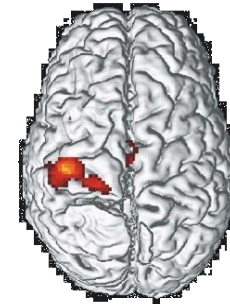
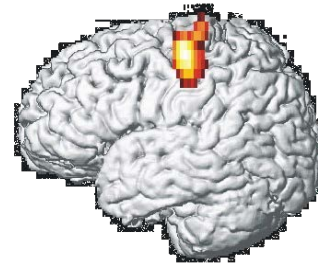


Functional Methods in the Magnetic Resonance Imaging (fMRI)



Michael Erb

Dept. Biomedical Magnetic Resonance
Eberhard-Karls University Tübingen

Michael.Erb@med.uni-tuebingen.de

Introduction

Brain Theory

MR Images

BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion

- Depiction of dynamic processes:
 - Blood flow → Perfusion imaging
 - Movement → heart phases, joints, speech production
 - Brain function → Activation with motor function, speech, ...

Requirement:

- High temporal resolution
- Synchronization

How do we think with our brain?



Introduction

Brain Theory

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fMRI

fMRI ↔ EEG

Examples

Discussion

- Spatial-temporal structure of brain function
- Different types of signals (electrical, chemical, ...)
- Parallel and synchronized processing in different substructures
- Learning, Plasticity and Reorganization
- Internal representation, independent of actual sensory input

How can we watch our brain at work?

Introduction

Brain Theory

MR Images

BOLD-Effect

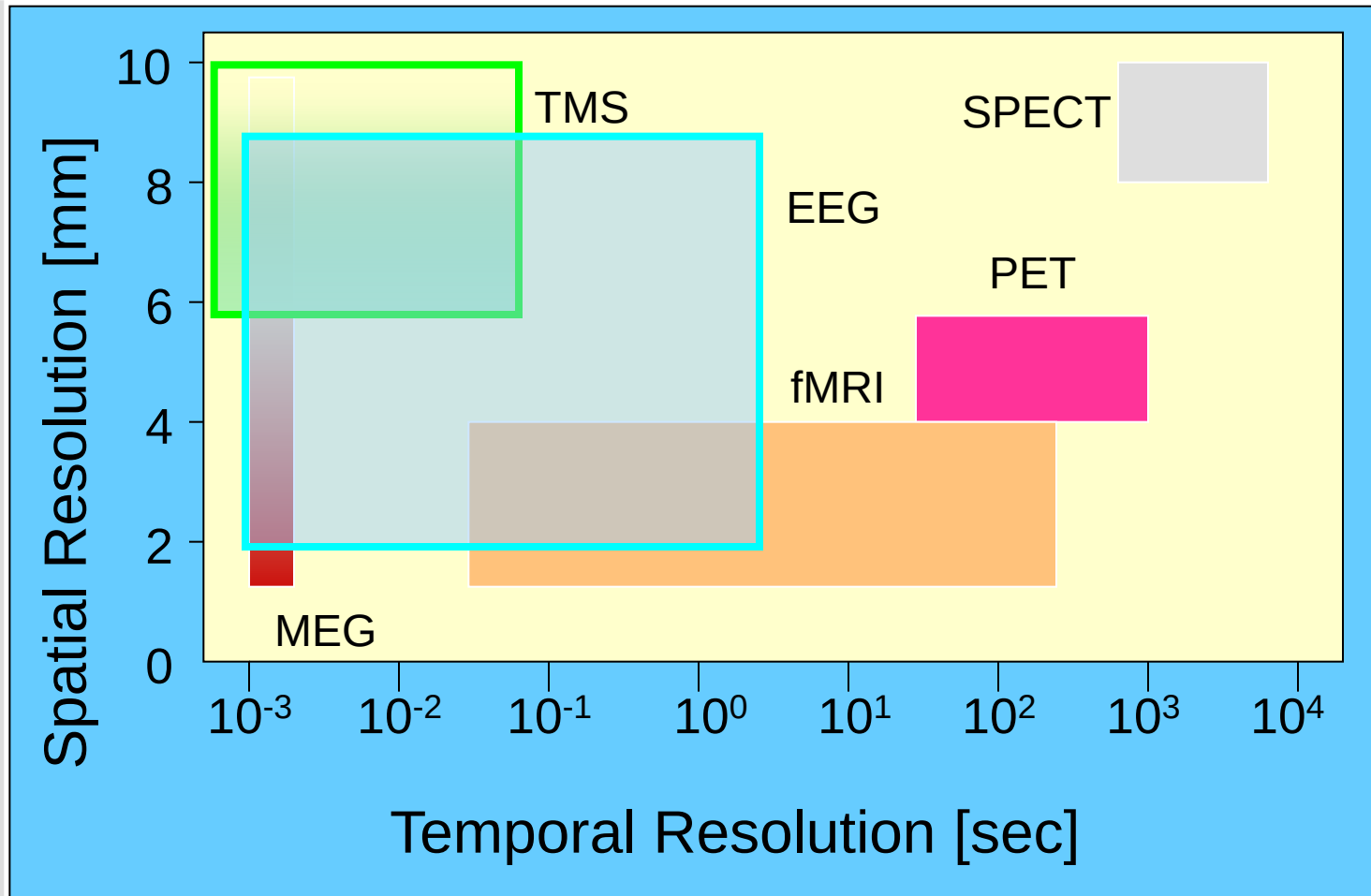
fMRI

fMRI ↔ EEG

Examples

Discussion

■ Methods for investigation



What is Magnetic Resonance?

Introduction

Brain Theory

MR Images

BOLD-Effect

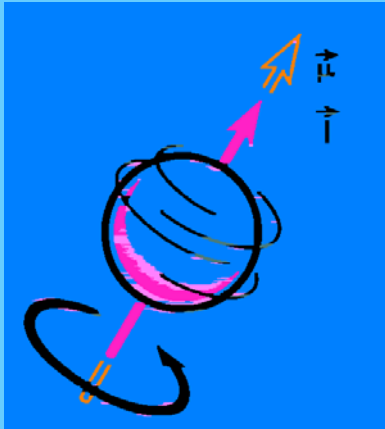
fMRI

fMRI ↔ EEG

Examples

Discussion

■ MR Experiment



Spin of ^1H
with two
states in
magnetic
field



strong
magnetic field
 B_0 splits into
two energy
levels



RF transmitter
and receiver
with resonance
frequency
 $f = g \cdot B_0$

Which parts do we need for a MR Scanner?

Introduction

■ Components

Brain Theory

MR Images

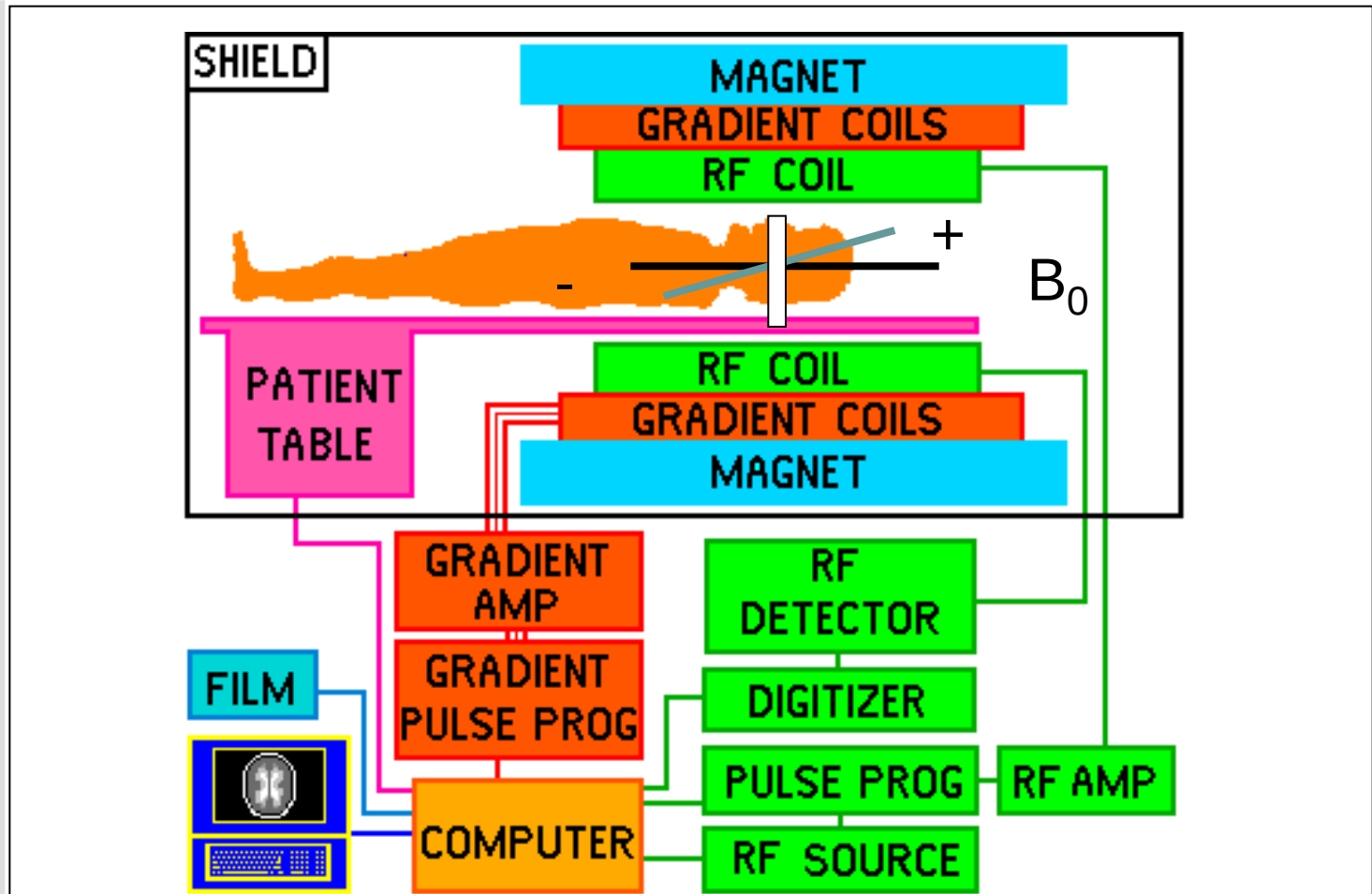
BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion



Which parts do we need for a MR Scanner?

Introduction

Brain Theory

MR Images

BOLD-Effect

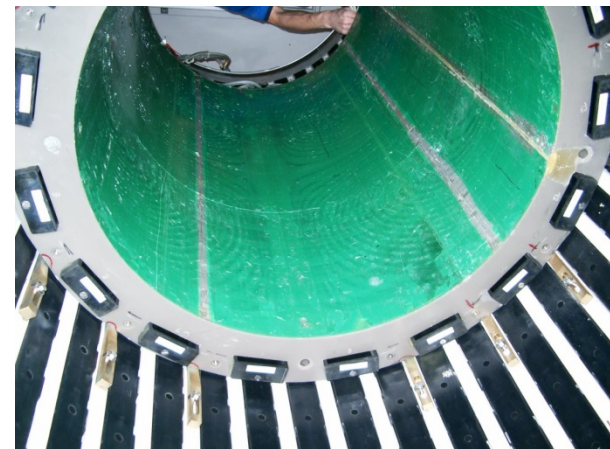
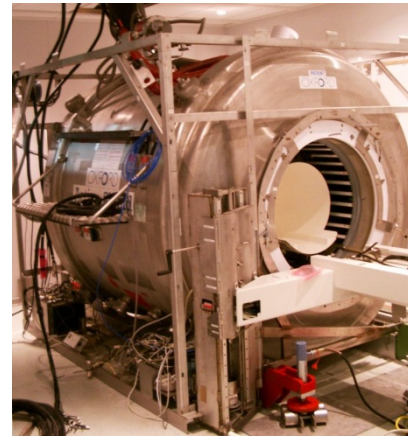
fMRI

fMRI ↔ EEG

Examples

Discussion

- Strong magnet
e.g. $B_0 = 1.5 \text{ T}$ (3T)
- RF transmitter with
 $f = 64 \text{ MHz}$ (128 MHz)
- Fast gradients
 $\Delta B / \Delta x = 40 \text{ mT/m}$,
 $\Delta B / \Delta x / \Delta t = 200 \text{ mT/m/ms}$



How do we get MR images?

Introduction

Brain Theory

MR Images

BOLD-Effect

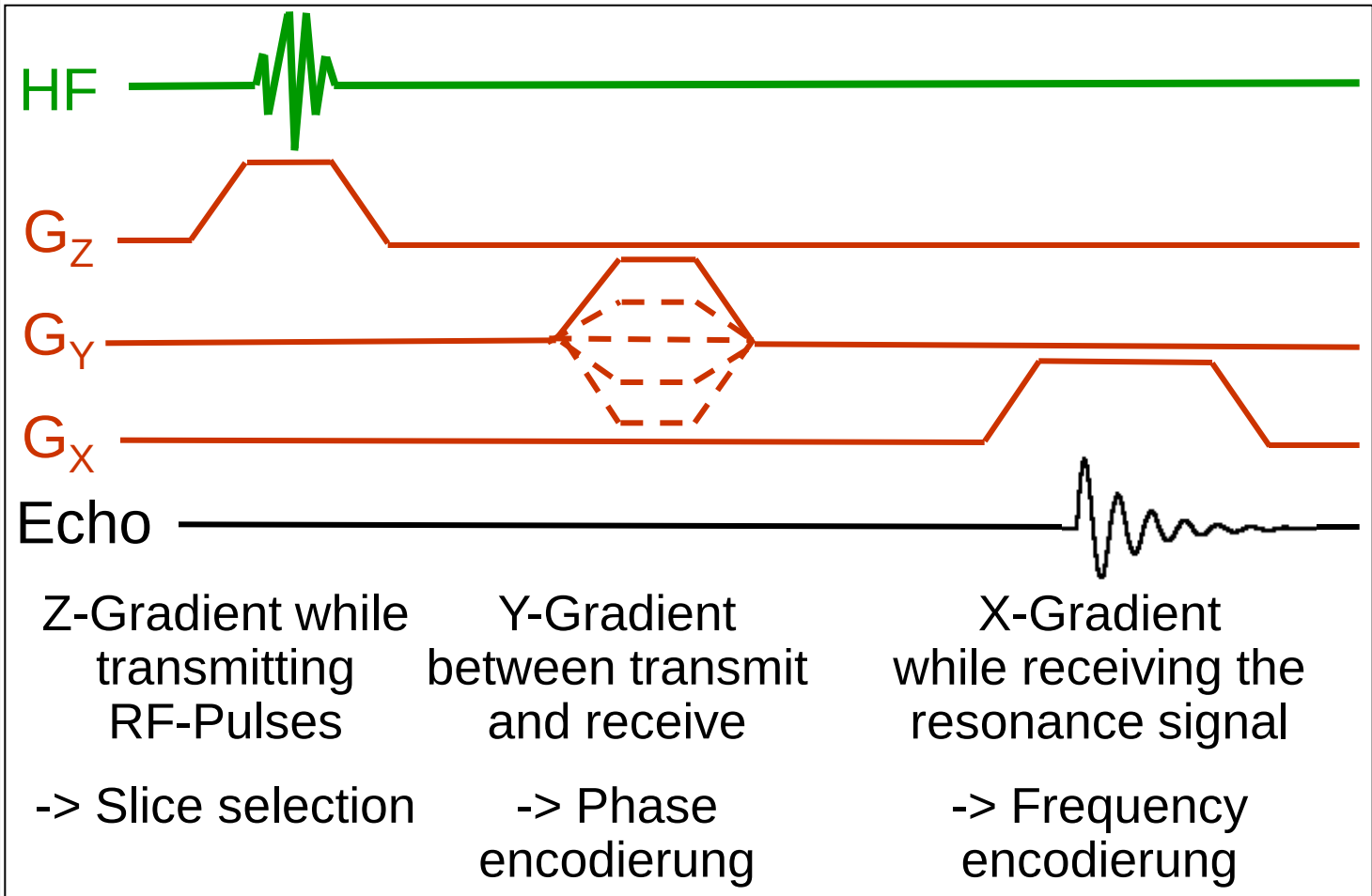
fMRI

fMRI ↔ EEG

Examples

Discussion

- Space encoding with gradients ΔB_0



How to calculate MR images from measurement data?

Introduction

- Reconstruction with 2D-Fourier transformation

Brain Theory

MR Images

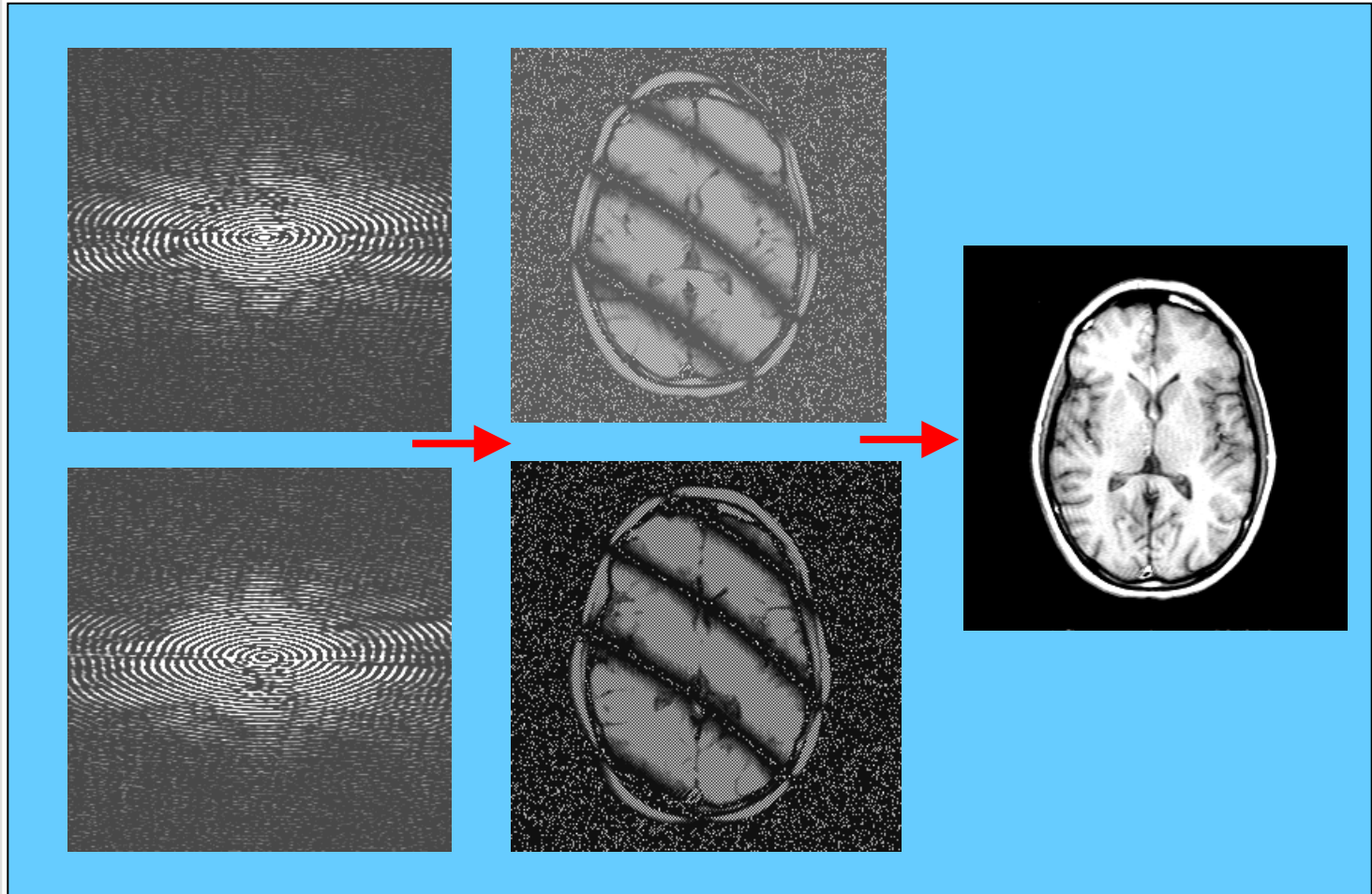
BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion



Fast imaging within less than 100ms per slice

Introduction

■ EPI (Echo Planar Imaging) Sequence

Brain Theory

MR Images

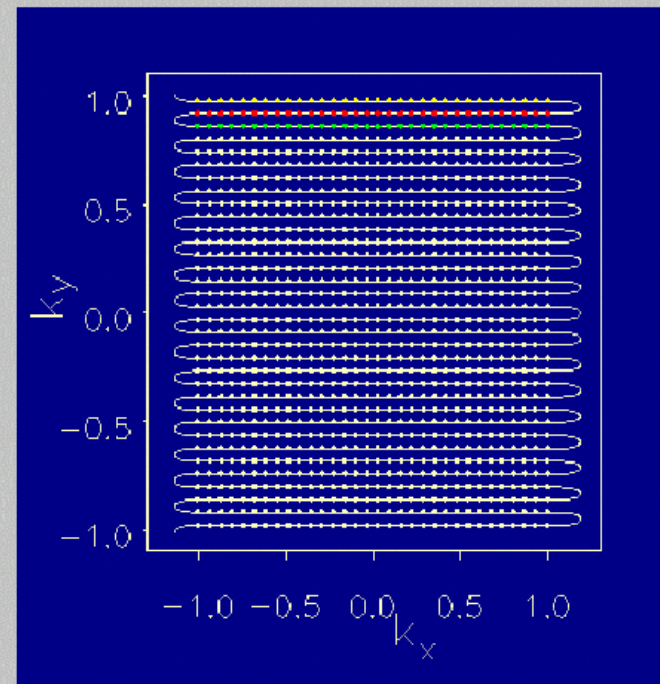
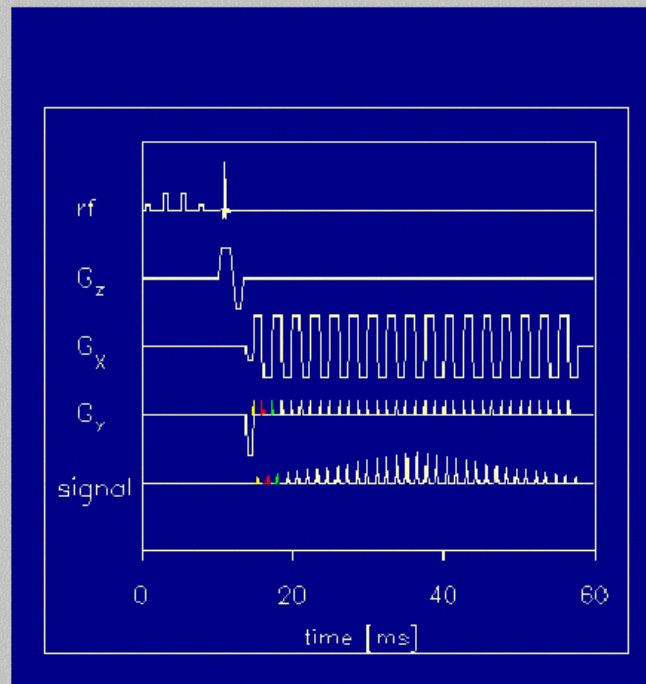
BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion



Mansfield (1977) , J. Phys. C, 10, L55-58

How can we study thinking with MRI?



Introduction

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MR Images

BOLD-Effect

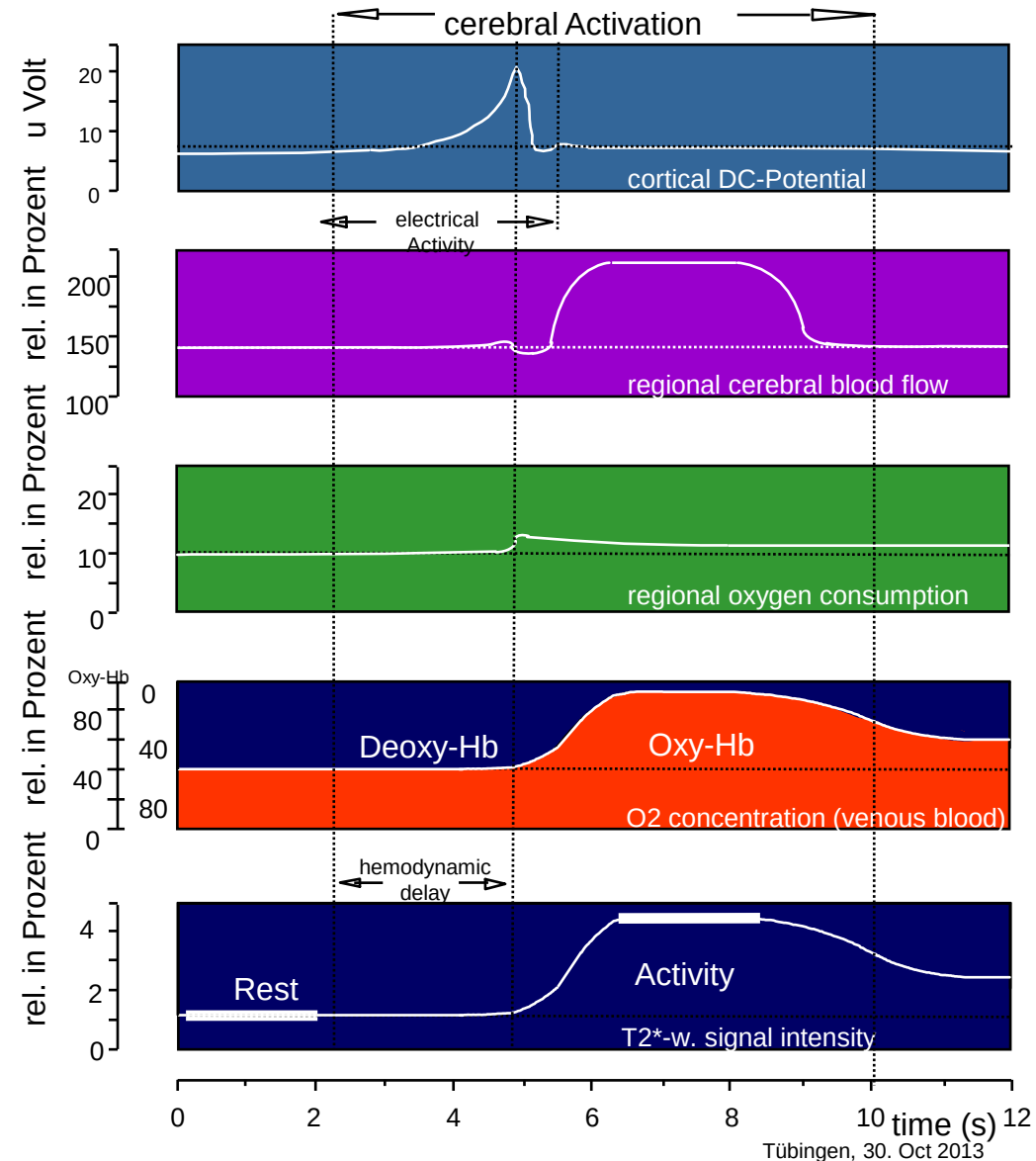
fMRI

fMRI ↔ EEG

Examples

Discussion

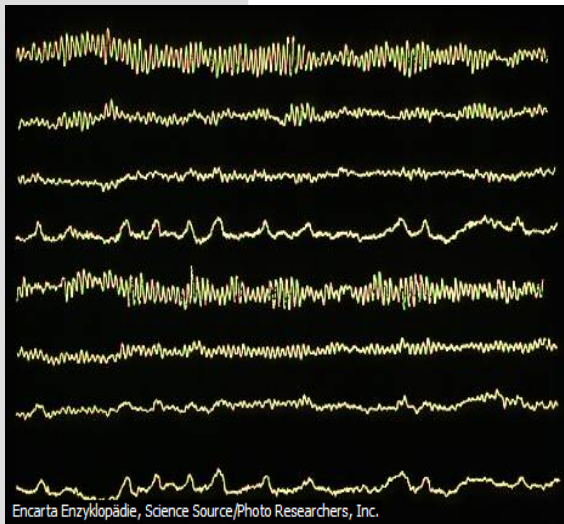
- BOLD: (Blood Oxygen Level Dependent)
- Oxygenation of Hemoglobin



Comparison: Brain and Computer

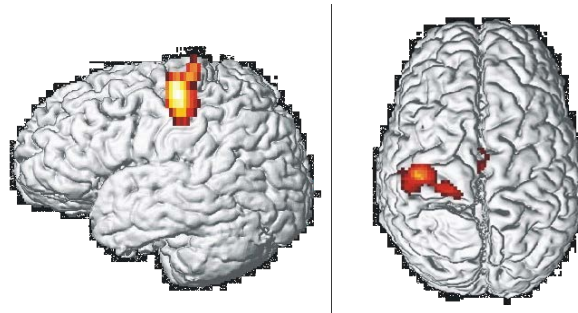


EEG/MEG



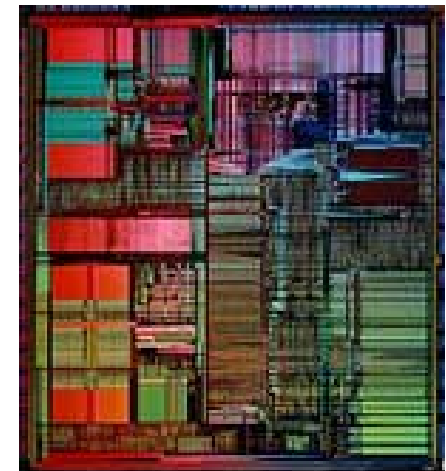
Neuronal
signals

fMRI



Energy
consumption

Computer



Intel® Pentium® Processor

Electric signals
and temperature

Why can we study thinking with MRI?

Introduction

Brain Theory

MR Images

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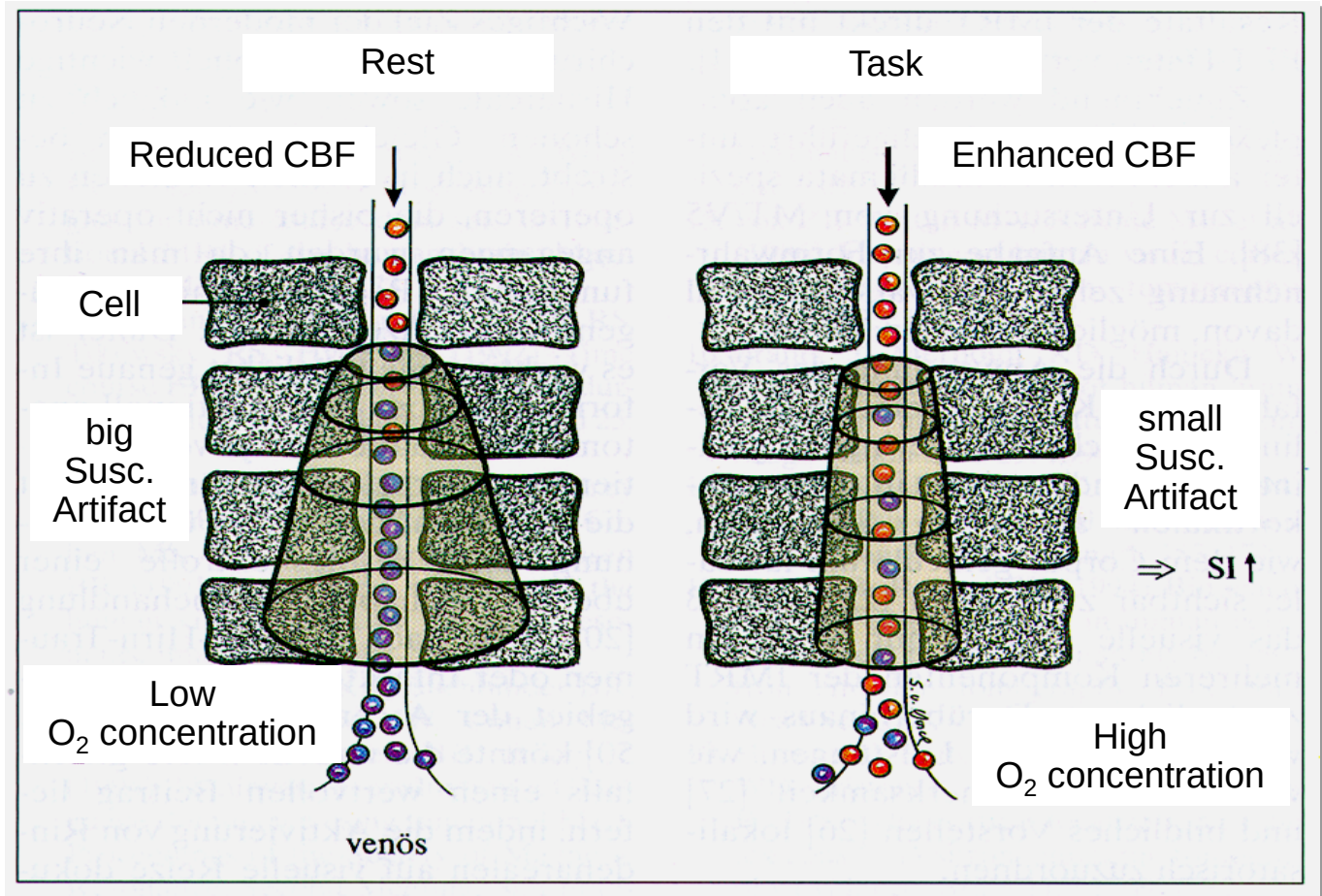
fMRI

fMRI ↔ EEG

Examples

Discussion

- Perfusion change due to neuronal activation



Modified from: R. Brüning u. A. Danek: Radiologe 35 (1995) 256-262

Why does the magnetic properties of the blood change?



Introduction

Brain Theory

MR Images

BOLD-Effect

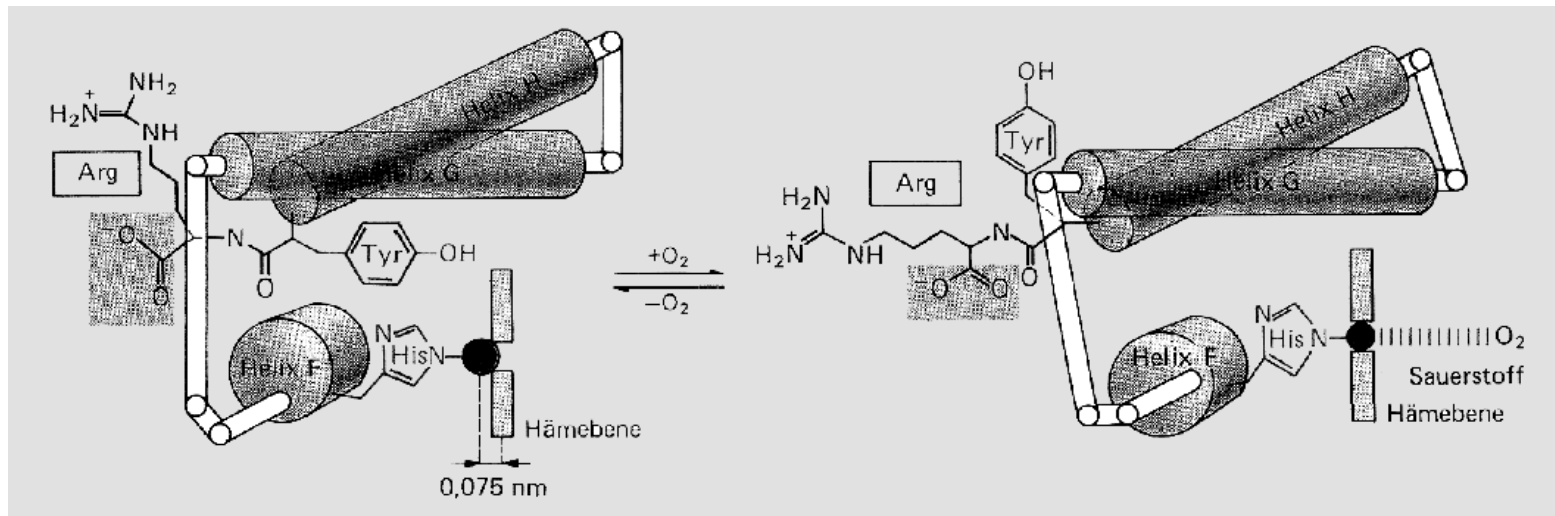
fMRI

fMRI ↔ EEG

Examples

Discussion

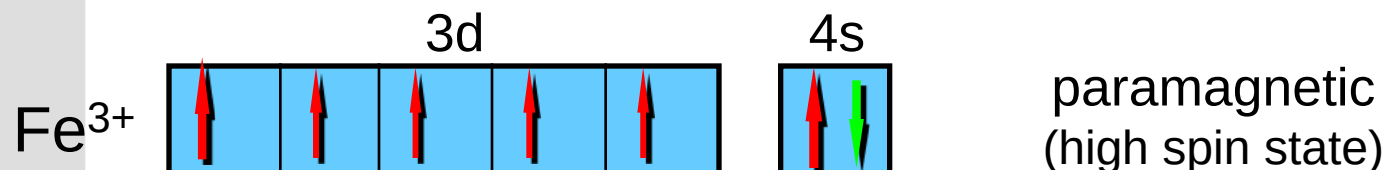
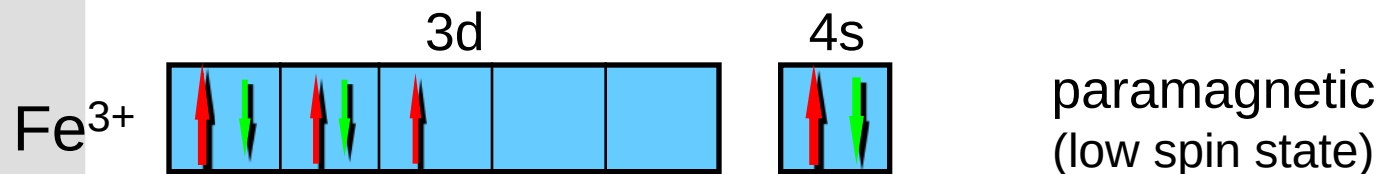
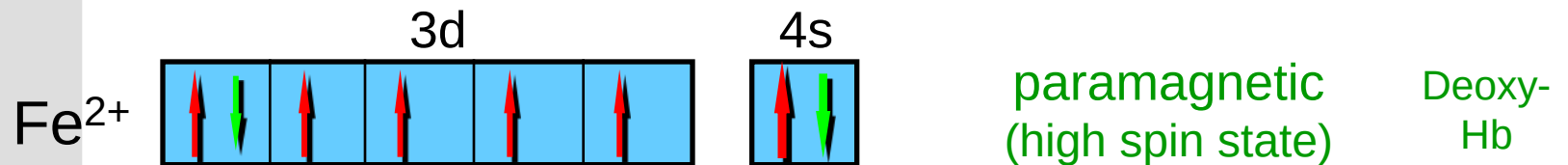
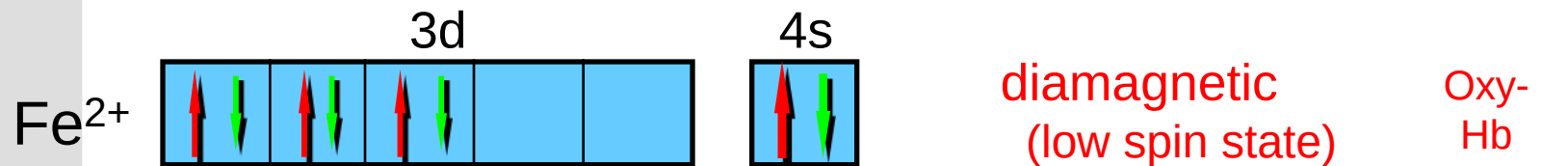
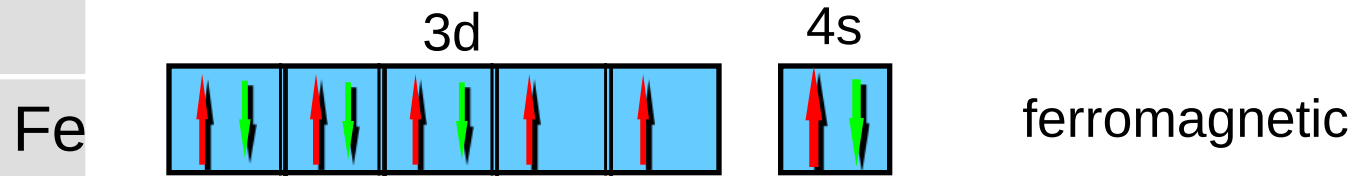
■ Configuration change of Hemoglobin



Desoxyhemoglobin
paramagnetic

Oxyhemoglobin
diamagnetic

Magnetic properties of iron atoms



Time course of the BOLD Effect

Introduction

Brain Theory

MR Images

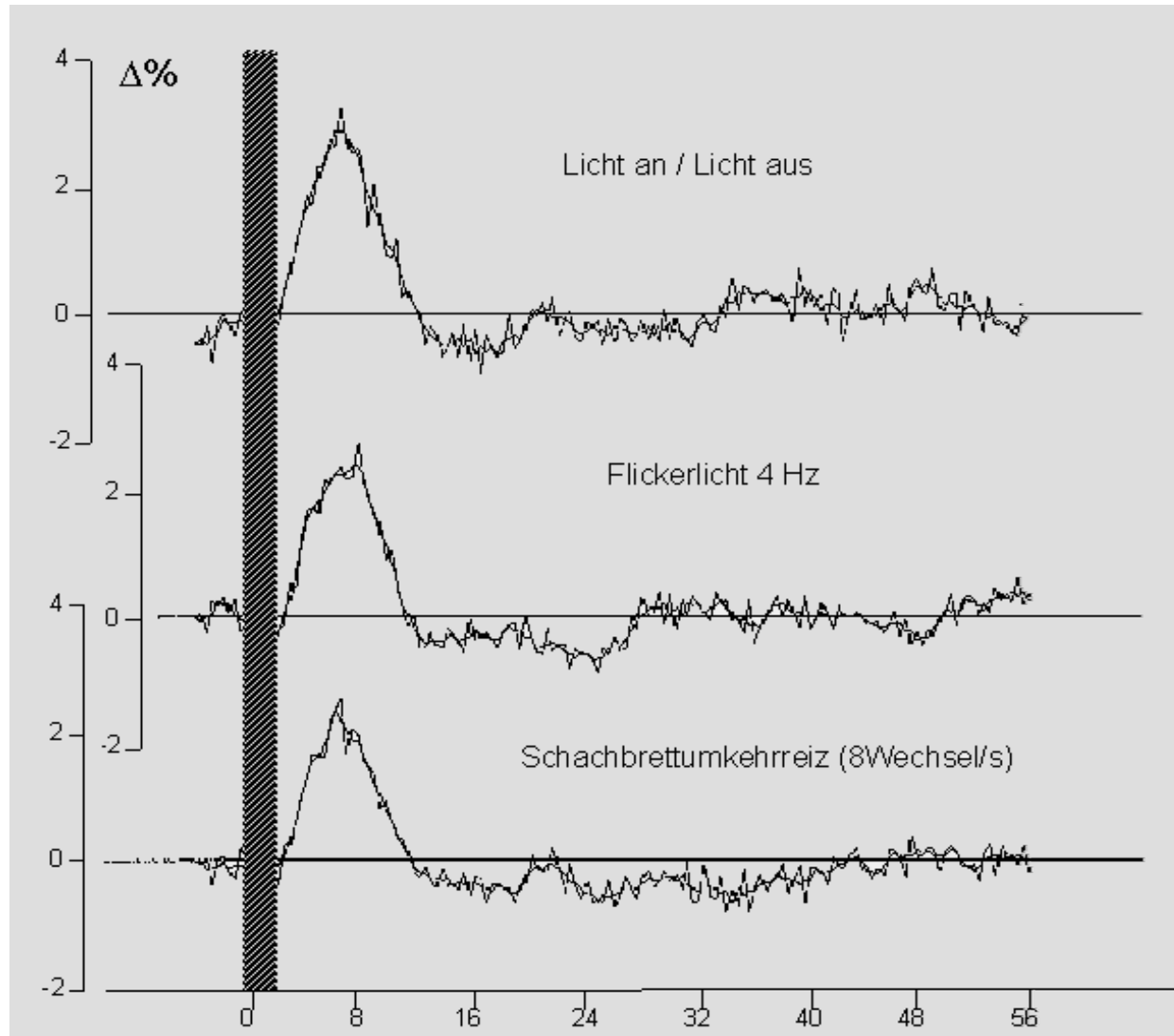
BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion



Adapted from C. Janz, O. Speck, J. Hennig: NMR in Biomedicine 10: 222-229 (1997)

Time course of the BOLD Effect



Introduction

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fMRI

fMRI ↔ EEG

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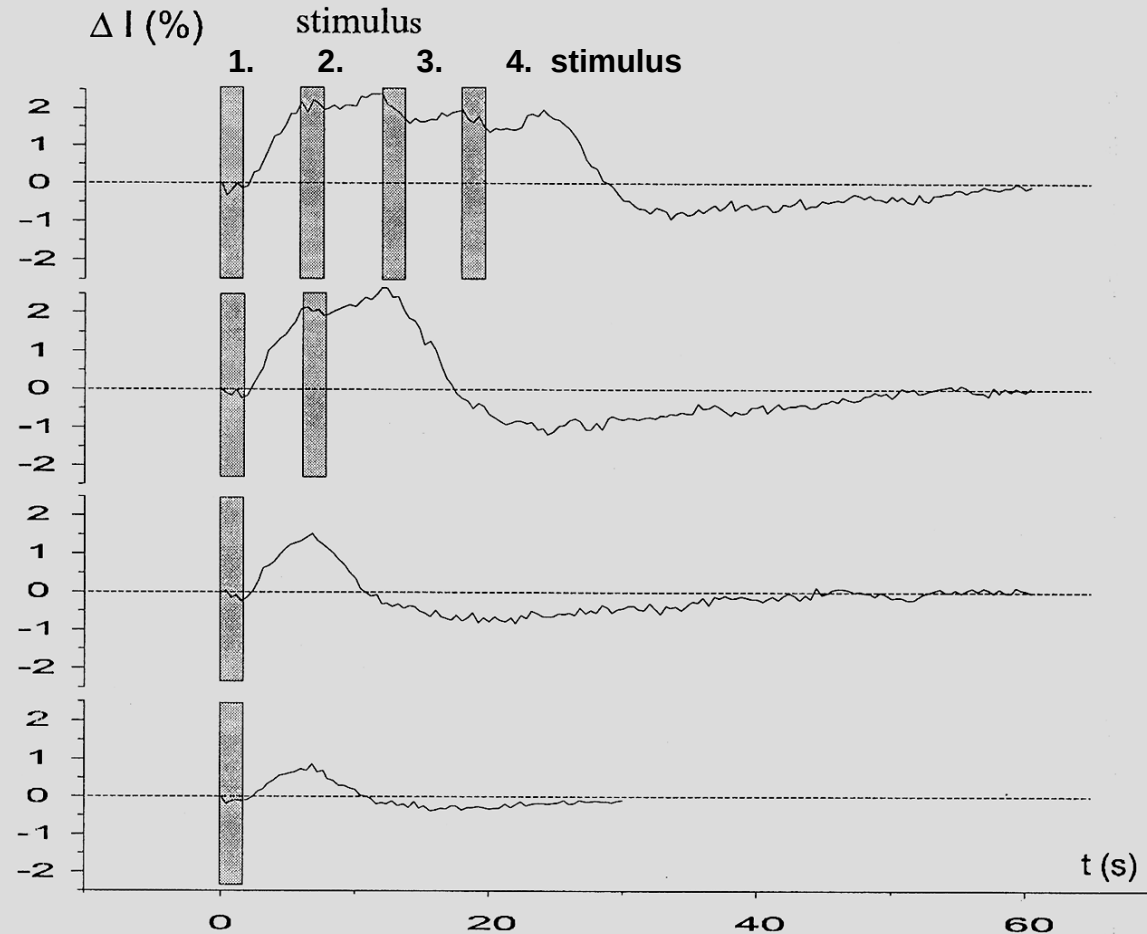


Abbildung 1: fMRI Zeitverlauf nach einem, zwei und vier 2s langen Lichtreizen, bei einer Reizwiederholzeit von 30.4s bzw. 60.8s. Die vertikalen Balken kennzeichnen die Dauer des eingeschalteten Lichtes. Die dargestellten Signalintensitäten entsprechen der beobachteten, relativen Signaländerung über der Zeit.

adapted from C. Janz, O. Speck, J. Hennig: NMR in Biomedicine 10: 222-229 (1997)

Why does the blood flow change?



Introduction

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BOLD-Effect

fMRI

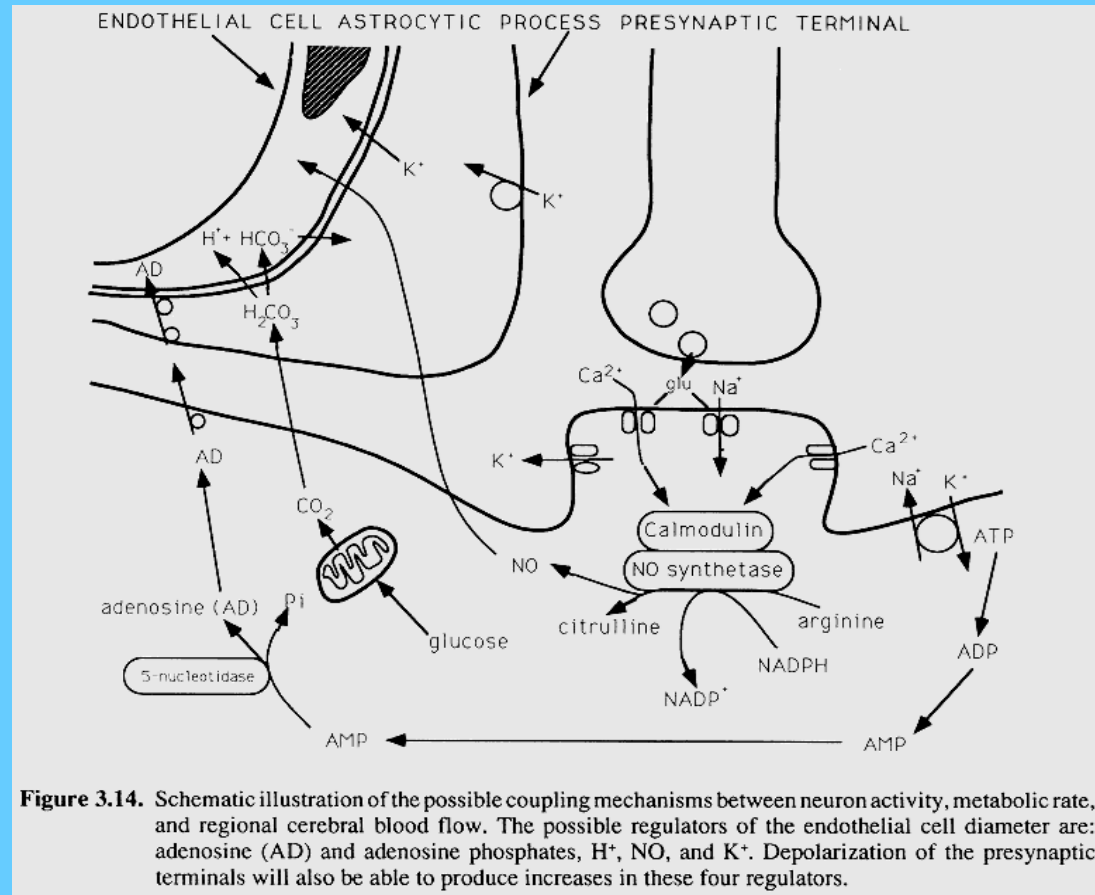
fMRI ↔ EEG

Examples

Discussion

■ Neurovascular coupling

from: P. Roland:
Brain Activation,
Wiley-Liss 1993



MRI capture of the BOLD signal

Introduction

Brain Theory

MR Images

BOLD-Effect

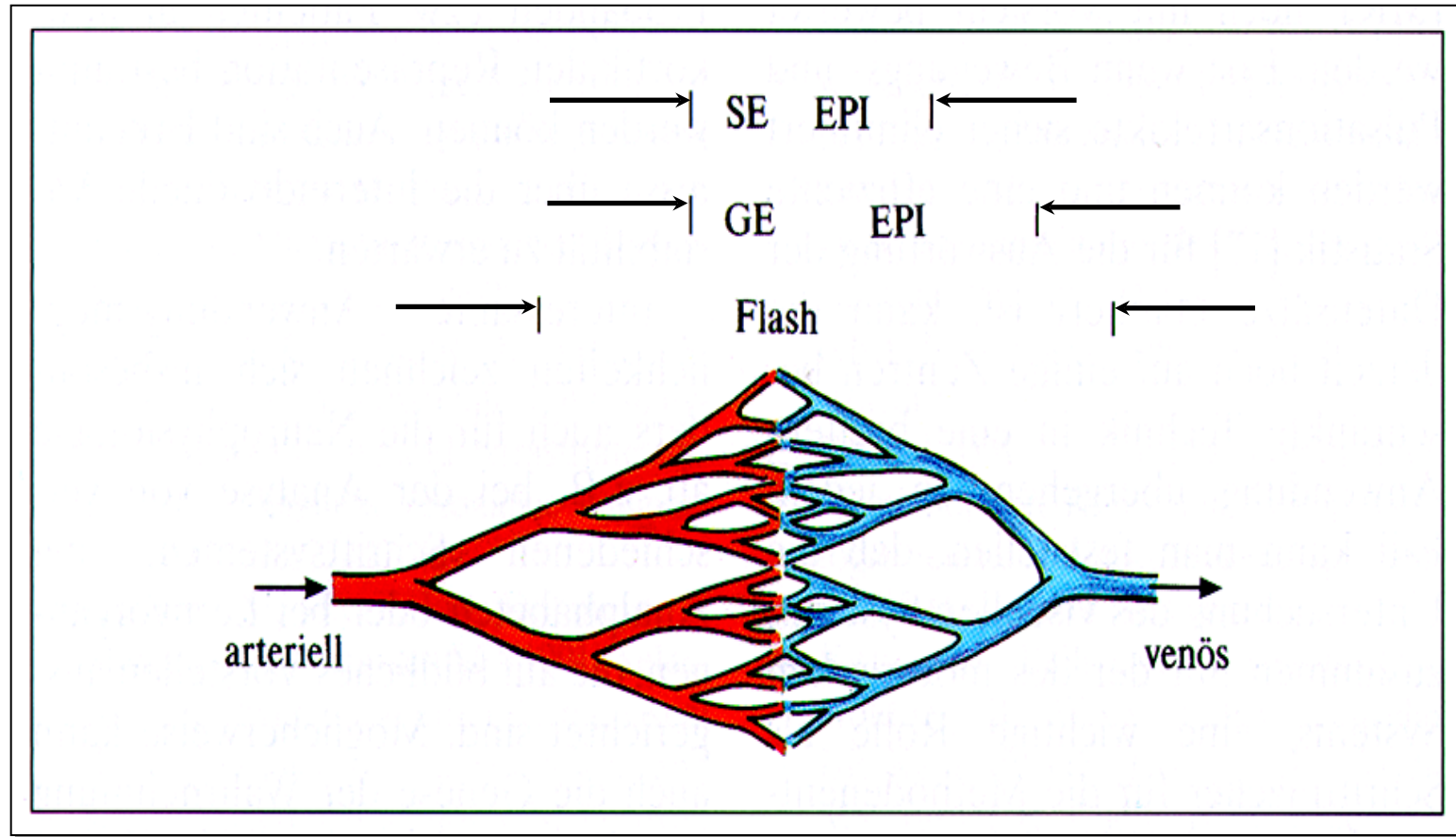
fMRI

fMRI ↔ EEG

Examples

Discussion

- Optimal TE: $TE = T2^*$ of gray matter



from: R. Brüning u. A. Danek: Radiologe 35 (1995) 256-262

Experimental investigations of the BOLD response

Introduction

Brain Theory

MR Images

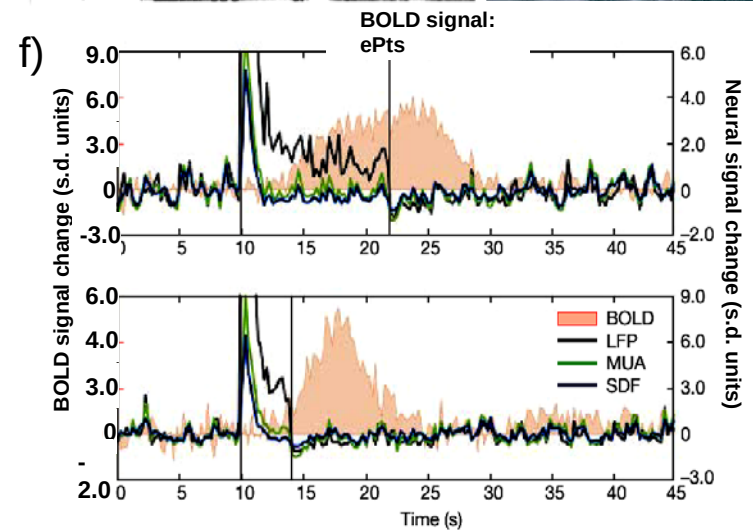
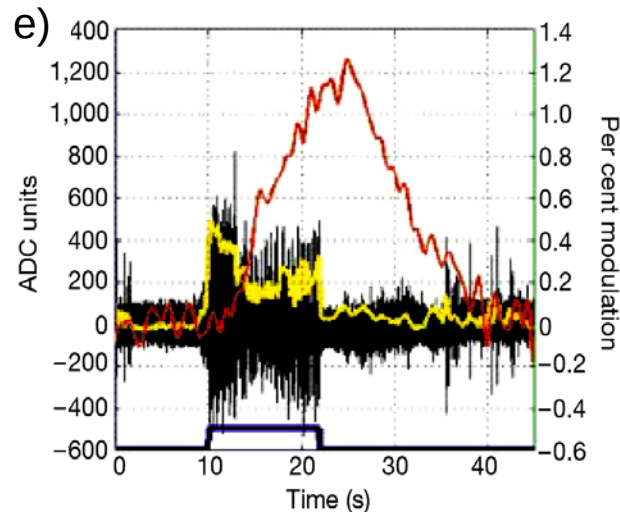
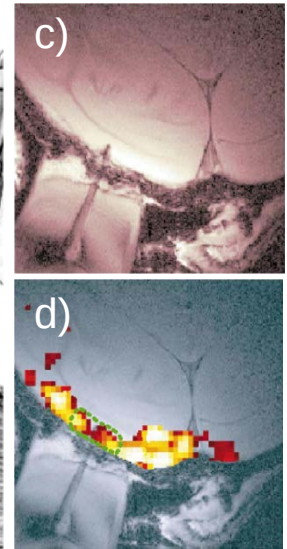
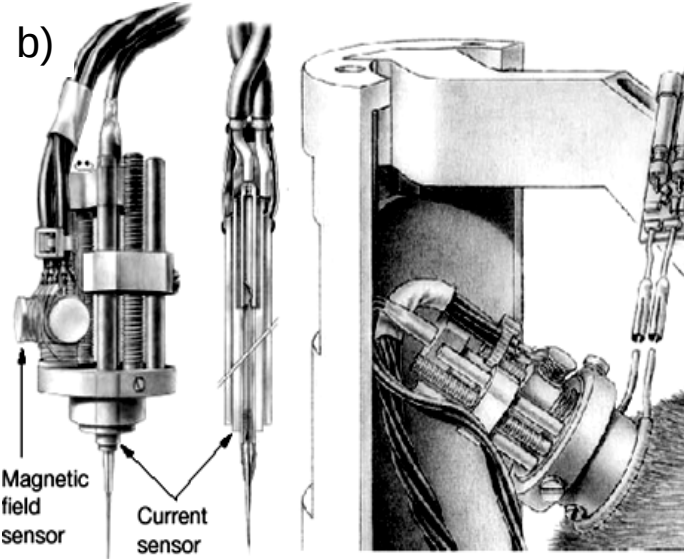
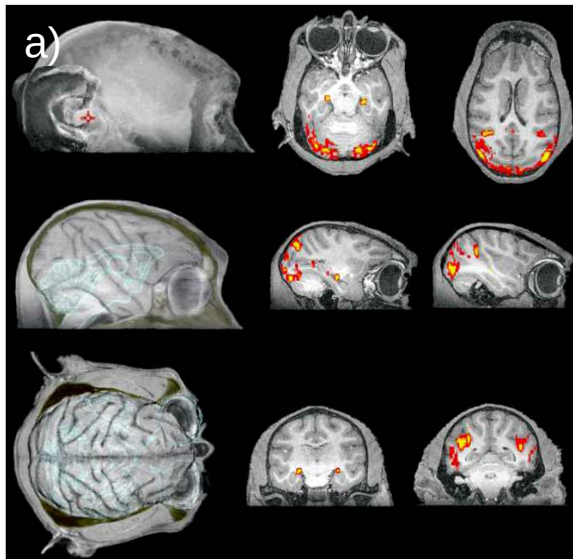
BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion



Which questions can be investigated with fMRI?

Introduction

Brain Theory

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fMRI

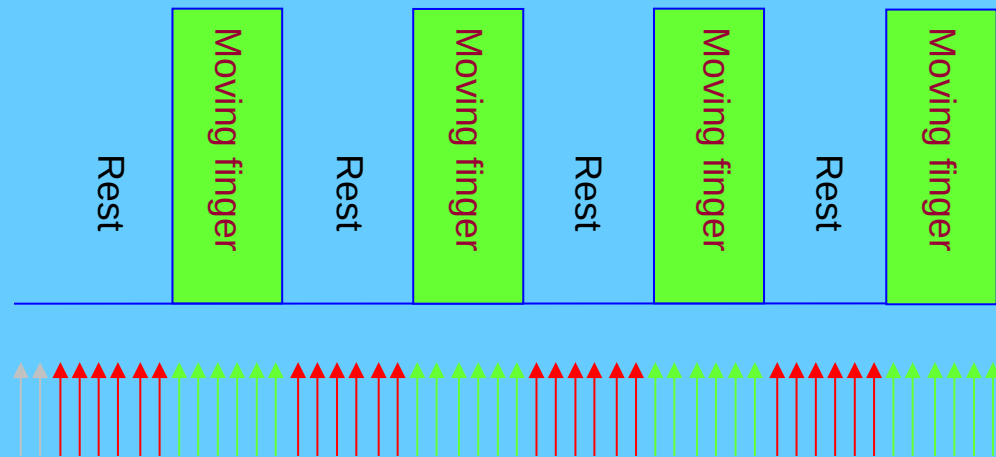
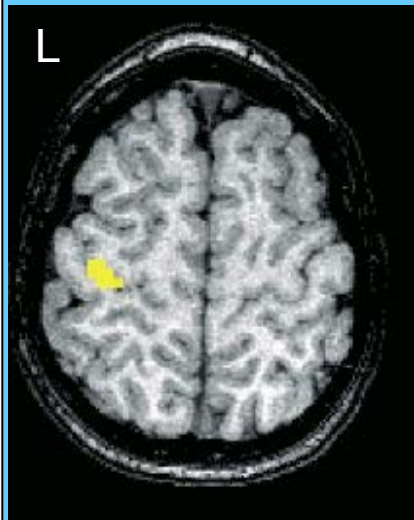
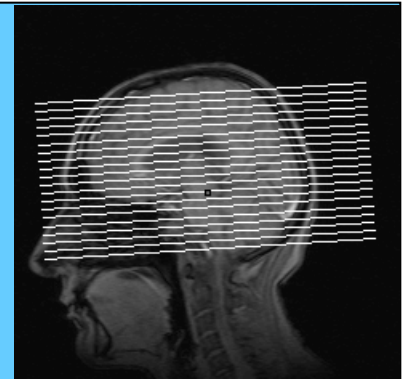
fMRI ↔ EEG

Examples

Discussion

■ Localization with block experiment

- Measurement of images while rest and activation condition
- Calculation of the difference between these groups
- Display of voxels with difference above threshold



Motoric Homunculus in cerebral cortex

Introduction

Brain Theory

MR Images

BOLD-Effect

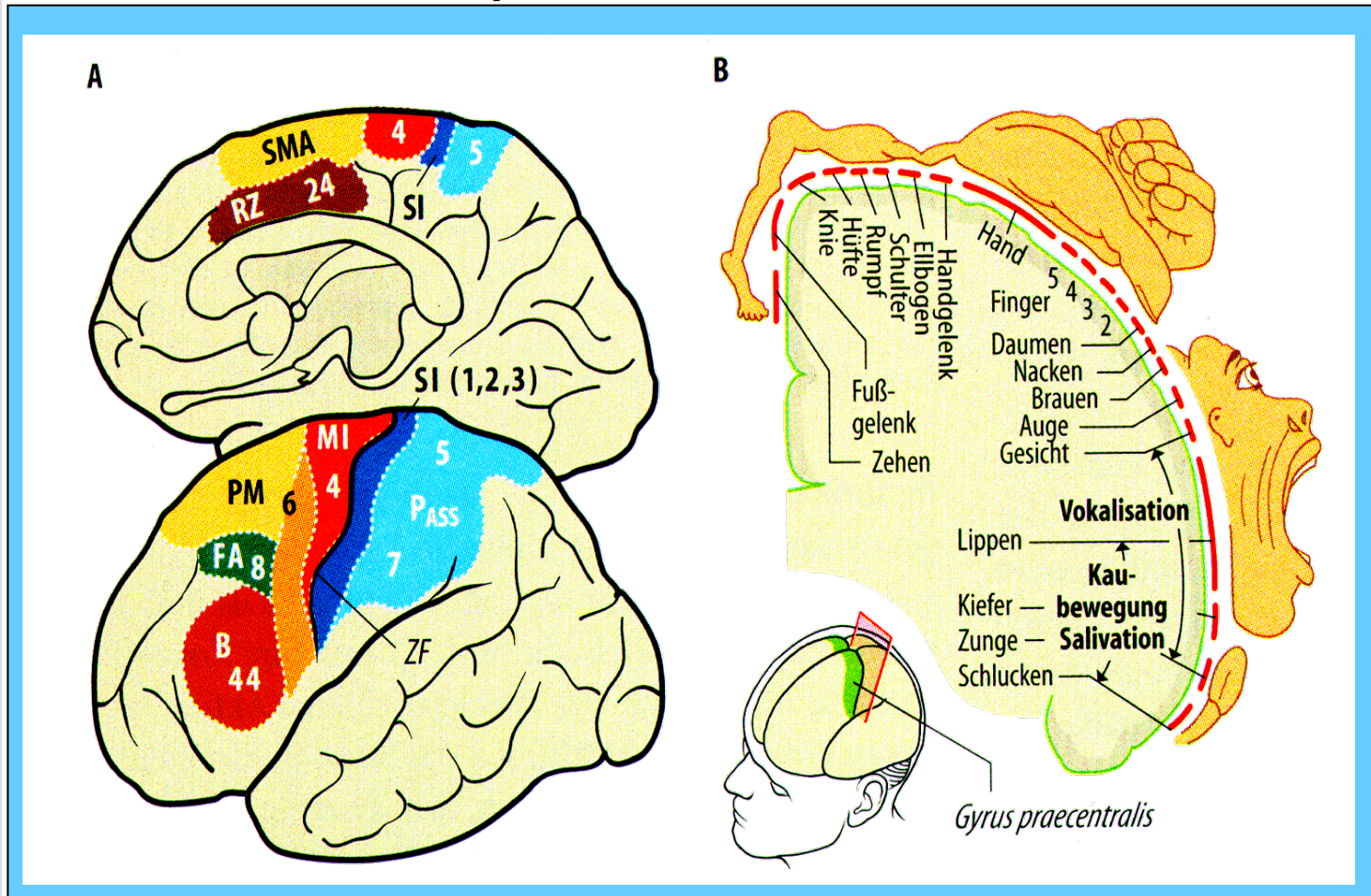
fMRI

fMRI ↔ EEG

Examples

Discussion

■ Hand, foot, lip



Introduction

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BOLD-Effect

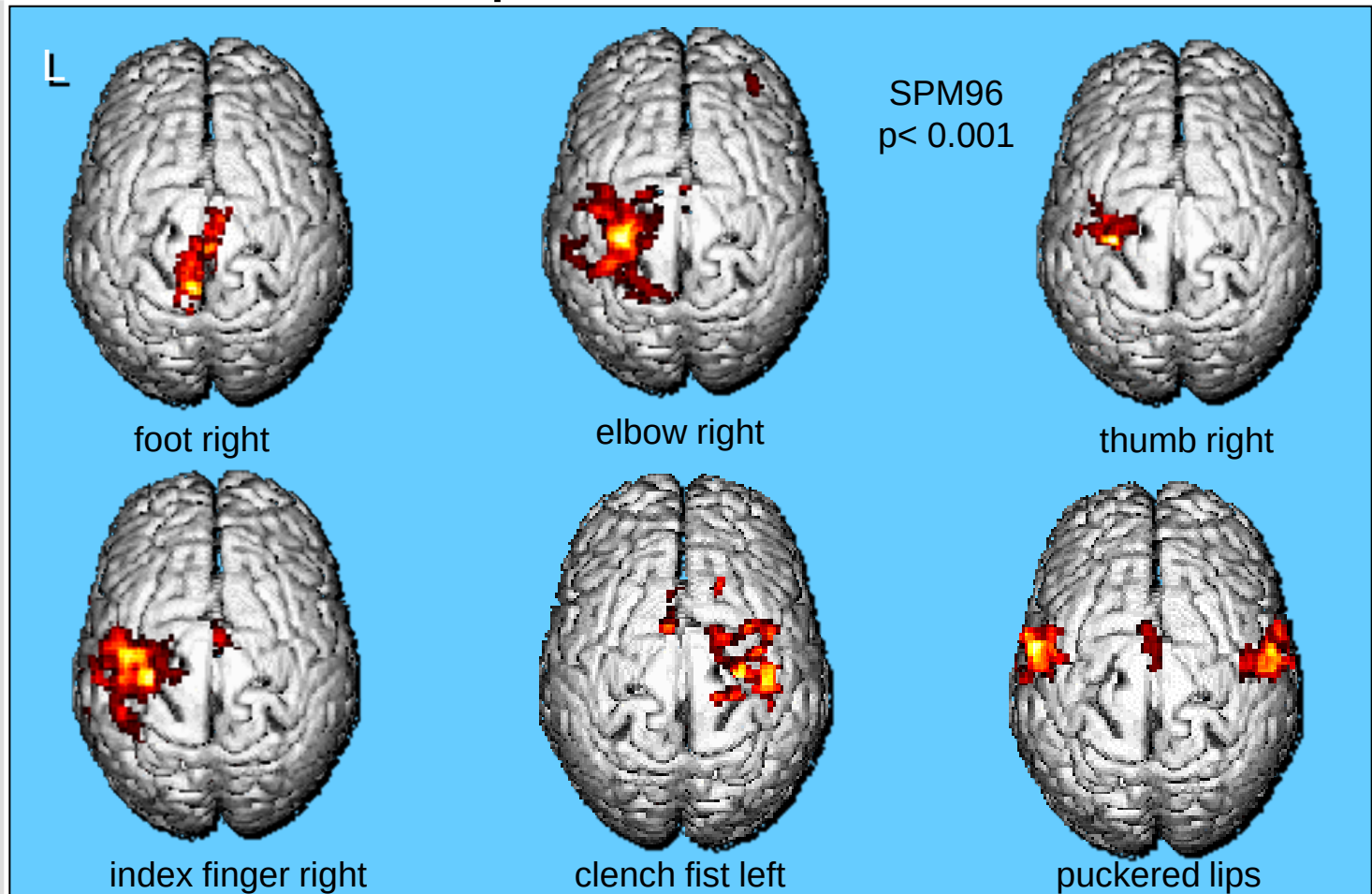
fMRI

fMRI ↔ EEG

Examples

Discussion

■ Hand, foot, lip



Lotze M. et al: *NeuroImage* 11: 473-481 (2000)

Introduction

Brain Theory

MR Images

BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion

- Average of signals relative to stimulation events
- EEG
 - „event related potential“ (ERP)
- fMRI
 - „event related BOLD-signal“ (ERB)

Question: When are which areas involved?



Introduction

Brain Theory

MR Images

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fMRI

fMRI ↔ EEG

Examples

Discussion

- Planning and execution of voluntary movement requires a balanced interplay of the different motoric involved brain regions.

These are:

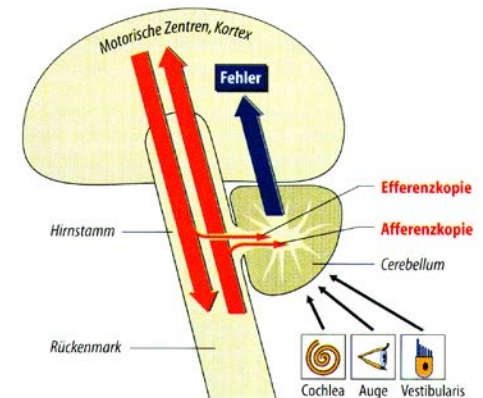
- Supplementary motor area (SMA)
- Pre-motor cortex (PM)
- Primary motor cortex (M1)
- Primary somatosensory cortex (S1)
- Basal ganglia (BG)
- **Cerebellum (CB).**

- Classical model:

- The CB is a planning- and storing matrix for sensomotoric tasks (Reafference copy). As the CB cannot be investigated with EEG and MEG, it is still unclear at which time points and in which amount the CB is involved in voluntary movement and cognitive tasks.

- Hypothesis

- In a complex task with sensory, cognitive and motoric aspects (e.g. a voluntary movement), the Cerebellum is activated at different time points (from lateral to medial).





fMRT Experiment



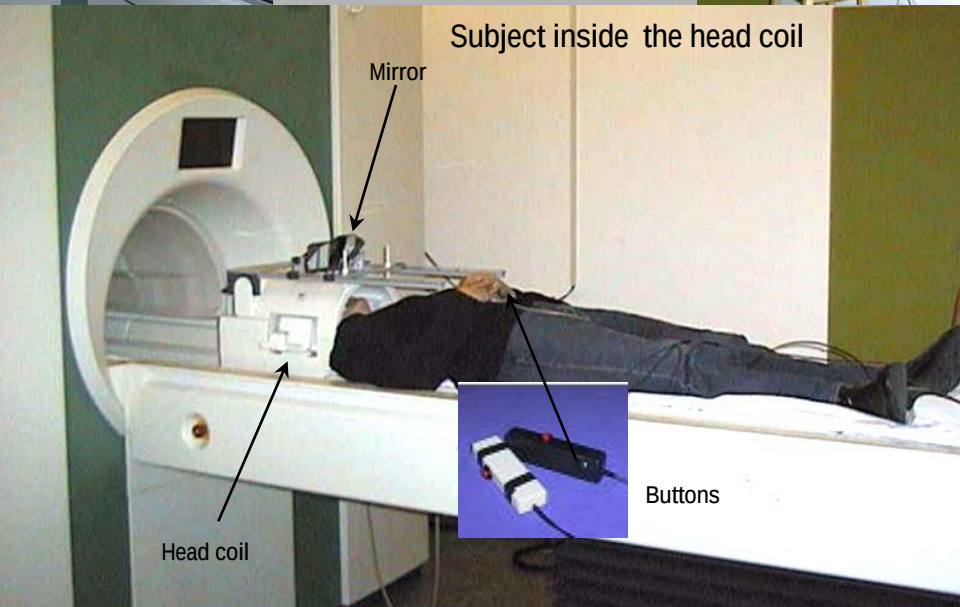
projection to screen

Experiment Setup

video projector



Subject inside the head coil



Paradigm

1.



flash

2.



direction
indicator

3.



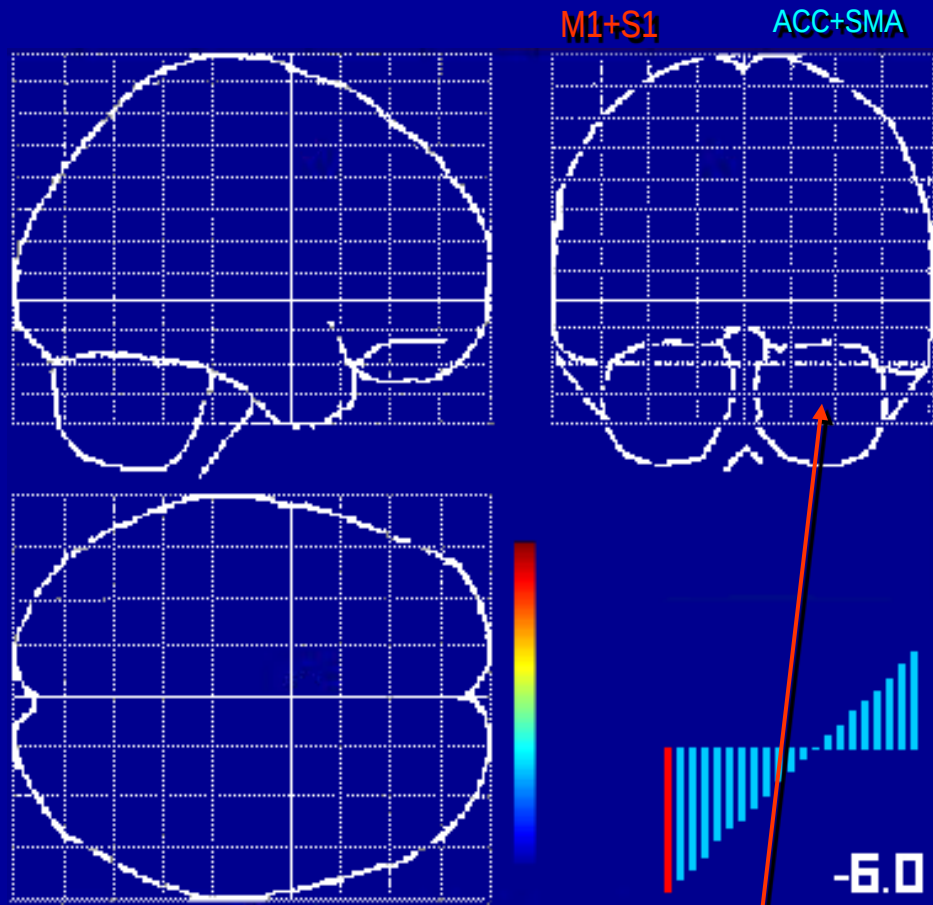
delay time
(0-15 sec.)

4.



movement

Dynamic analysis



SPM99; $p < 0.05$; corrected; $n = 10$

re CB

Analysis program SPM8 (SPM12)

Introduction

Brain Theory

MR Images

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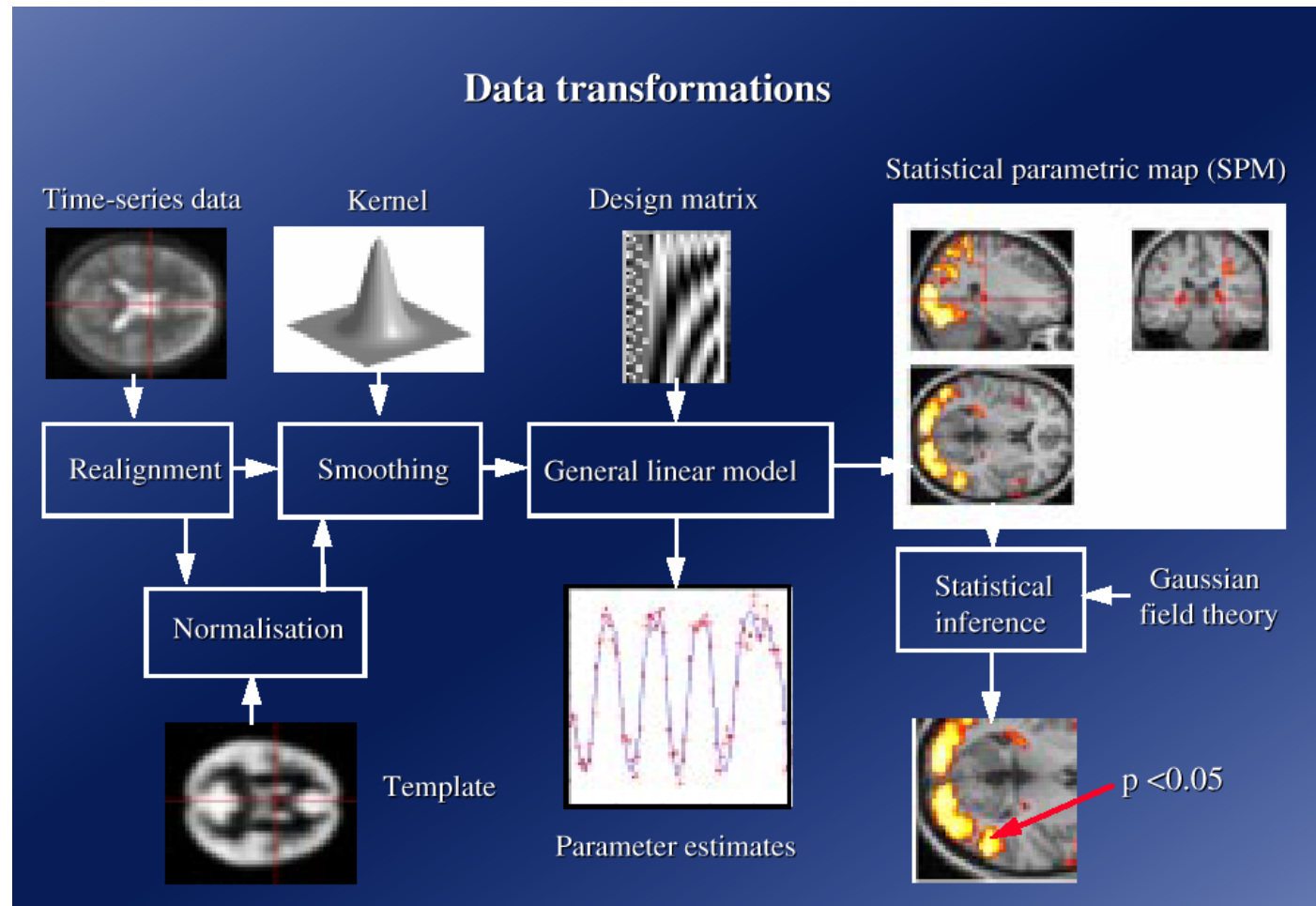
fMRI

fMRI ↔ EEG

Examples

Discussion

- SPM: Statistical parametric mapping (Friston et al., London)



Introduction

Brain Theory

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fMRI

fMRI ↔ EEG

Examples

Discussion

- Analysis with SPM99
 - Slice time correction
 - Movement correction (realignment)
 - Nonlinear normalization to EPI-Template (MNI space)
 - Interpolation 2x2x2 mm³ voxel
 - Smoothing with Gaussian filter (6 mm FWHM)
 - General linear model
- Evaluation of logfiles: onset times
- Calculation of models with different time delays
 - Time points (-6s, -5s, -4s, -3s, -2,5s, -2s, -1,5s -1s, -0,5s, 0s, 0,5s, 1s, 2s, 3s, 4s)
 - t-maps (group) with threshold $p < 0.05$ corrected

Time points of activation maxima



Introduction

■ Button press right

Brain Theory

MR Images

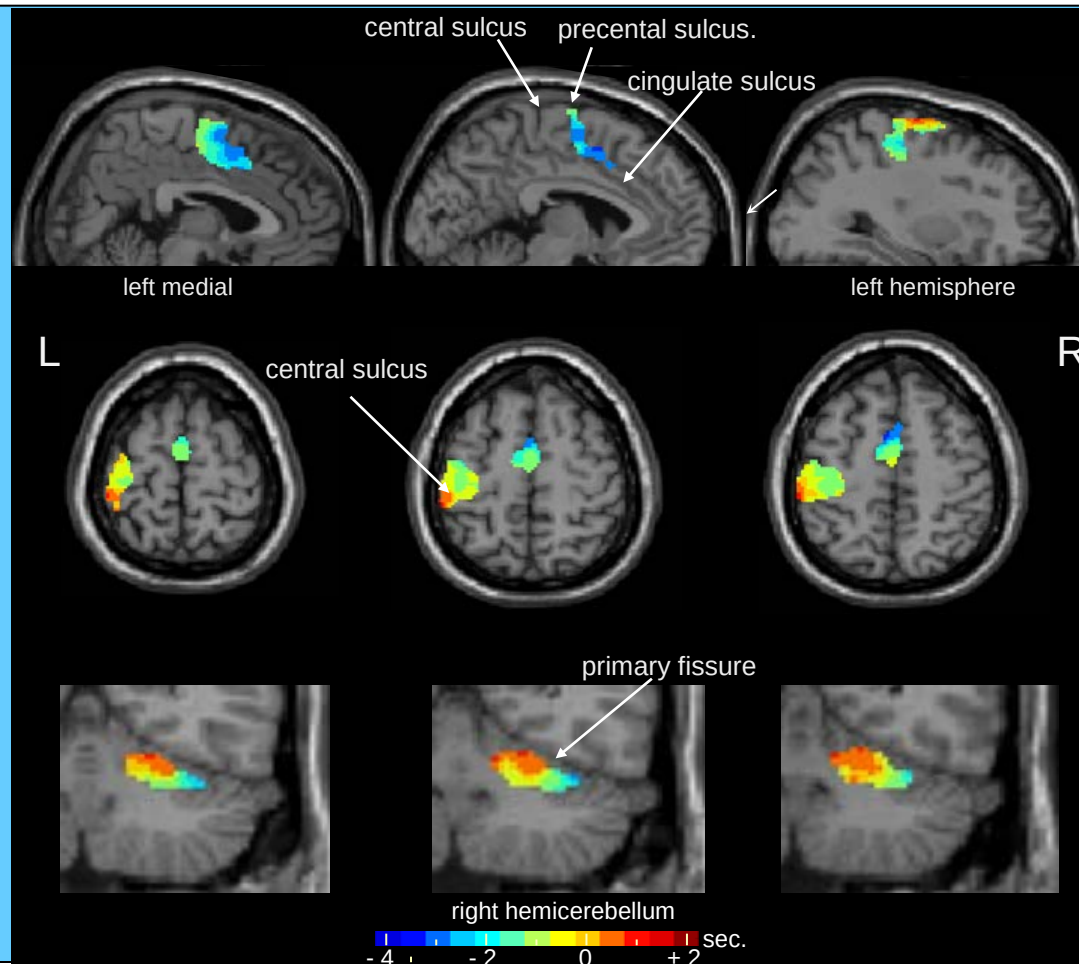
BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion



Delay maps of hemodynamic response



Introduction

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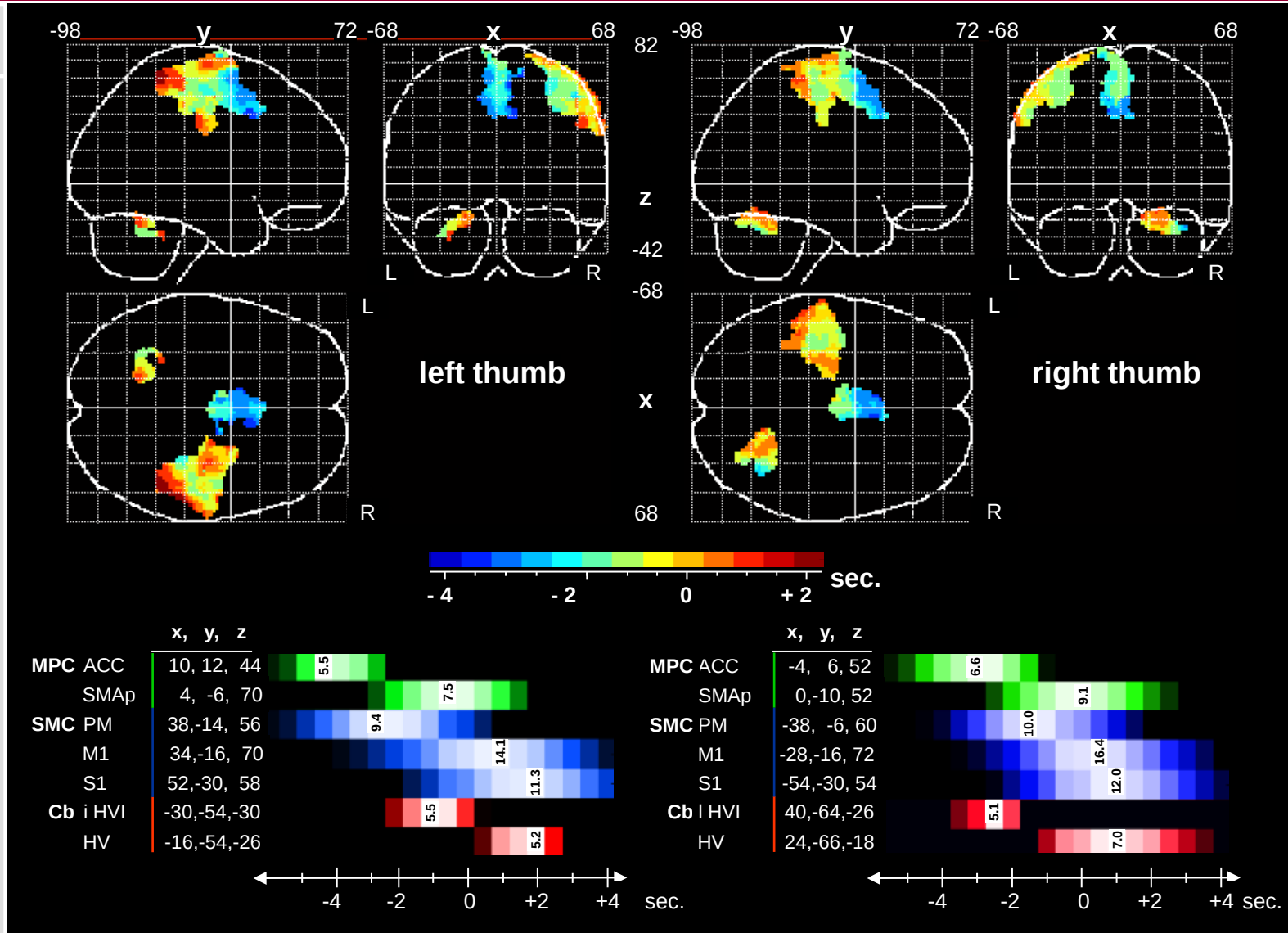
BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion



Introduction

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fMRI

fMRI ↔ EEG

Examples

Discussion

- It was possible to show a sequential activation of motoric brain areas
- We found a contralateral activation in the order known from electrophysiology: pre SMA, SMA, M1 und S1.
- In addition, the ipsilateral cerebellum shows a temporal dependent activation in the early and late phase of the movement.
- The lateral CB corresponds with SMA (involved in planning of movement), whereas the medial CB may reflect the somatosensory reafference.

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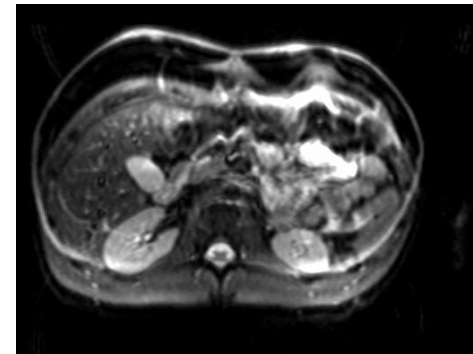
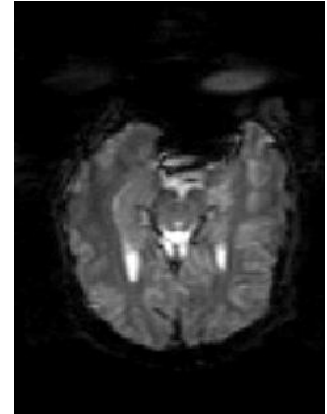
fMRI

fMRI ↔ EEG

Examples

Discussion

- Distortions and signal dropouts caused by inhomogeneous static field (B_0)
- Inhomogeneity of signals caused by inhomogeneous coil sensitivity
- Nyquist ($N/2$) ghost caused by asymmetry of odd and even echoes
- Shifted fat images caused by chemical shift
- Signal changes caused by head movement (most important)
-> realignment and movement regressors



Artifacts with gradient echo EPI for fMRI



Introduction

Brain Theory

MR Images

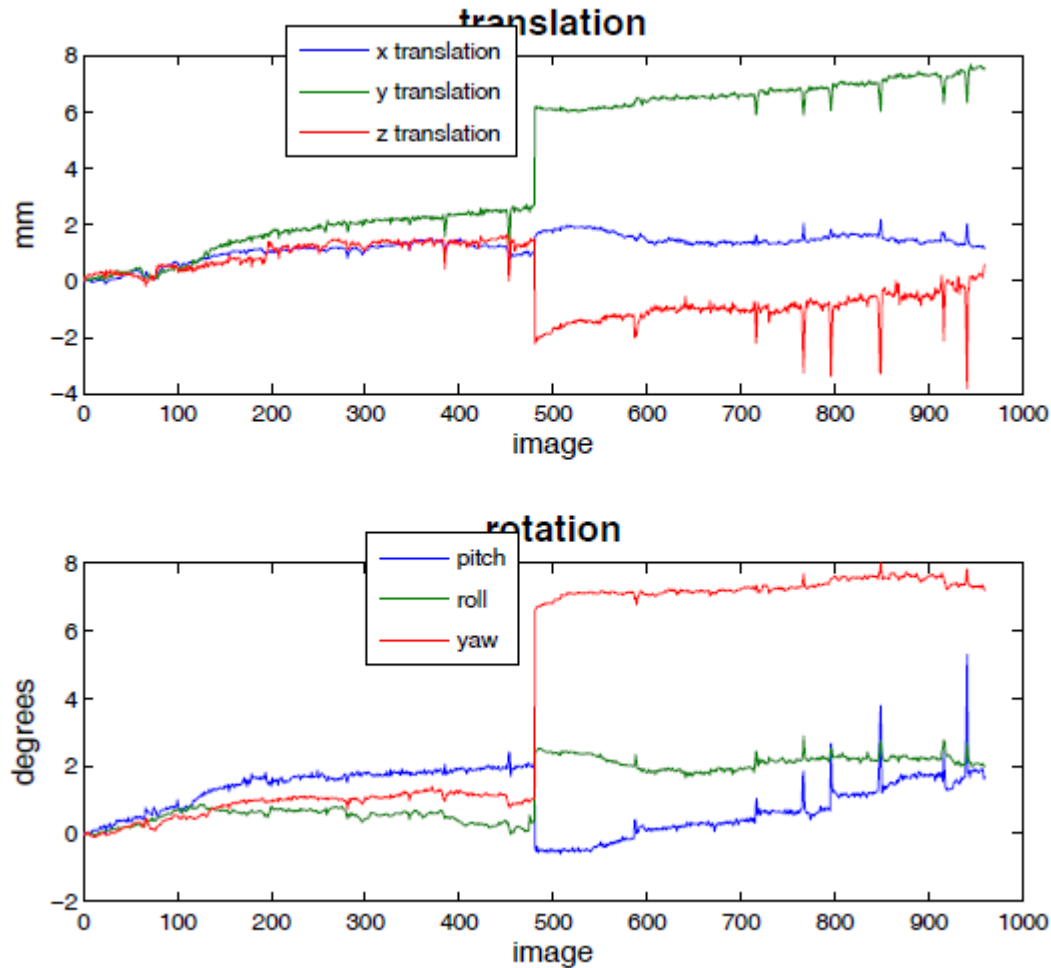
BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion



Introduction

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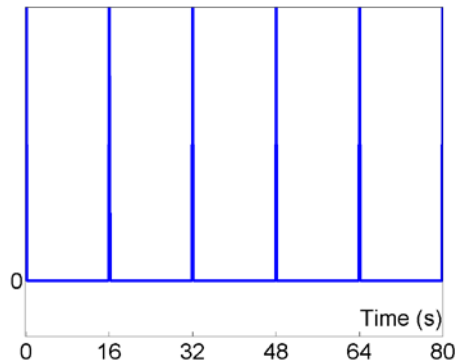
fMRI

fMRI ↔ EEG

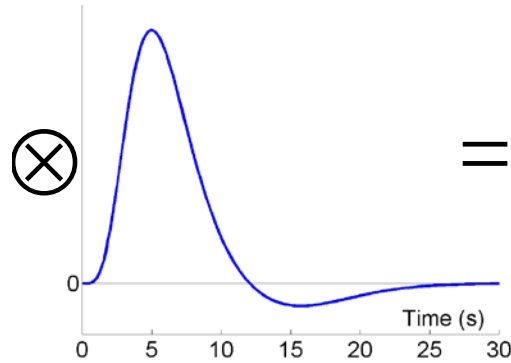
Examples

Discussion

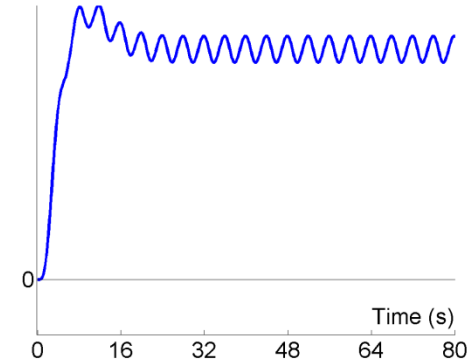
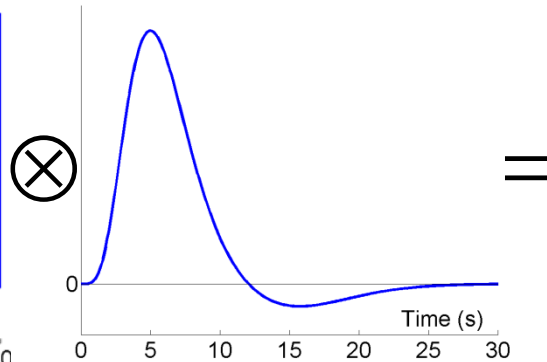
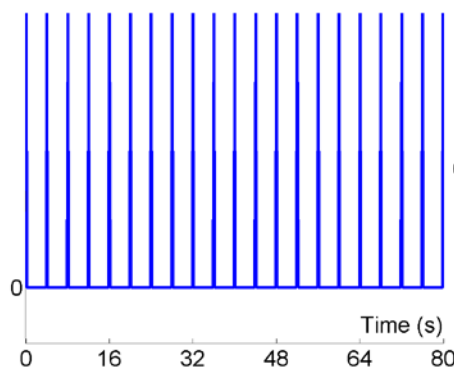
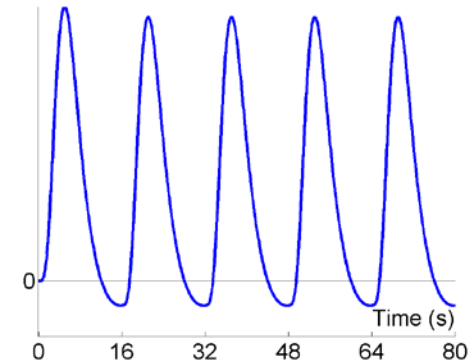
Stimulus (“Neural”)



HRF



Predicted Data



Efficiency of fMRI designs



Introduction

Brain Theory

MR Image

BOLD-Effect

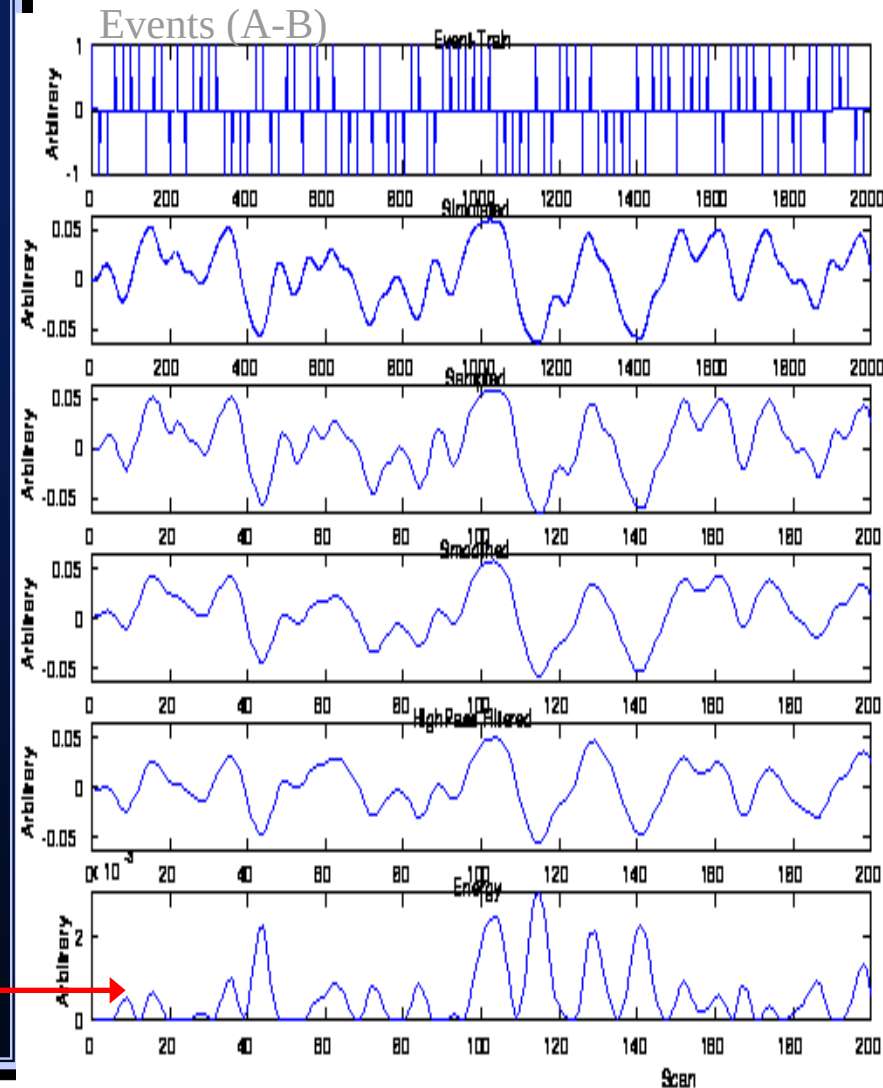
fMRI

fMRI ↔ E

Examples

Discussion

- $T = c^T \beta / \text{std}(c^T \beta)$
- $\text{std}(c^T \beta) = \sqrt{\sigma^2 c^T (X^T X)^{-1} c}$ (i.i.d)
- For max. T , want min. contrast variability (Friston et al, 1999)
- If assume that noise variance (σ^2) is unaffected by changes in X ...
- ...then want maximal efficiency, e :
- $$e(c, X) = \Sigma \{ c^T (X^T X)^{-1} c \}^{-1}$$
- = maximal bandpassed signal energy (Josephs & Henson, 1999)



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Examples

Discussion

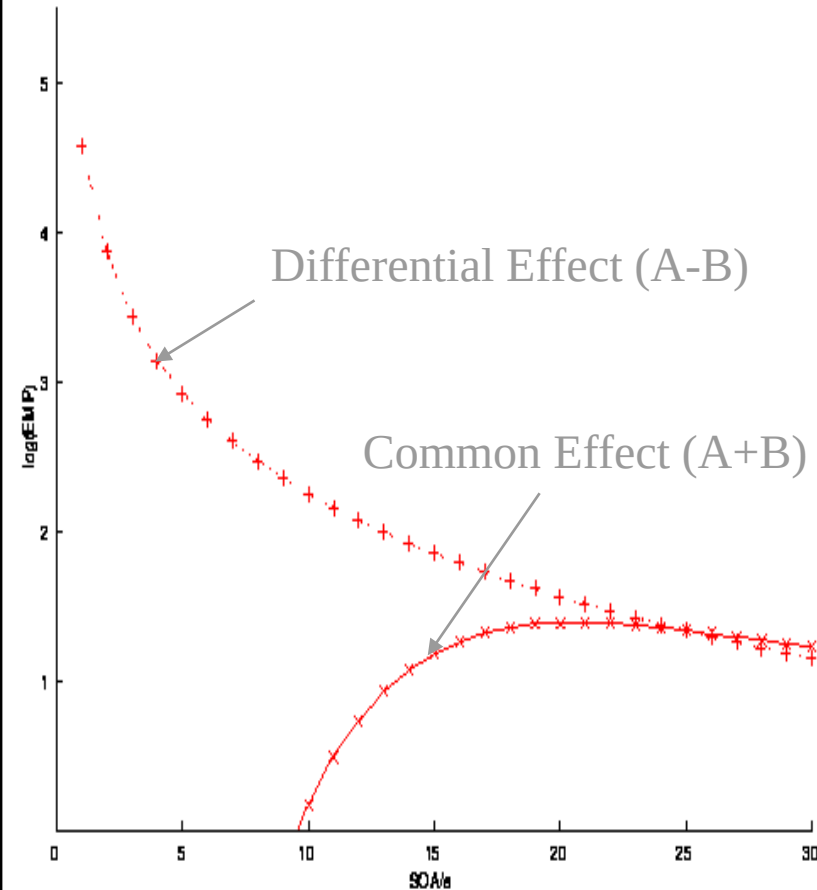
- Design parametrised by:
 SOA_{min} Minimum SOA
 $p_i(\mathbf{h})$ Probability of event-type i given history $\mathbf{h}$ of last m events

- With n event-types $p_i(\mathbf{h})$ is a $n^m \times n$ Transition Matrix

- Example: Randomised AB

	A	B
A	0.5	0.5
B	0.5	0.5

=> ABBBABAABABAAA...



4s smoothing; 1/60s highpass filtering

Efficiency of fMRI designs



Introduction

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MR Images

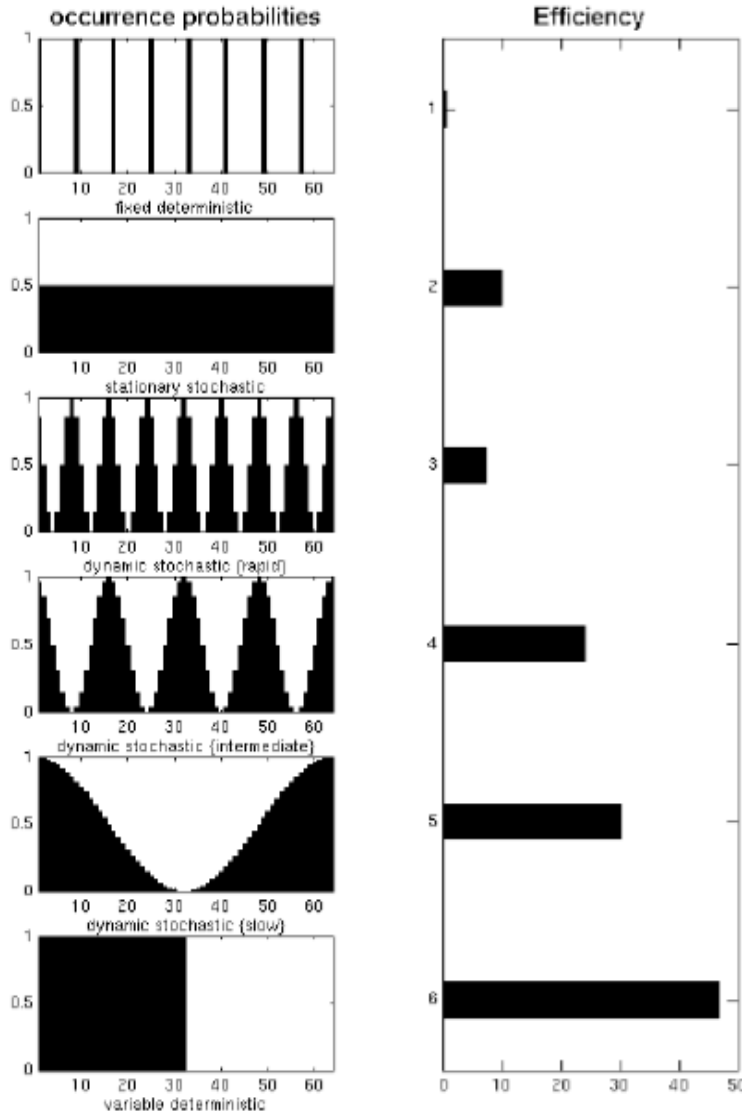
BOLD-Effect

fMRI

fMRI ↔ EEG

Examples

Discussion



- Deterministic model
- Stochastic model with stationary uniform probability
- Sinus modulation (with different frequencies)
- Classical block design

Introduction

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fMRI

fMRI ↔ EEG

Examples

Discussion

- Most efficient design to detect a brain function is block design with 16 - 20s
- If you want to estimate the HRF (or ERB) you can use, a slow event related design
- To differentiate between trial types a fast event related design is more efficient

Experiment for the practical course



- Block design with 5 rest and 4 activation blocks
(10+10+10+10+10+10+10+10+10, TR=2.5s)
- Three conditions: right hand, left hand, imagined movement of left or right hand
- Mind reading!