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EEG/MEG: a contribution of the electromagnetic research to the clinical diagnostics

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TECHNISCHE UNIVERSITÄT ILMENAU

Overview

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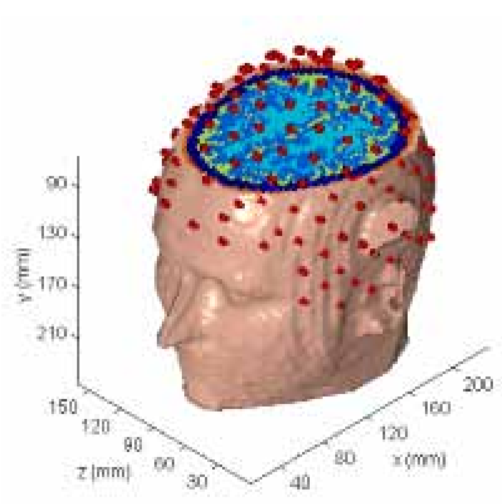
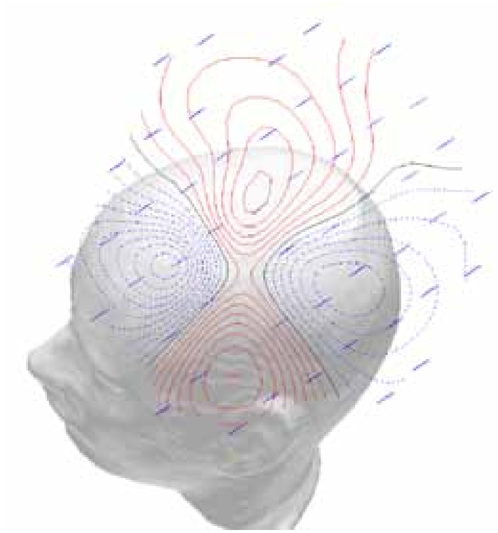
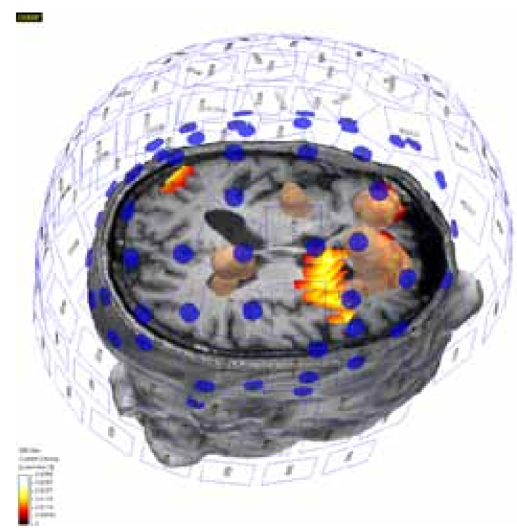
1. Introduction
2. Signal genesis and measurement techniques
3. Influence of anisotropic volume conduction
4. Information transfer in the brain





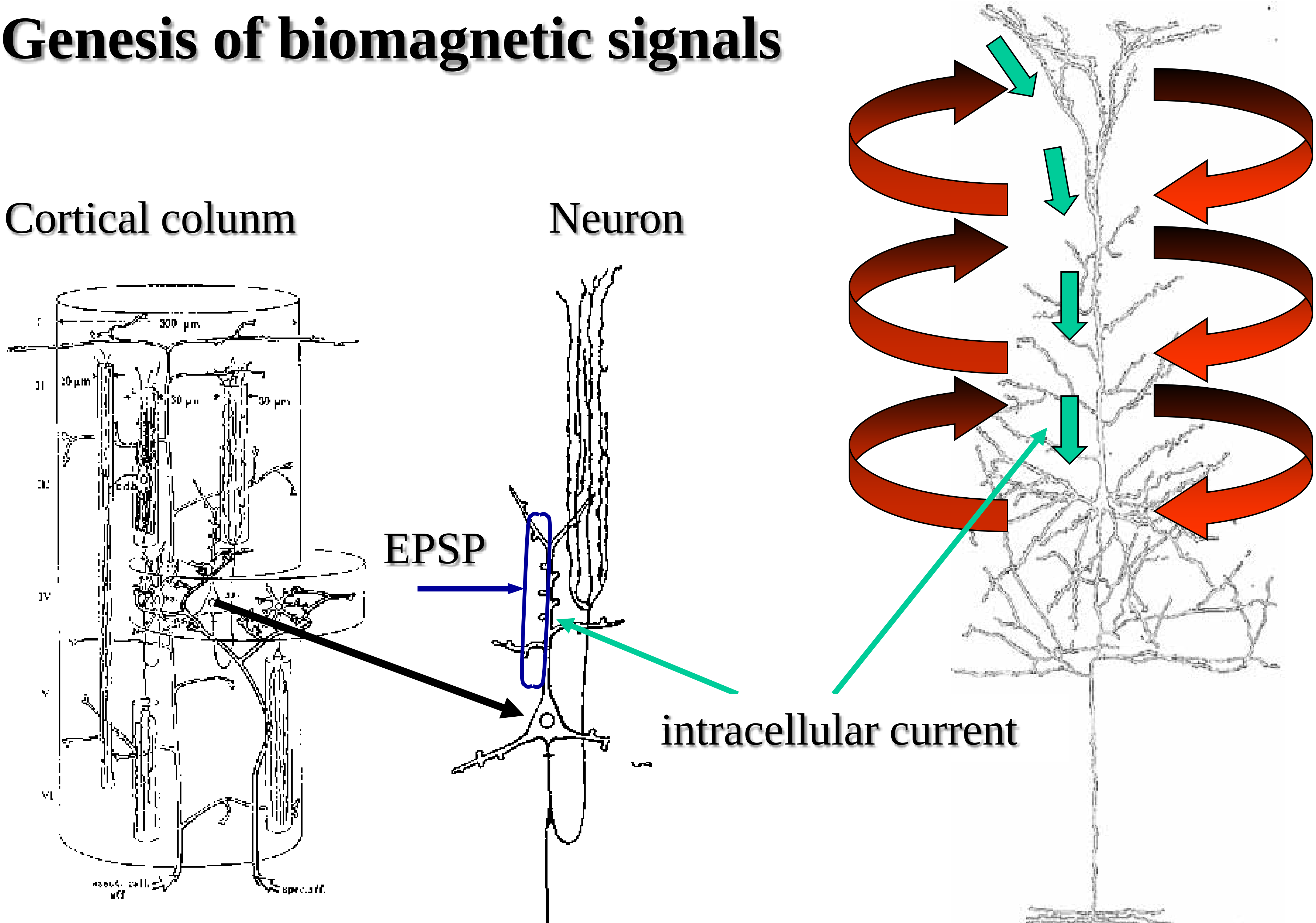


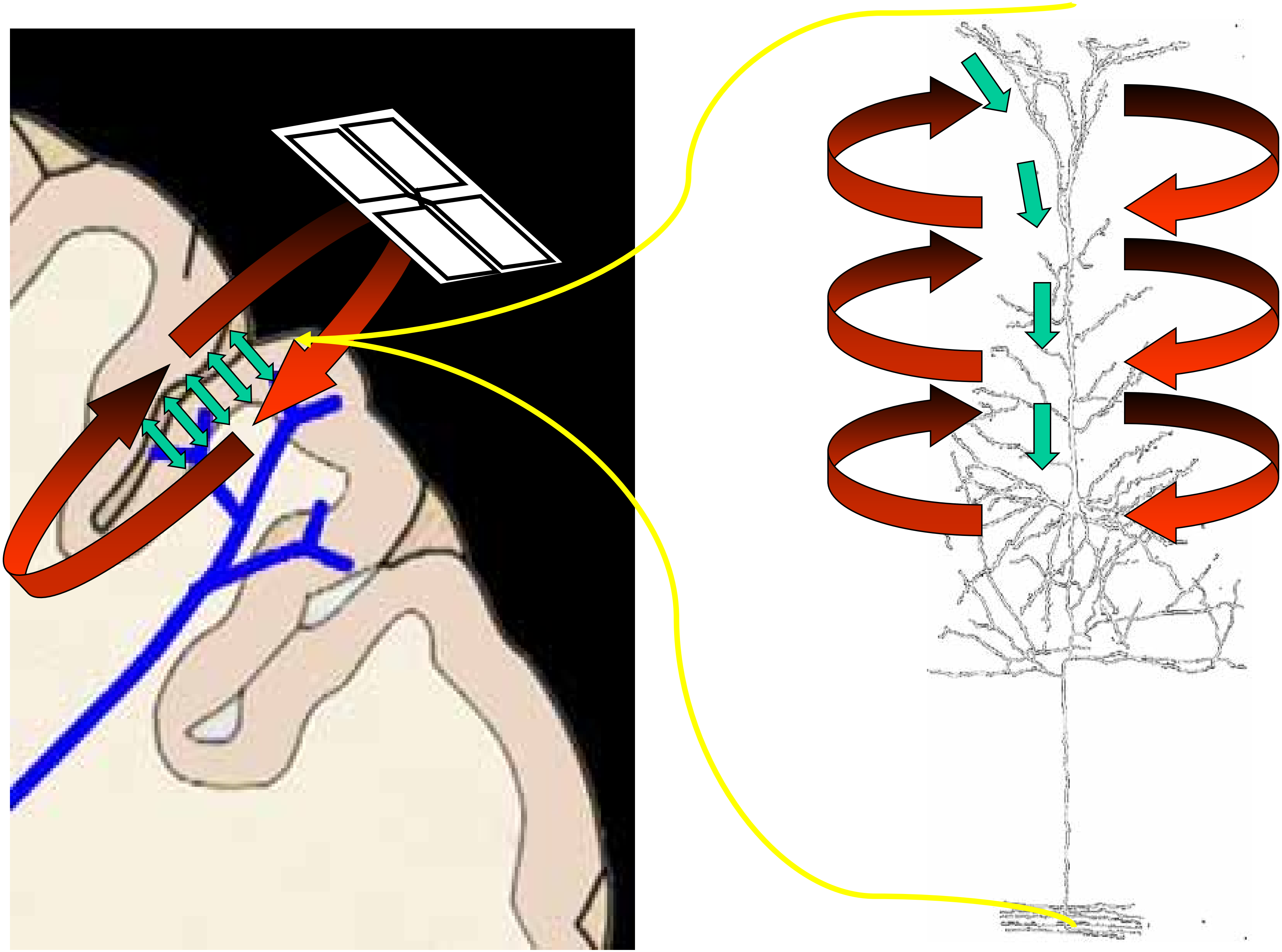
Introduction

Reconstruction of electric current sources in the brain

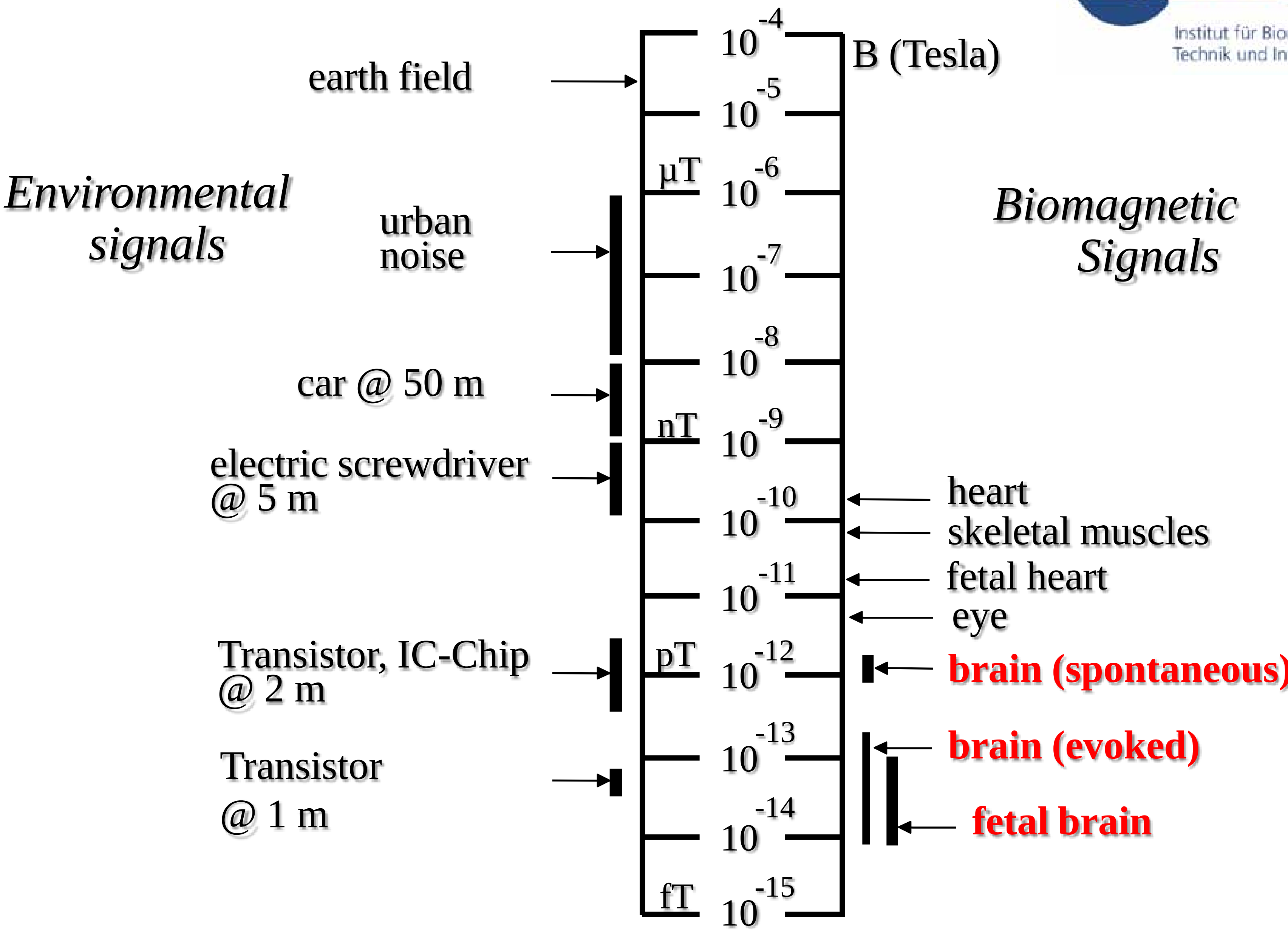
- Basic research: How does the brain work?
- Clinical application: Neurology, Psychiatry, Pediatrics, Cardiology, …
- Other: BCI, Prosthetics, …

Genesis of biomagnetic signals





Amplitudes of the magnetic induction B



Biomagnetometer

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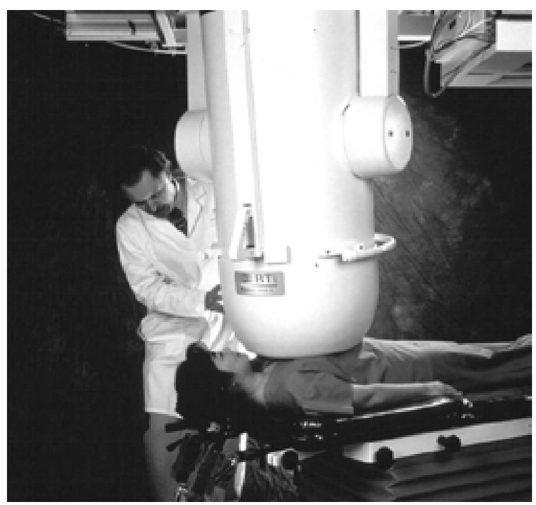
Systems specific for fetal measurements

Multipurpose systems



Systems specific for brain measurements

Andrä & Nowak, Magnetism in Medicine, Wiley, 2007

EEG measurements

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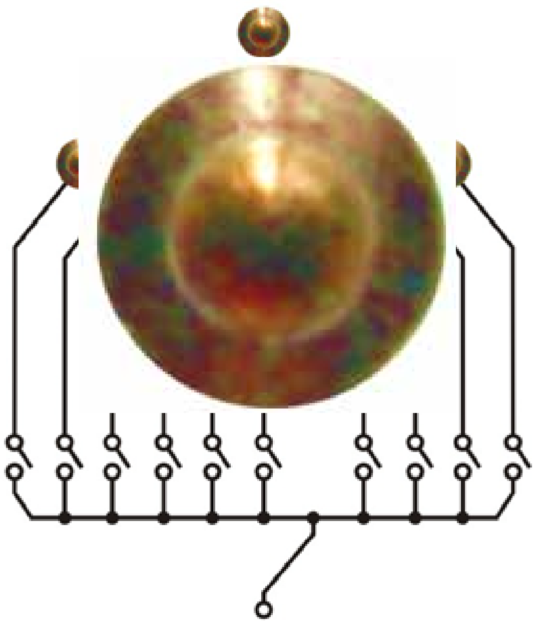
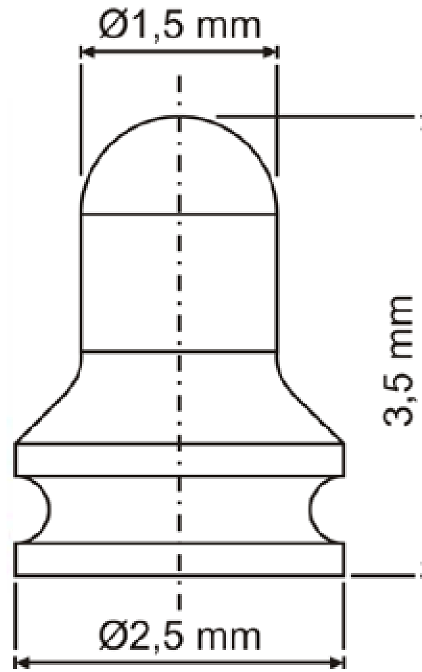


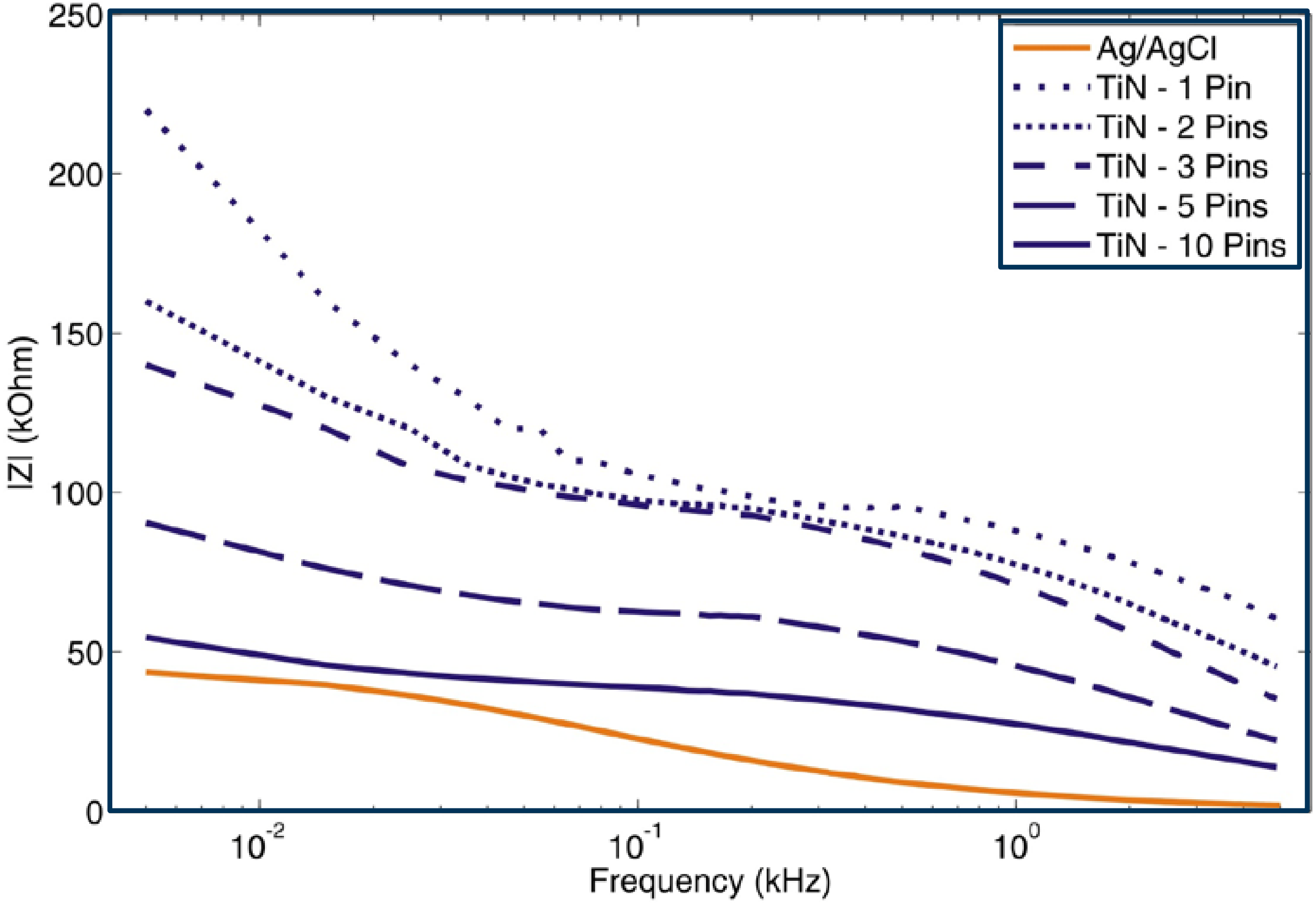


Dry electrodes with TiN nanocoating

Fiedler et al. Meas Sci Tech, 2011, in press

EEG measurements

Impedance measurement



EEG measurements

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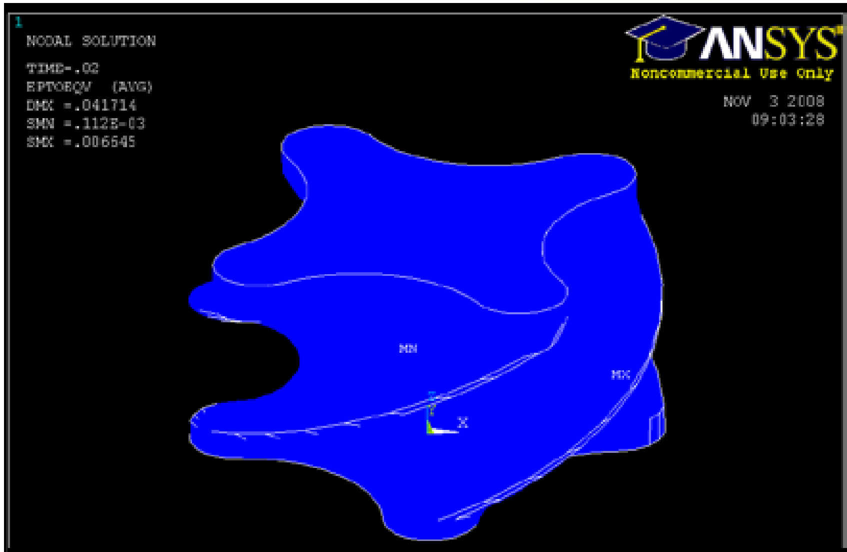
EEG cap

Compliant mechanism for electrode placement



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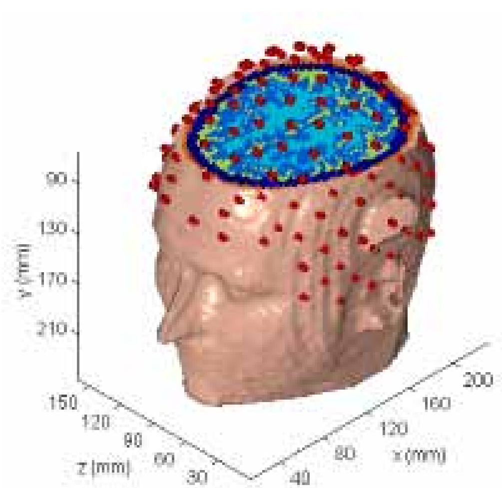

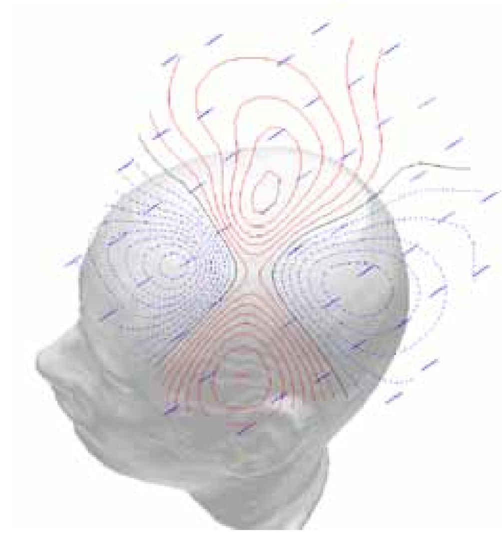

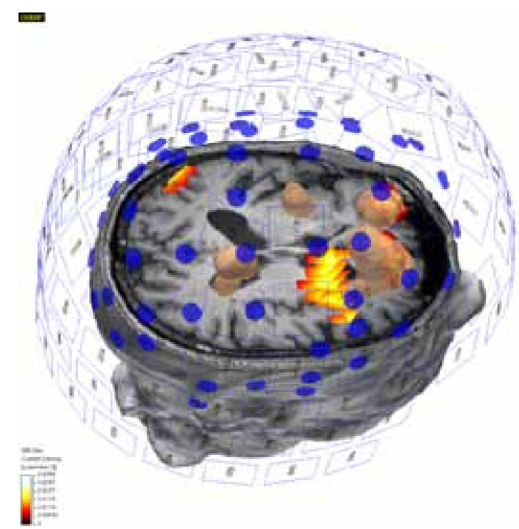

Forward problem

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Computation of field/potential at sensors arising from given sources

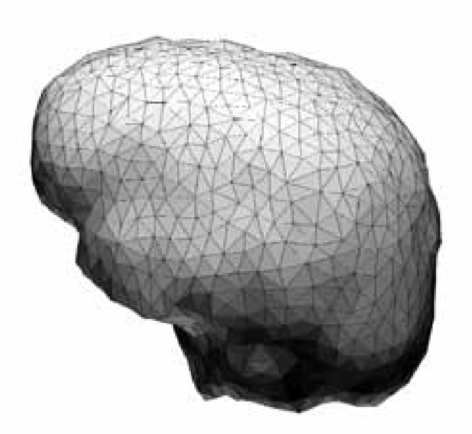
Comparison of numerical methods

2.5-D methods (BEM / MMP)

pro

+ Discretization of surfaces

+ Model construction and computation



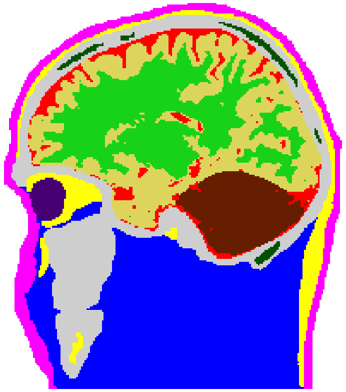
3-D methods (FEM / FDM)

pro

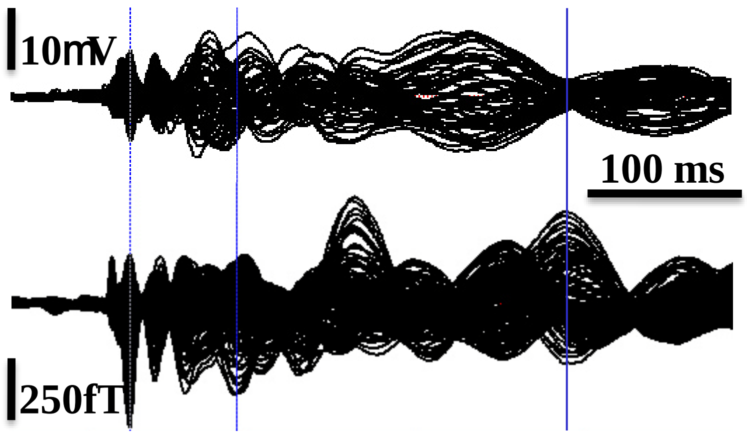
+ Modeling of inhomogeneities

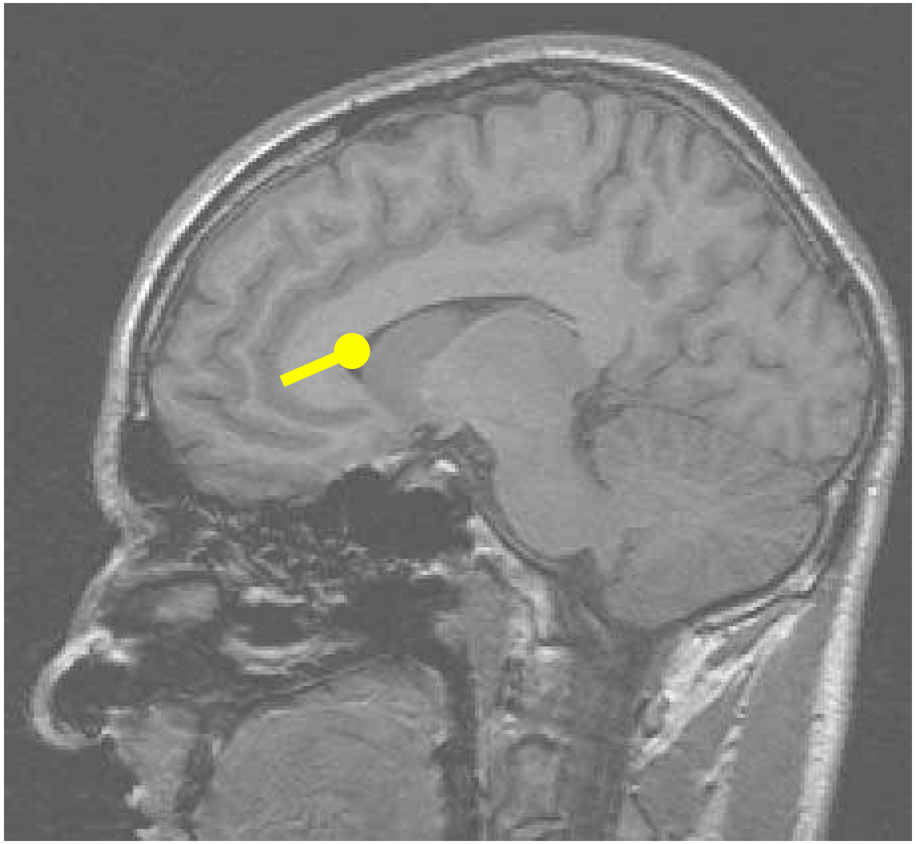
+ Modeling of anisotropy

+ Properties for each element



Introduction





- How does volume conduction influence source estimation?
- How does anisotropy influence source estimation?

SimBio and NeuroFEM

Image Registration (T1, T2, PD)

↓

Segmentation

↓

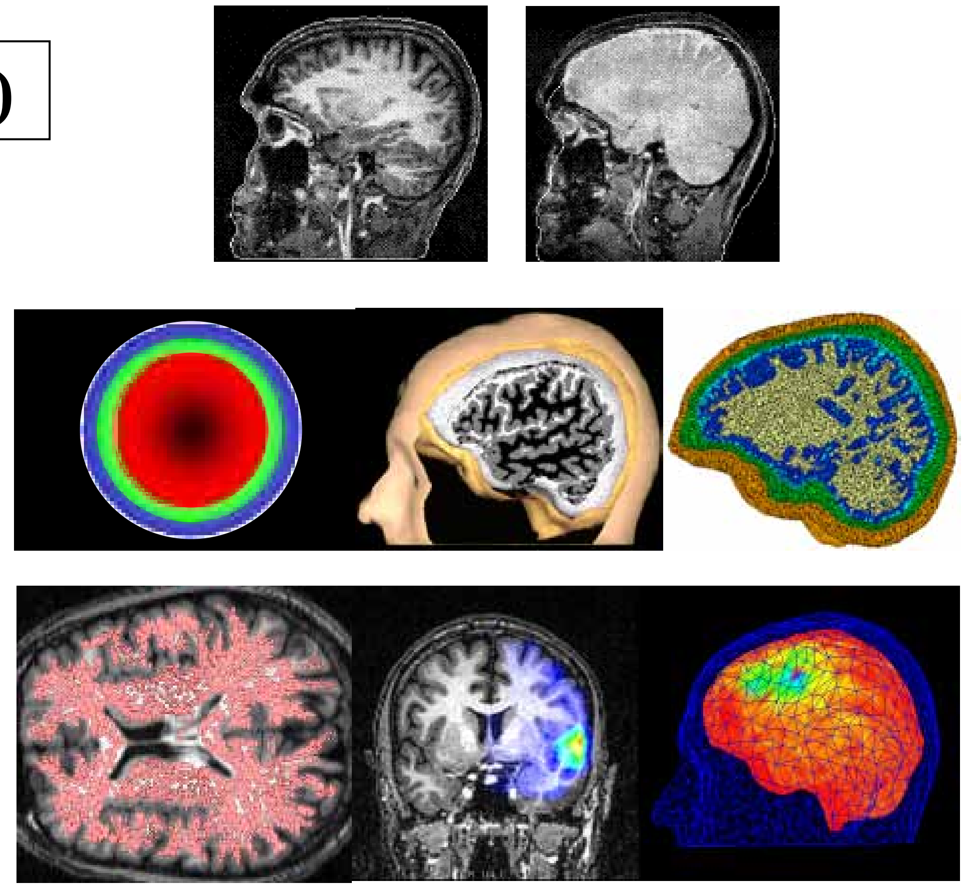
Mesh Generation BEM/FEM

↓

Forward toolbox
Inverse toolbox

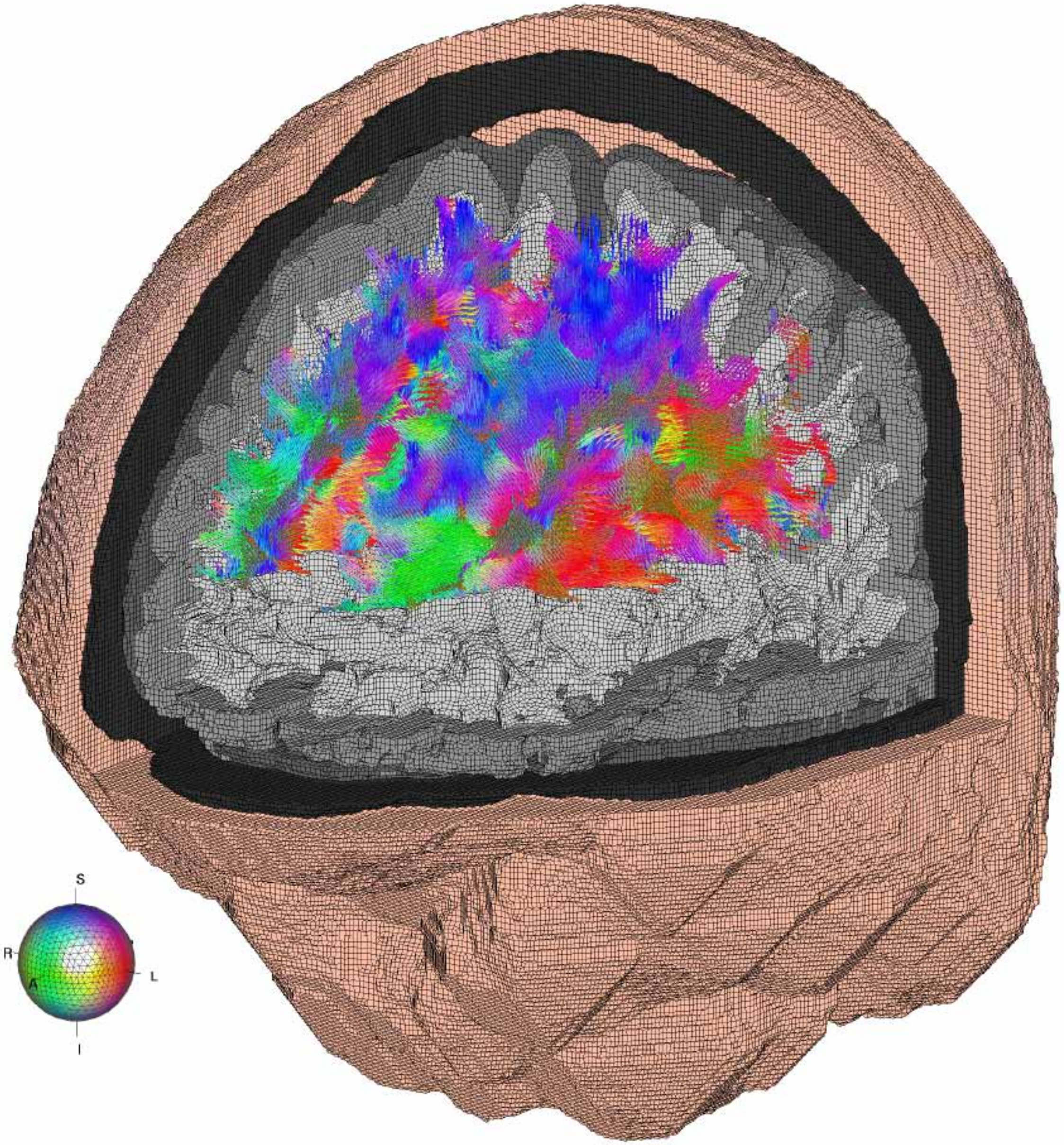
↓

Visualisation

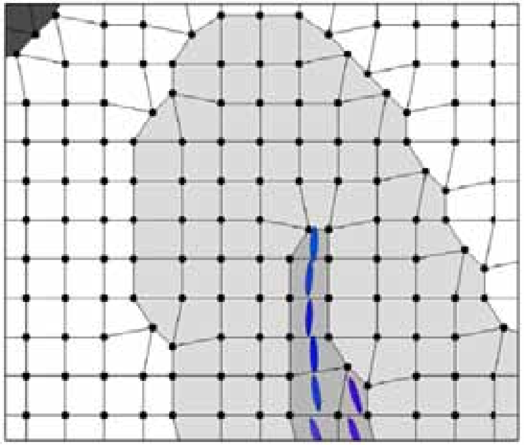


Güllmar et al., IEEE TBME, 53:1841-1850, 2006

SimBio and NeuroFEM



FEM model II
- Resolution of 1 mm³
- 3.2 Mio elements
- Node shift



Wolters et al. IEEE TBME, 54:1446-1453, 2007

Güllmar et al., Neuroimage, 2010

Conductivity and anisotropy data

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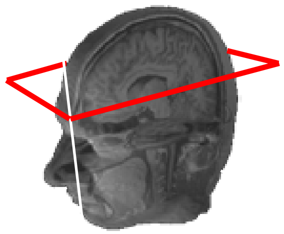
Tensor of conductivity und tensor of diffusion

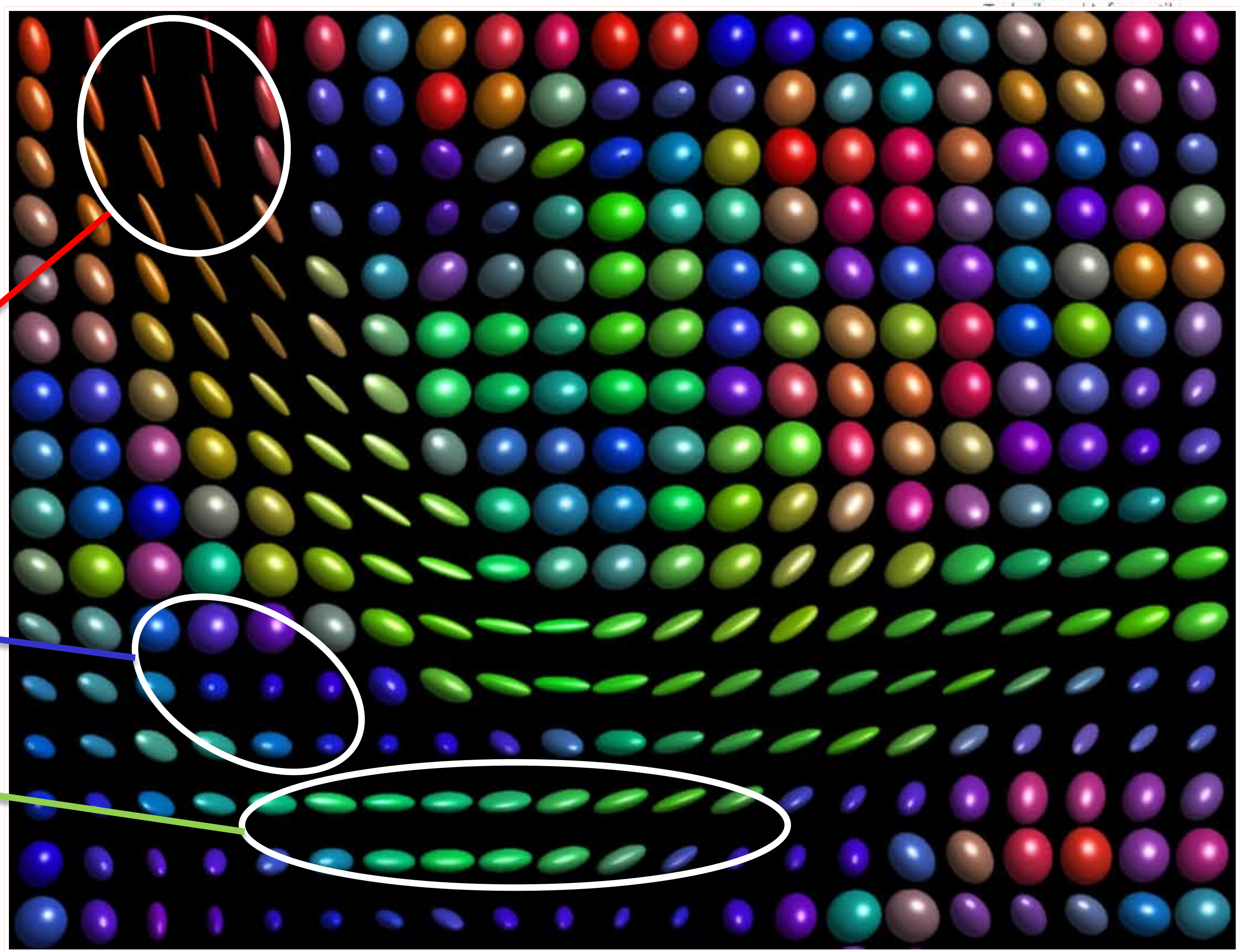
$$s = k \times D$$

$$k = k(s_e, d_e)$$

Tuch et al., PNAS, 98:11697-11701, 2001

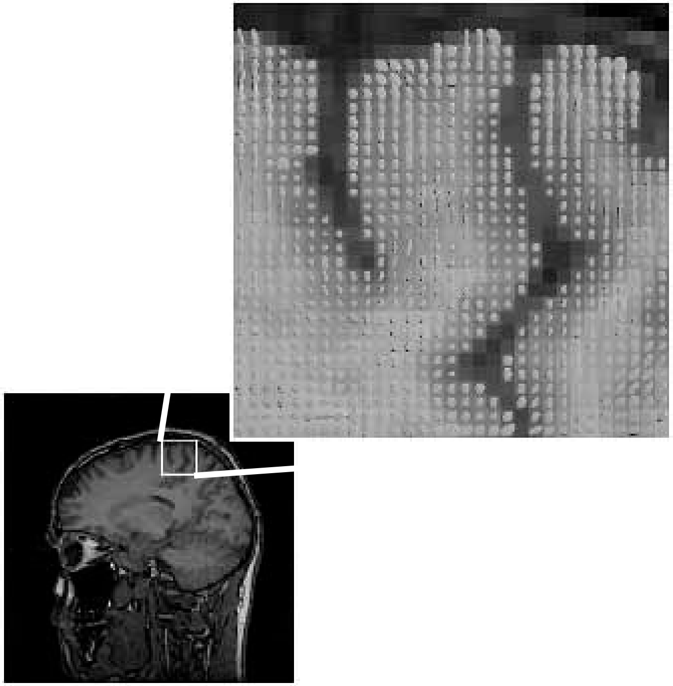
Conductivity and anisotropy data

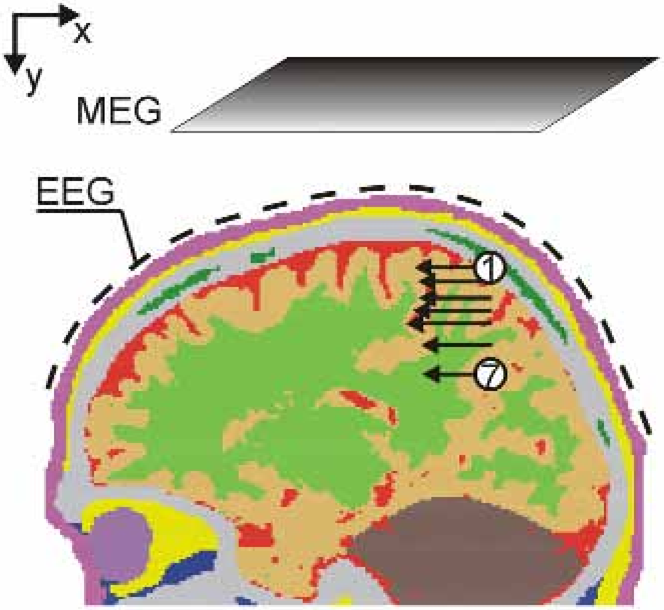




Sensitivity analysis

Forward simulations with isotropic and anisotropic human head models



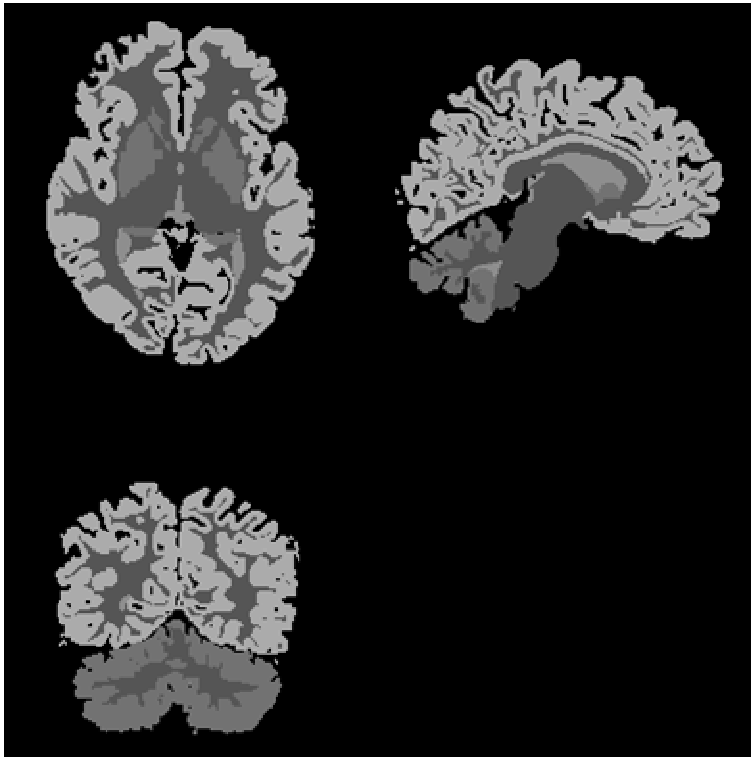


Results:
Correlation:
above 0.98
Magnitude:
more than 50% change

Tissue anisotropy seems to have a minor influence on source localization but a major influence on dipole strength estimation.

Haueisen et al., Neuroimage 15:159-166, 2002

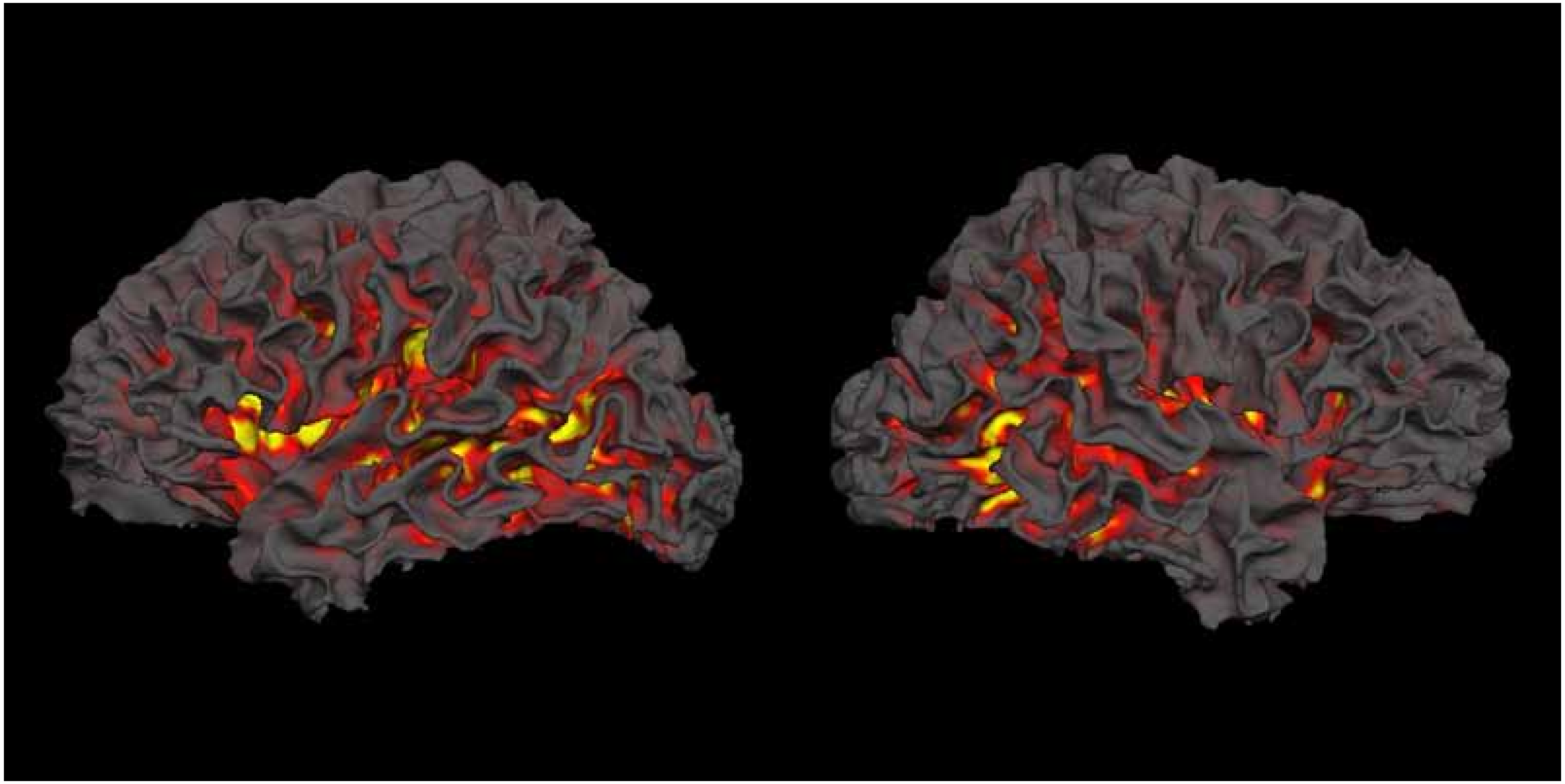
Sensitivity analysis



- 5 tissue types
- 3.2 million cubic elements (1mm)
- 130 electrodes
- 25,000 dipoles perpendicular to cortical surface
- anisotropies of 1:2, 1:5, 1:10 and 1:100

Comparison of isotropic and anisotropic model output by RDM and MAG mapped to each dipole position

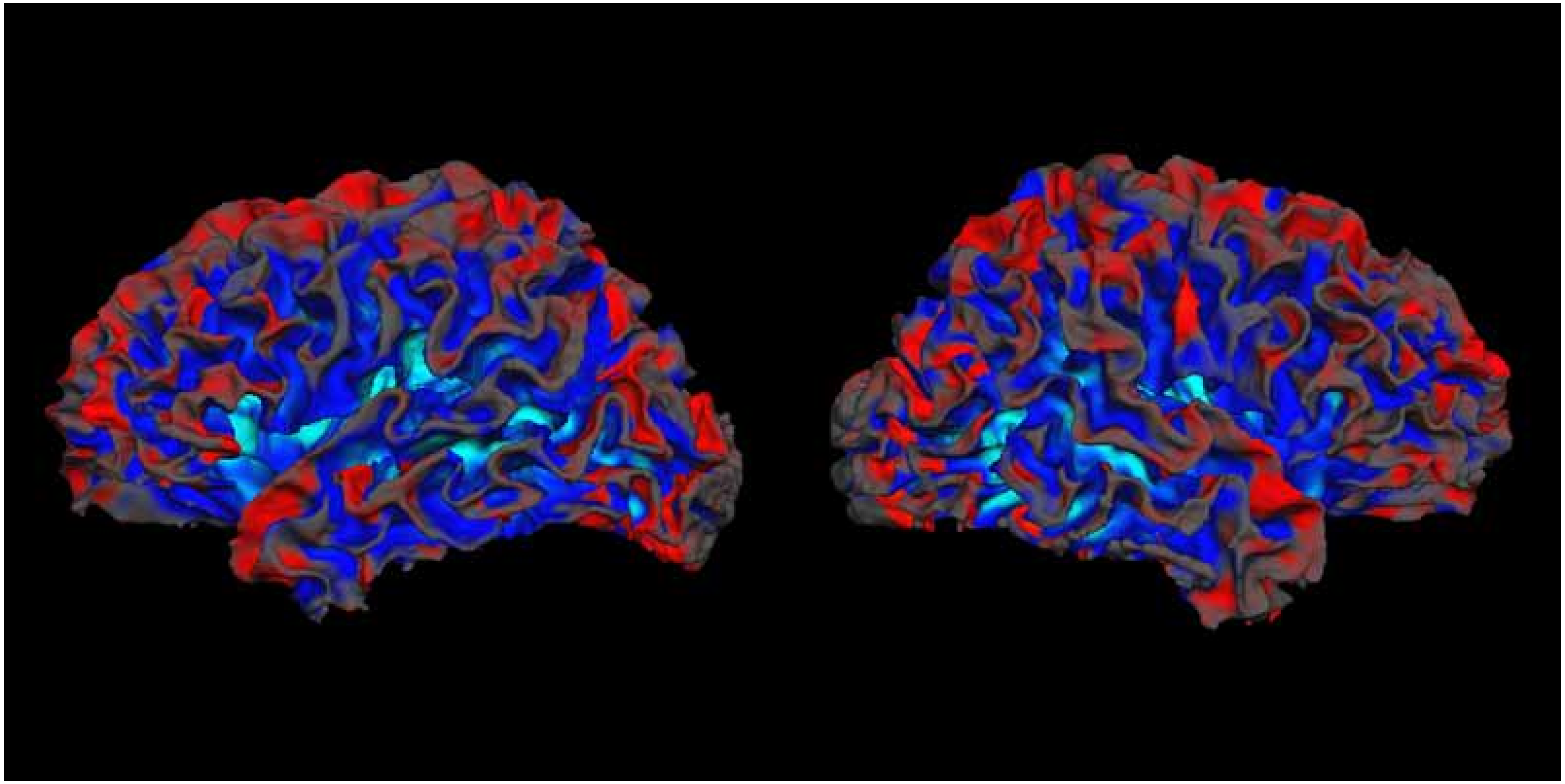
Sensitivity analysis



right hemisphere left hemisphere

Relative Difference Measure – outside view

Sensitivity analysis



right hemisphere

left hemisphere

MAG – outside view

Sensitivity analysis

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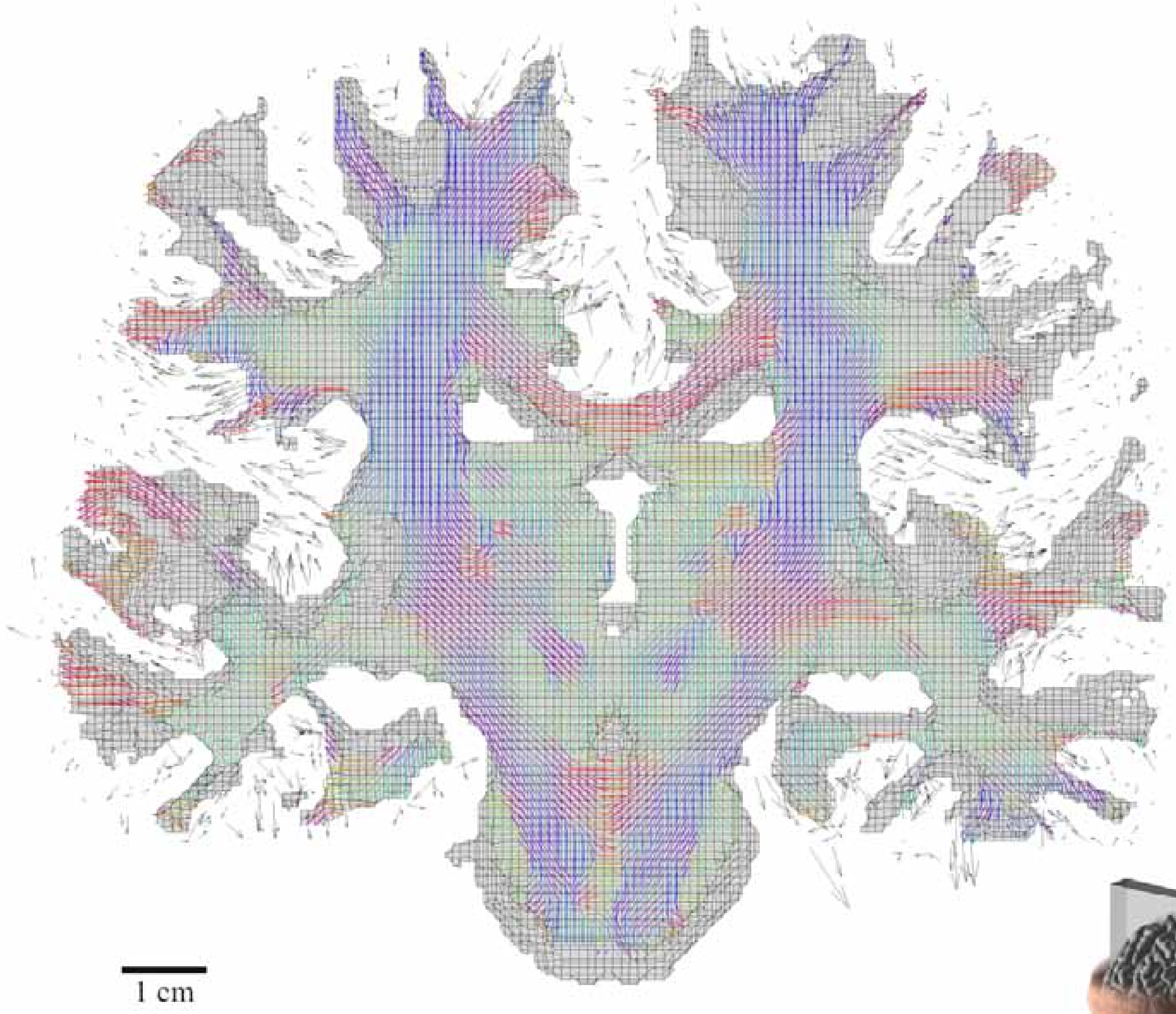

Dipole displacement if neglecting the anisotropic conductivity of 1:10.

Güllmar et al., Neuroimage, 2010

Sensitivity analysis

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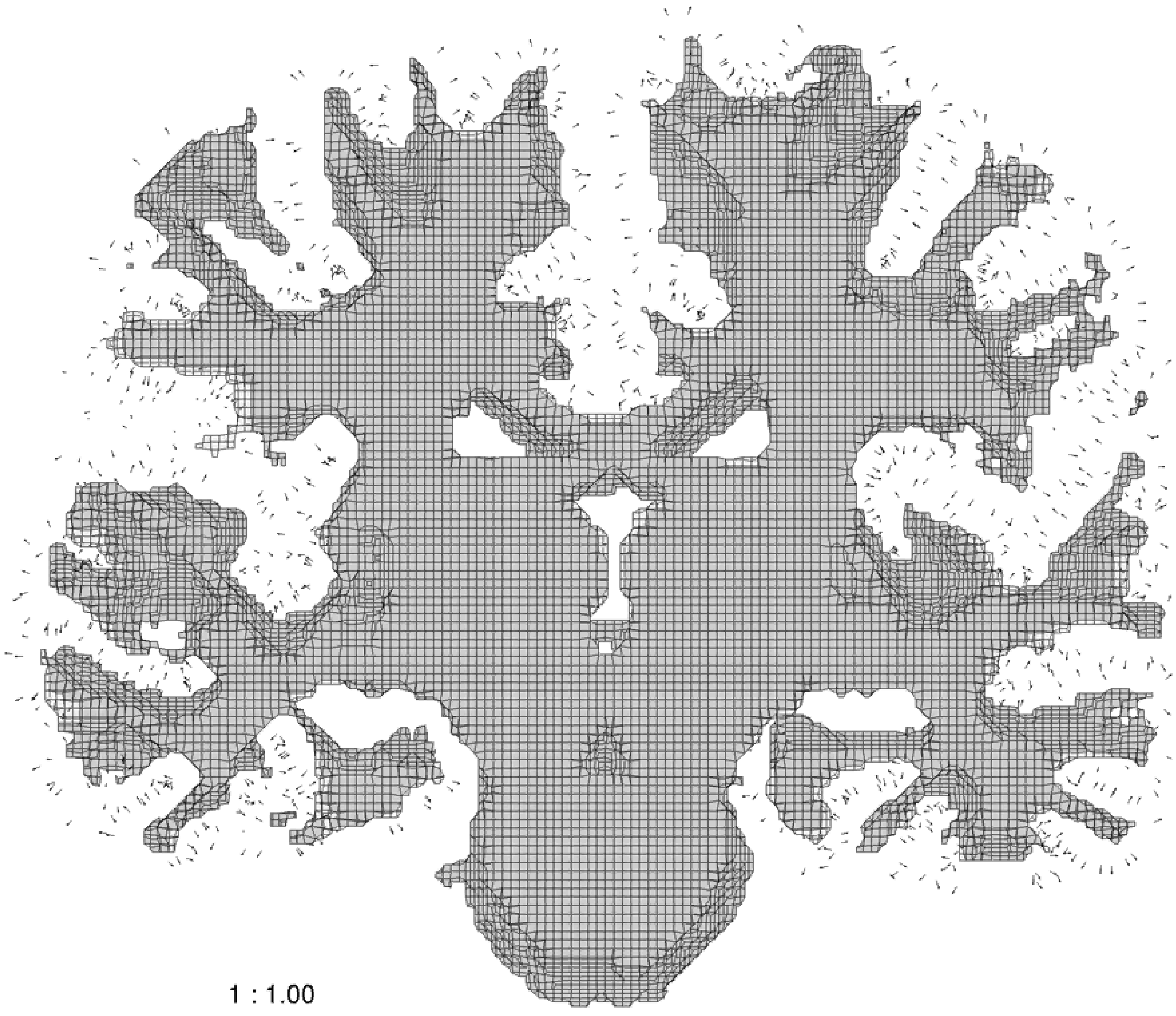
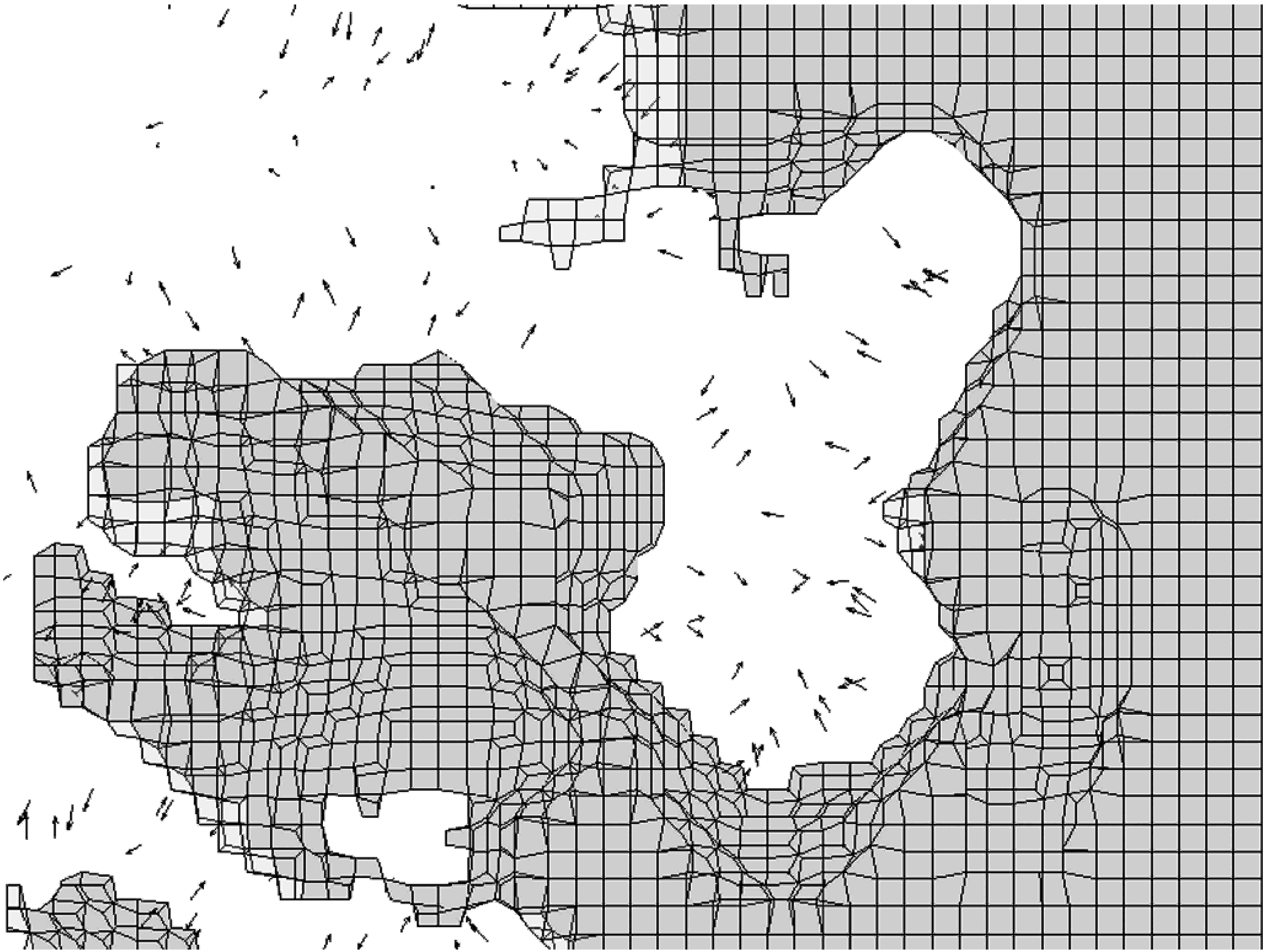


Sensitivity analysis



Conclusions sensitivity analysis

- Anisotropic volume conduction influences source strength and source orientation estimation more than source location estimation.
- Local conductivity properties in the vicinity of the source crucially influence source estimation.
- Model errors both on a local and a global scale are not Gaussian.

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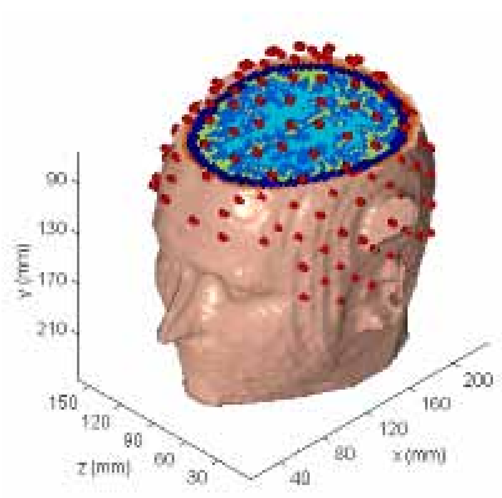

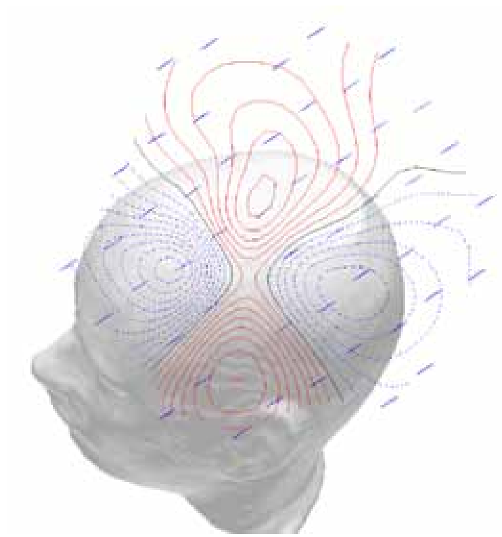

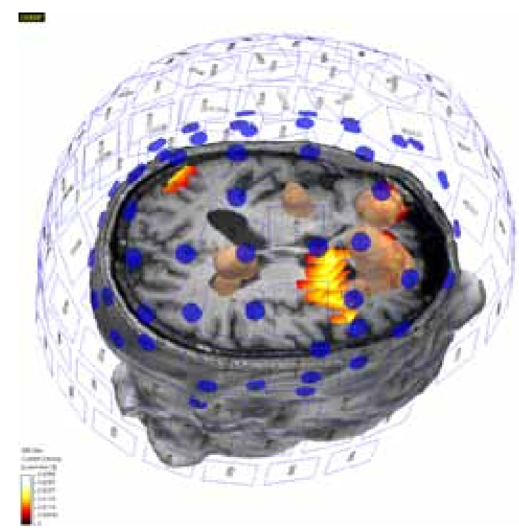

Inverse problem

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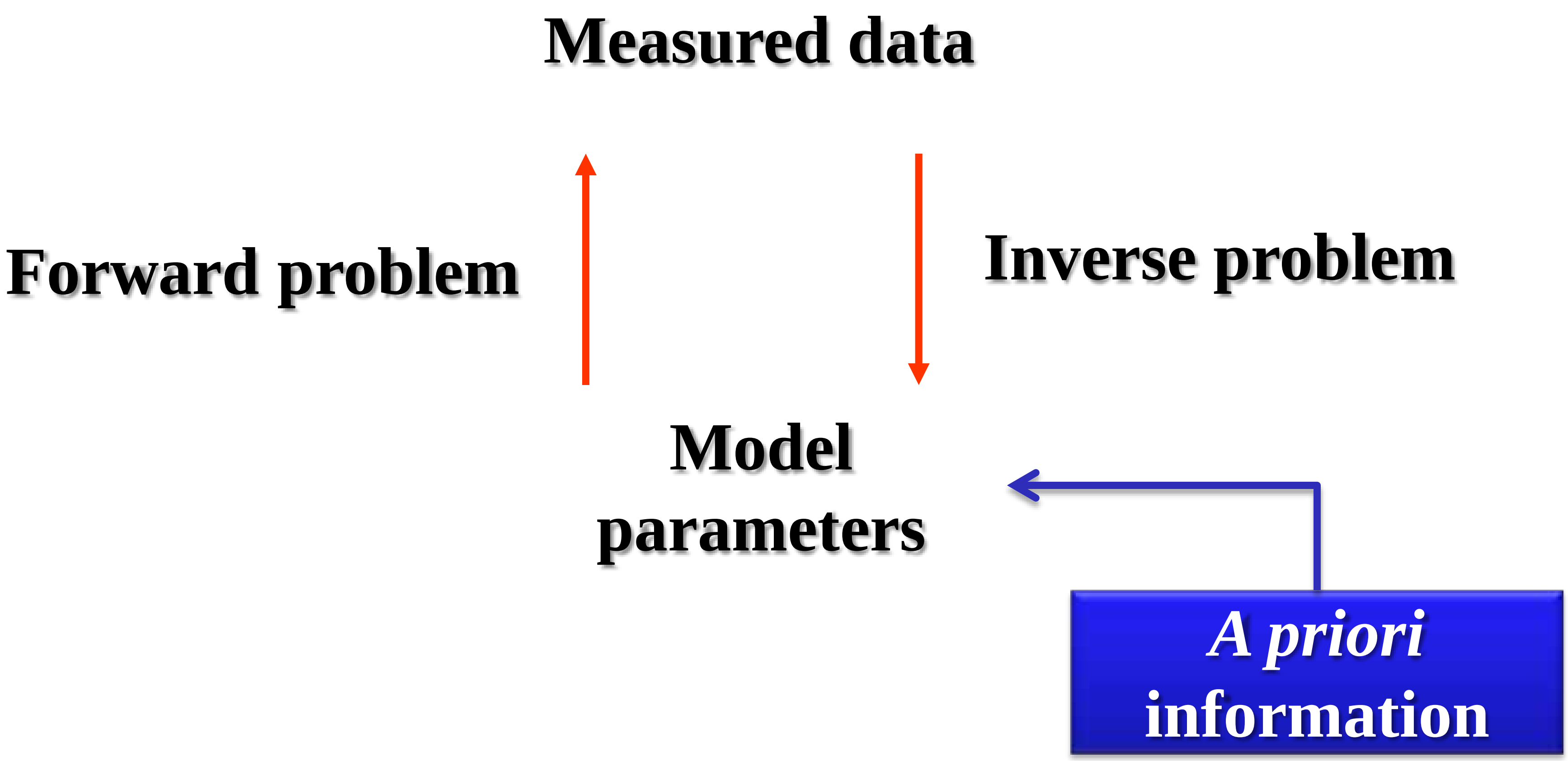
Estimation of model parameters based on observed variables.



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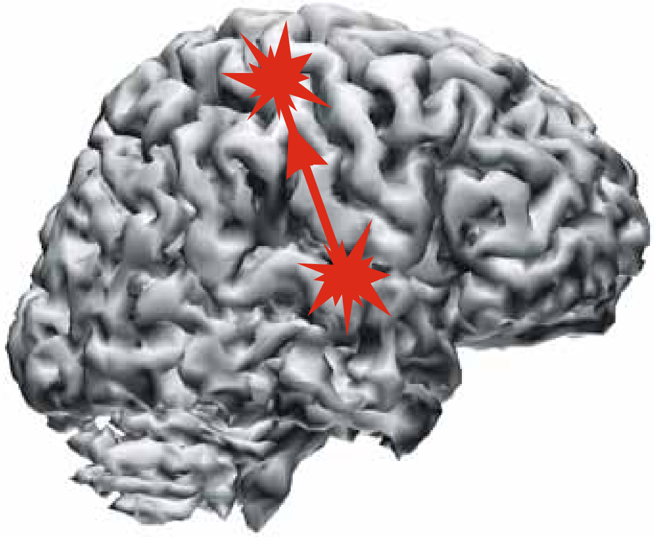
Understanding information transfer in the brain



Potential application areas:

- Therapeutic Systems
- BCI
- Prosthetics
- Etc.

Investigation on cortical 600 Hz Oscillations

Introduction

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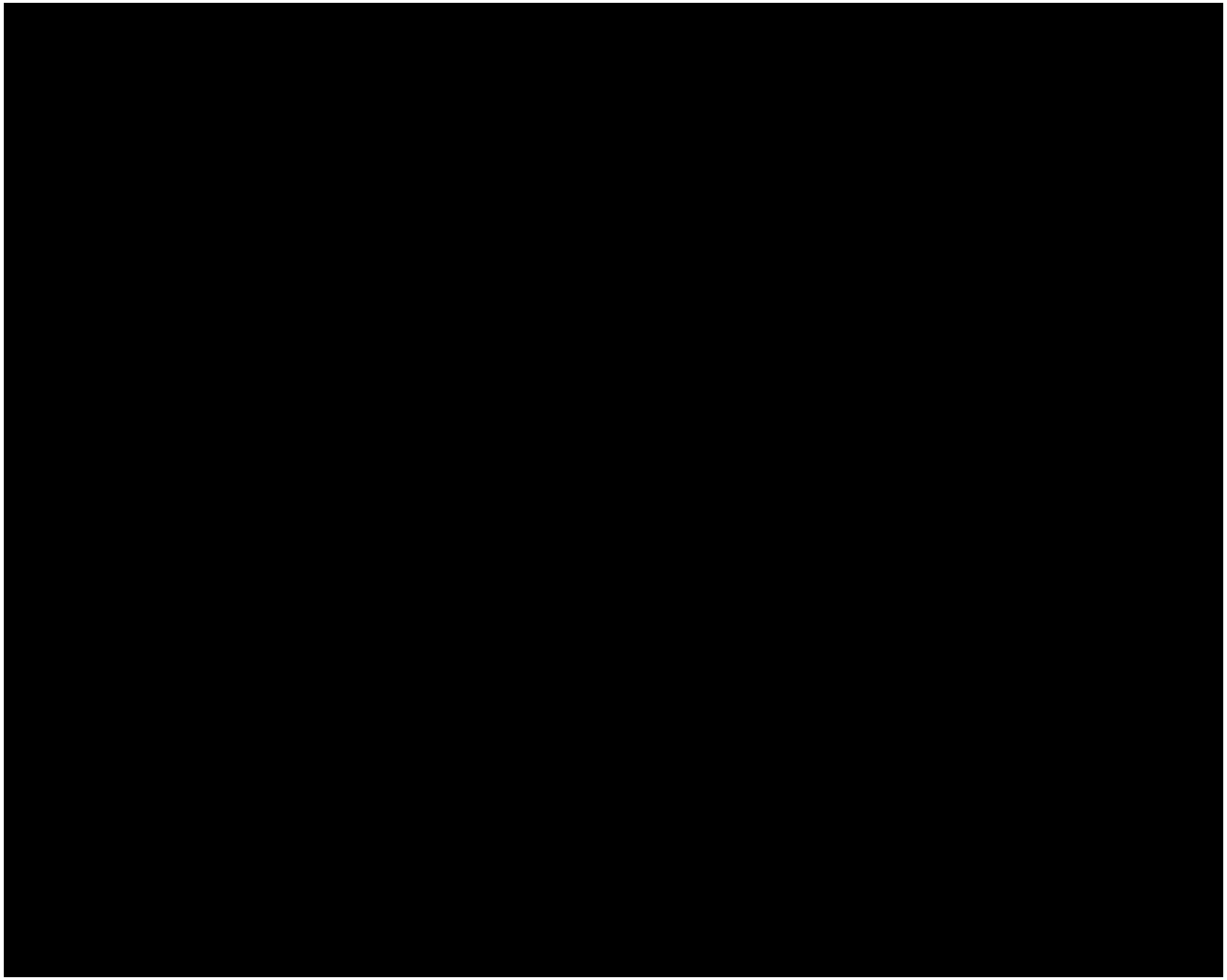
Median nerve stimulation

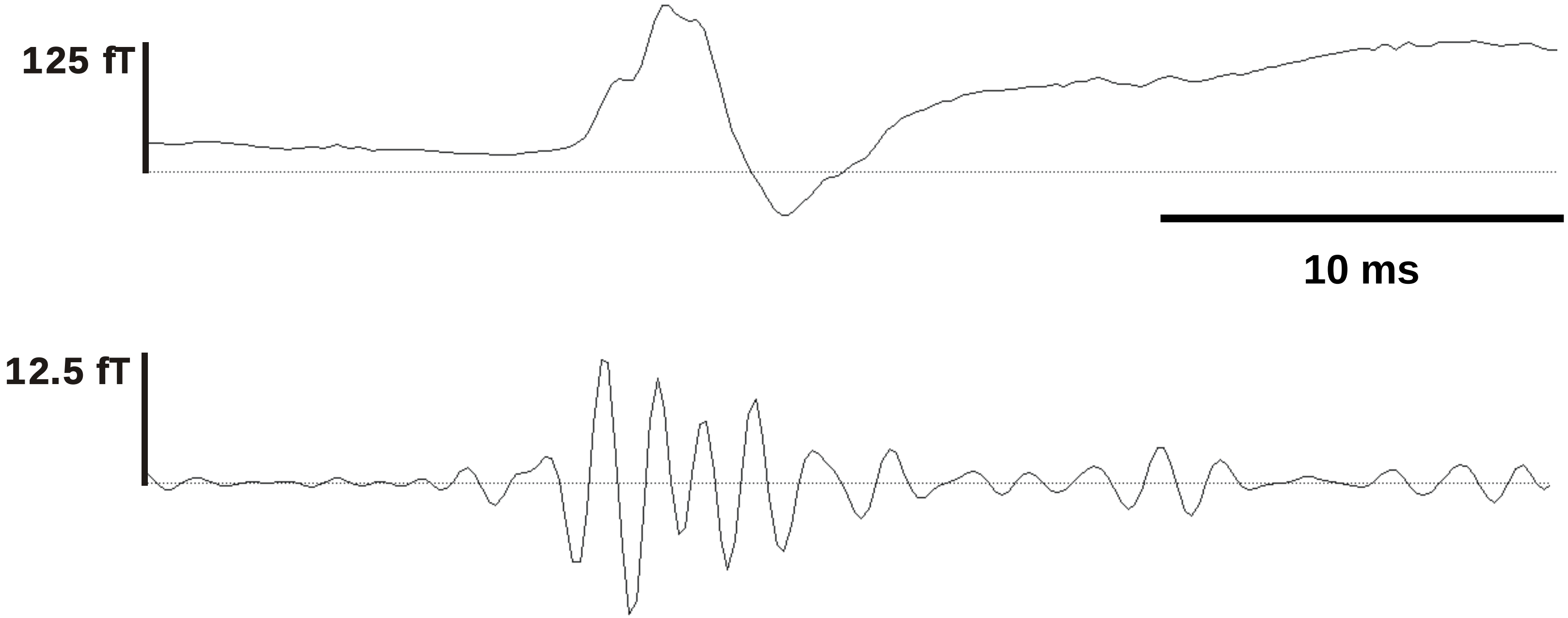


Routine procedure in the clinic

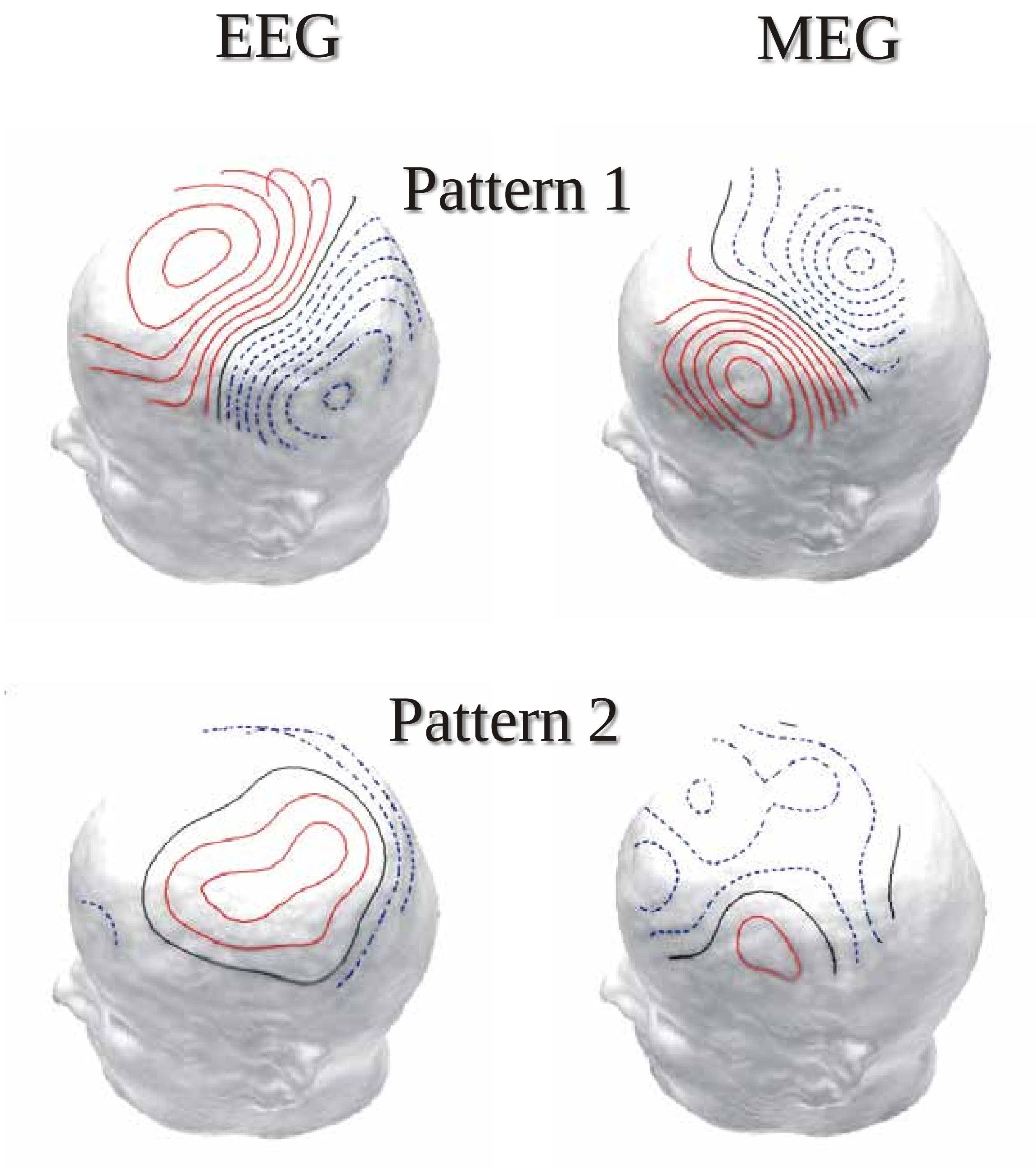
Other peripheral nerves possible

Philips-Biomagnetometer

Introduction



Fast oscillatory activity (around 600Hz) overlays low frequency (N20, P25) activity of the somato-sensory evoked field/potential.



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Initial cortical components

SVD in the time interval of N20 / P25 (filter: 450 - 750 Hz). First two spatial HF components.

Source localization

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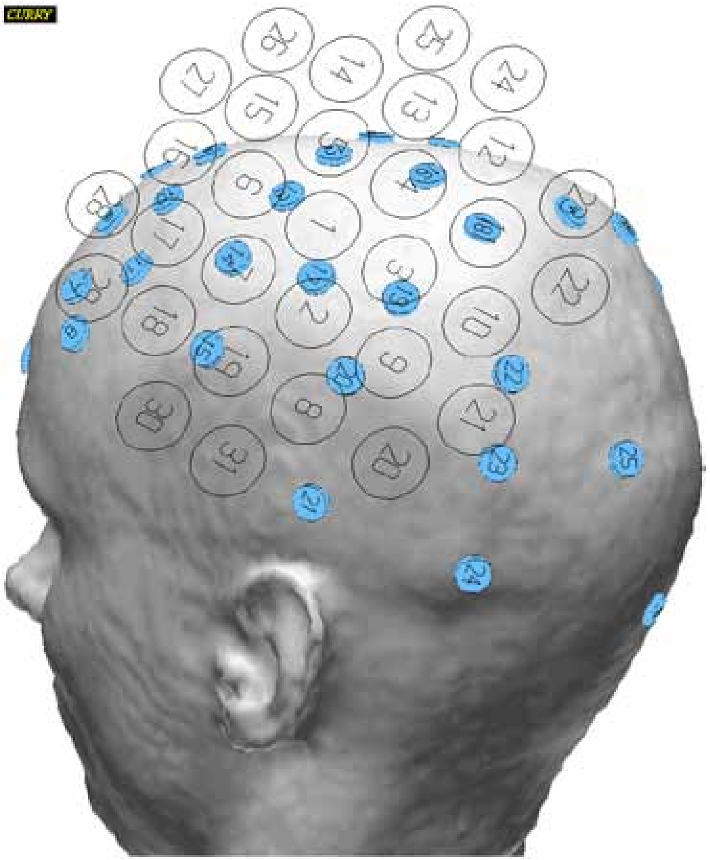
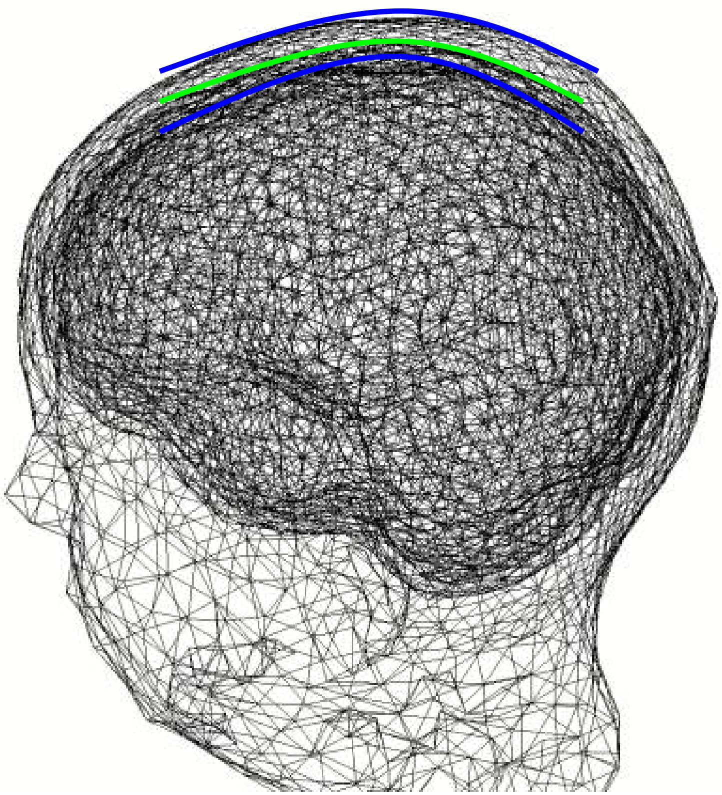
Modeling of the head

Skin: 0.33 S/m; skull: 0.0042 S/m; brain: 0.33 S/m

Triangle side length: 7 mm



Electrode and gradiometer positions



BEM model

Source localization

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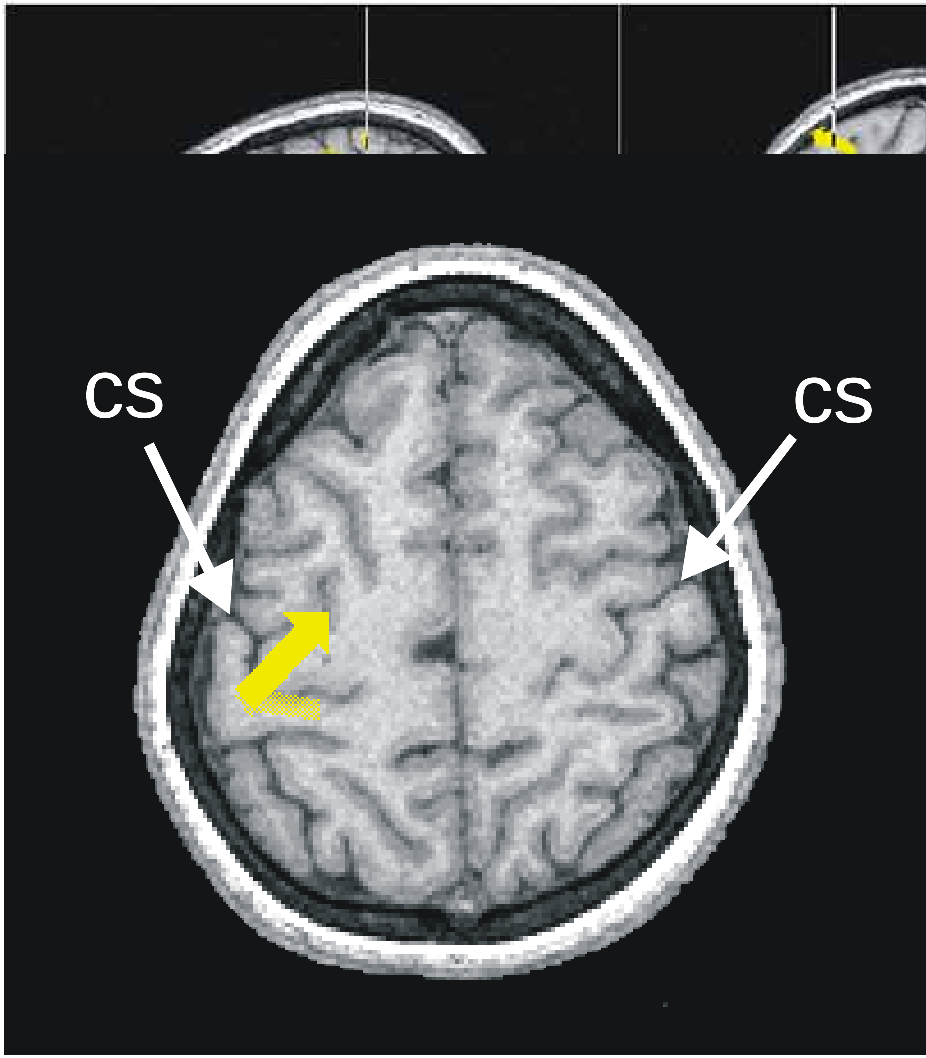
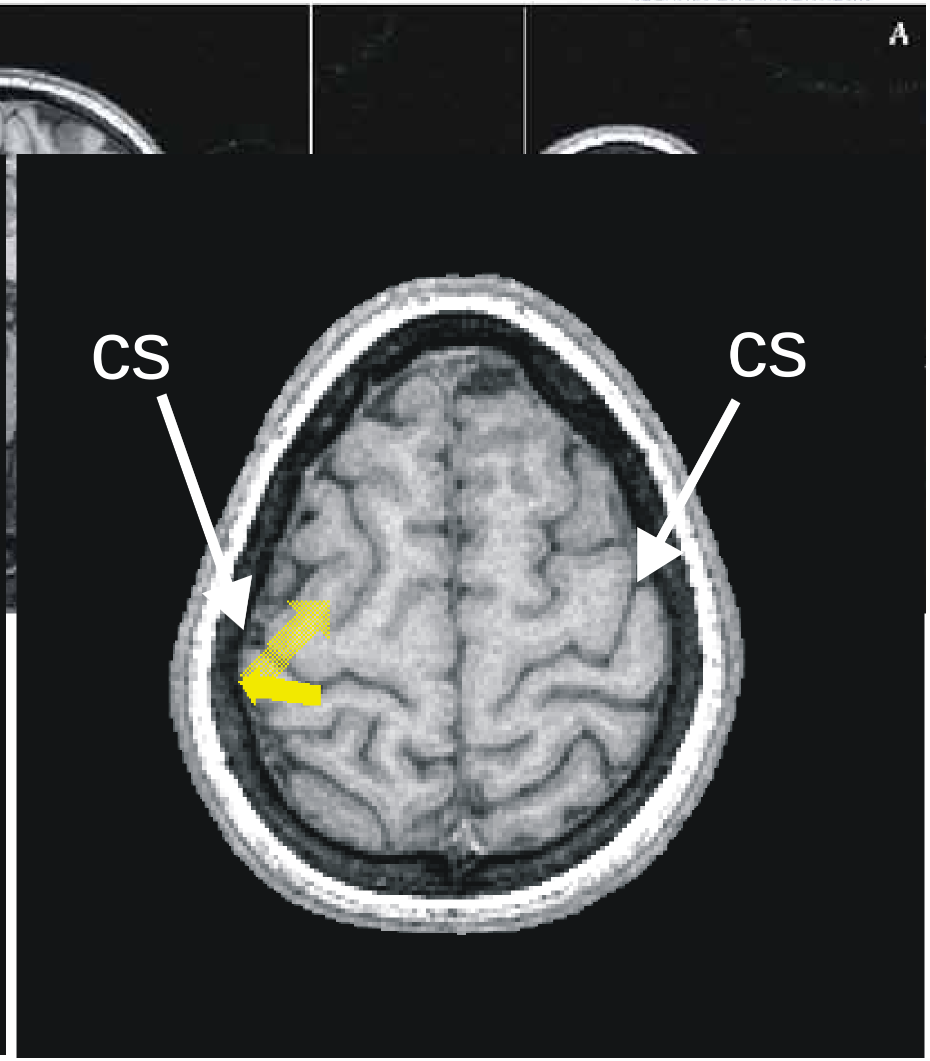


Cross section at tangential source



Cross section at radial source

Source localization

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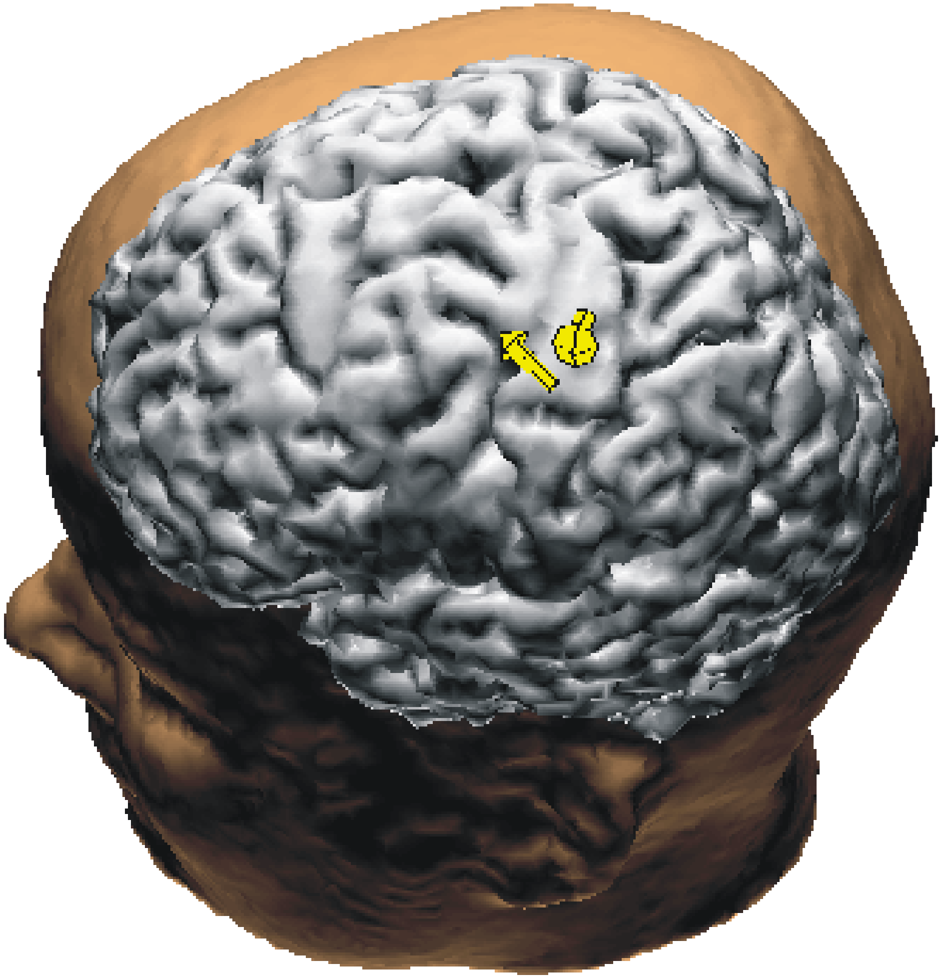
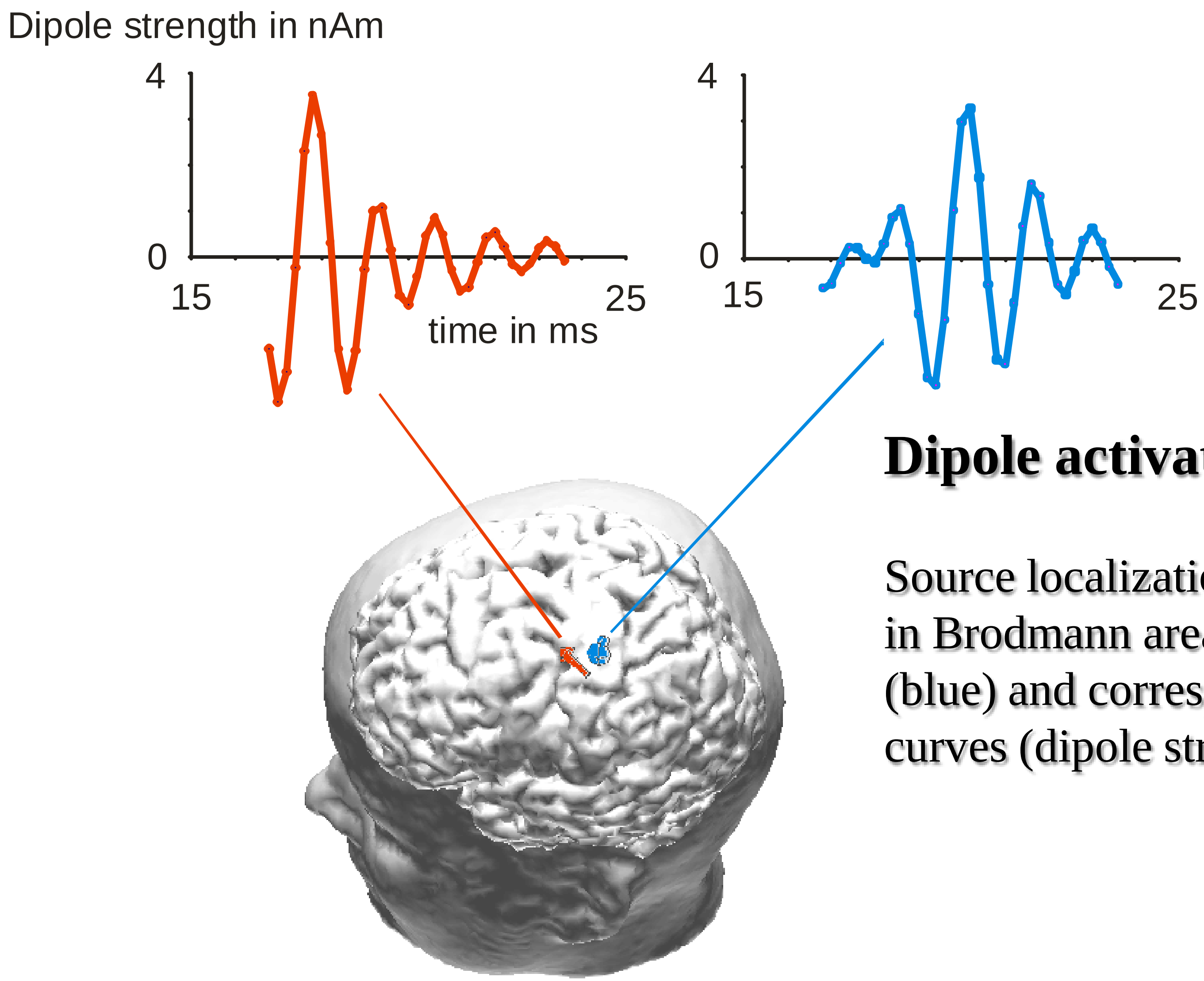


The radial dipole is more superior than the tangential dipole ($p<0.05$, 3-D distance is 13.5 ± 6 mm).

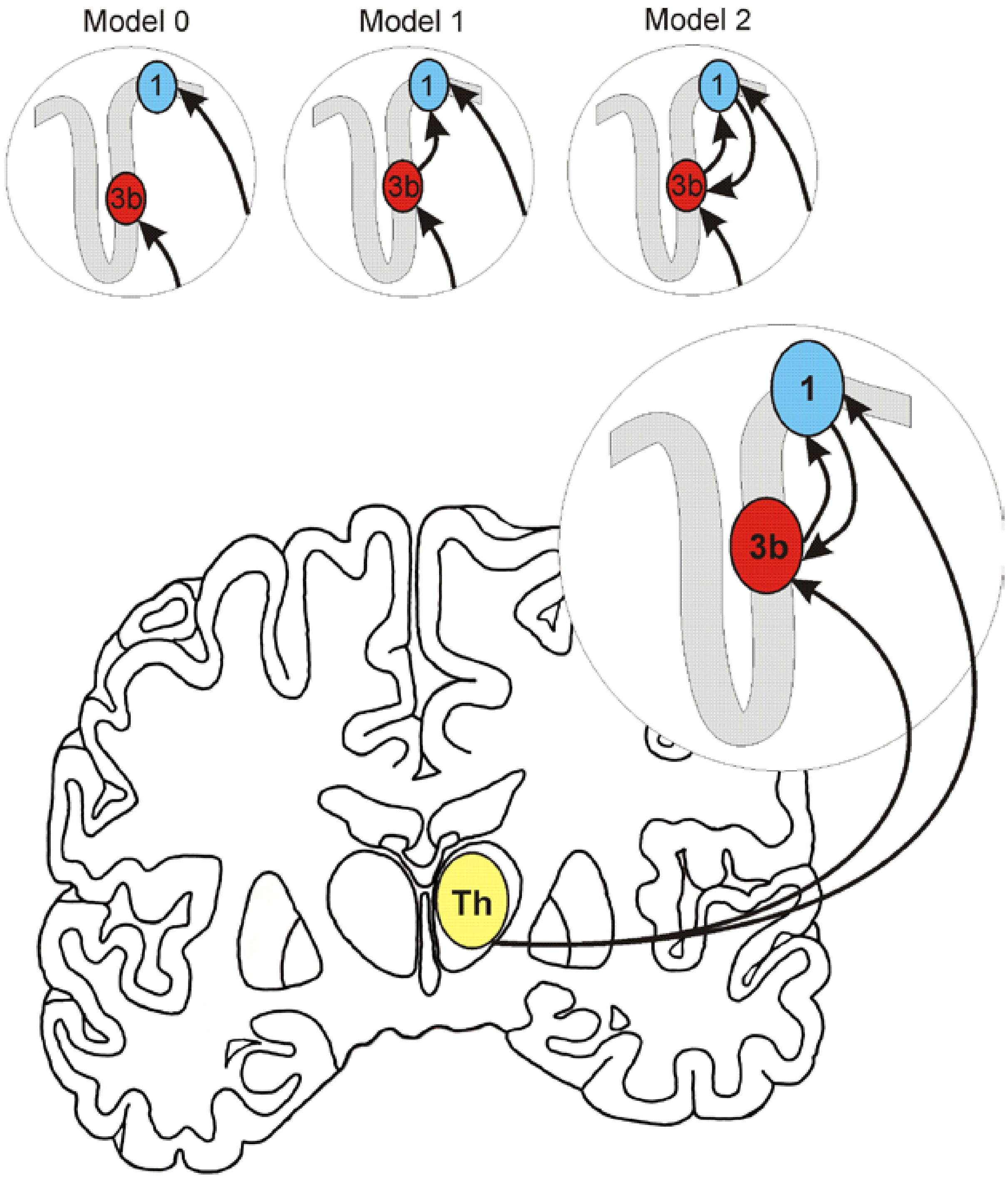
The amplitude maximum of the tangential dipole is earlier than the maximum of the radial dipole (1.7±1.8ms; $p<0.02$).

Information transfer



Dipole activation curves

Source localization results for dipoles in Brodmann area 3b (red) and 1 (blue) and corresponding activation curves (dipole strength over time)



Models describing the coupling between Brodmann areas 3b and 1

Input impulse originating from the thalamus is delivered to cortical area 3b and 1 for all three models

- model 0: no coupling between 3b and 1
- model 1: feed forward coupling between 3b and 1
- model 2: mutual coupling between 3b and 1

Information transfer

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$$\ddot{x} = \mu_1 \dot{x} + \varepsilon_{11} x + \varepsilon_{12} y + \varepsilon_{13} z(t - 0.0012),\; x(0) = \dot{x}(0) = 0$$

$$\ddot{y} = \mu_2 \dot{y} + \varepsilon_{21} x + \varepsilon_{22} y + \varepsilon_{23} z(t - \delta),\; y(0) = \dot{y}(0) = 0$$

$$z(t) = e^{-\frac{(t-\mu)^2}{2\sigma^2}} \times \cos(2\pi\nu t + \varphi)$$

Variables: x: Brodmann 3b; y: Brodmann 1; z: Thalamus

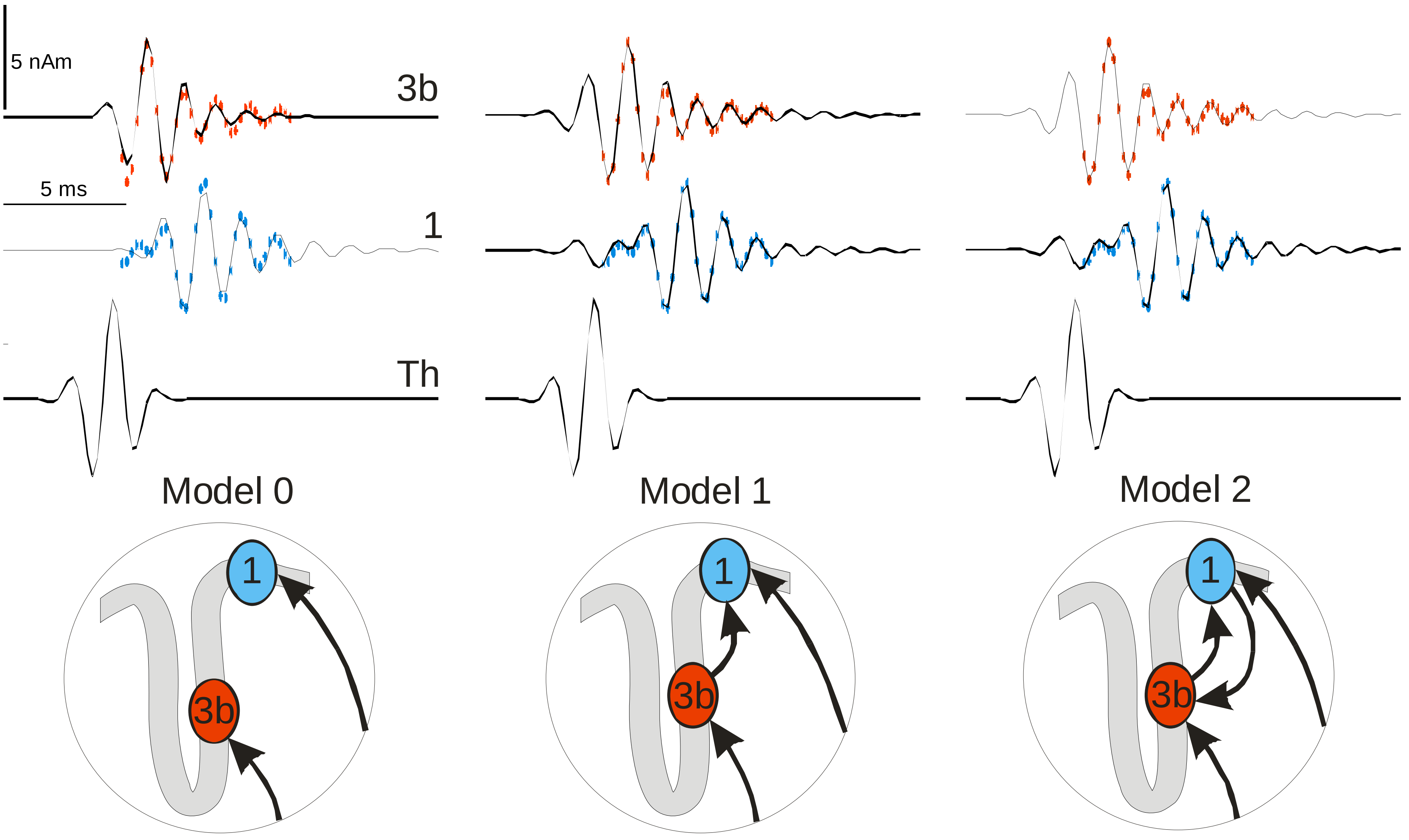
13 unknown parameter: $\mathbf{p} = \left(\mu, \mu_1, \mu_2, \sigma, \nu, \varphi, \varepsilon_{11}, \varepsilon_{12}, \varepsilon_{13}, \varepsilon_{21}, \varepsilon_{22}, \varepsilon_{23}, \delta\right)$

Zeroing of ε_{12} and ε_{21} yields model 0.

Zeroing of ε_{12} yields model 1.

Information transfer

Dipole activation and model predicted curves



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Mean cross validation errors

Subject	1	2	3	4	5	6	7	8	9	10
Model 0	0.309	0.547	0.547	0.585	0.647	0.165	0.153	1.532	0.977	0.019
Model 1	0.079	0.415	0.079	0.581	0.657	0.149	0.006	0.987	1.000	0.014
Model 2	0.077	0.422	0.072	0.085	0.122	0.122	0.005	0.192	0.130	0.005

Difference between the model predicted dipole activation curves and the dipole activation curves from source reconstruction.

model 2 vs. 1: p=0.02

model 2 vs. 0: p=0.002

model 1 vs. 0: p=0.001

Information transfer

Summary

- First combined EEG/MEG study of 600 Hz activity.
- Bidirectional information transfer is opposed to the assumed serial information processing in low frequency signals.
- Anatomical evidence for reciprocal pathways between areas 3b and 1 in monkey (Felleman and Van Essen 1991; Burton and Fabri 1995; Morecraft et al. 2004).
- Second-order differential equation modeling motivated by appeal to neural-mass models (Lopes da Silva et al. 1974; Freeman 1975).

Haueisen et al. Neuroimage, 2007

Thanks to:

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