# How do Gyral Orientation and White Matter Anisotropy Affect the Electric Field Induced by TMS?

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## Introduction

- **Goal:** Investigation of the underlying biophysical effects of transcranial magnetic stimulation (TMS).
- The biophysics of transcranial magnetic stimulation (TMS) is not yet well understood. We characterize in detail the electric field induced in gray (GM) and white matter (WM), using a geometrically accurate model of an individual head combined with high-resolution diffusion weighted imaging (DWI). Use of finite element methods (FEM) allows determination of the impact of gyrus orientation and WM anisotropy on the field induced by a figure-8 coil.
- **Questions:**
  - How does the modelling of white matter anisotropy influence the electric field distribution induced by TMS?
  - Where does stimulation occur?

## Methods

### Segmentation & meshing

A high-resolution tetrahedral head mesh was created (Thielscher 2010) based on T1- and T2-weighted MR images (Siemens 3T TIM Trio) . (Segmentation using Freesurfer, FSL; Meshing with ReMESH, Gmsh)

Distinguished tissues: white matter (WM), gray matter (GM), cerebrospinal fluid (CSF) including the ventricles, skull and skin.

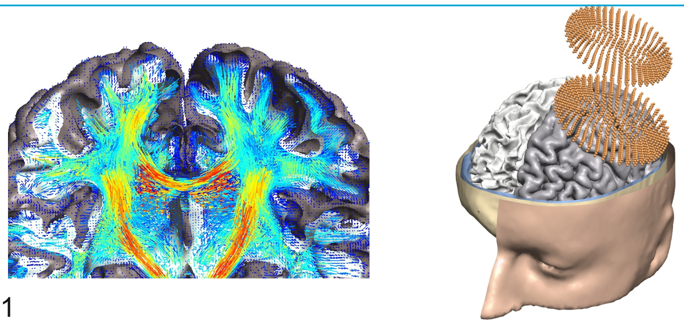
### Conductivity assignment

DWI acquisition was performed on a Siemens 7T scanner using the ZOOPPA sequence (Heidemann 2010).Conductivity anisotropy was estimated using three different mappings between the DTI and the conductivity tensor:

1. Volume normalized approach (Güllmar 2010; GM/WM: 0.276/0.127 S/m)
2. Volume normalized approach (mean conductivity in GM=WM= 0.127 S/m)
3. Direct mapping with adjusted scale factor (Tuch 2001; Wolters, 2009)

For each anisotropic model an isotropic reference model was created.

CSF (1.654 S/m) , skull (0.010 S/m) and skin (0.465 S/m) were modelled as isotropic.



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### Calculation of the electric field and the activating function

The electric field was calculated for a figure-8 coil (standard Magstim 70mm) (coil current 1A/µs) at five different positions with the coil either directed perpendicular or parallel to the local gyri. (Implementation using MATLAB, C++ and GetFEM++)

The nerve activating function (Rattay 1986) was computed along exemplary fibre tracts. DWI tracking (using Camino) was based on seed masks in the brain area situated underneath the coil centre. The WM parts of the fibres were extended into GM by assuming that the GM path was perpendicular to the local WM/GM boundary (similar to the orientation of the cortical columns).

## References

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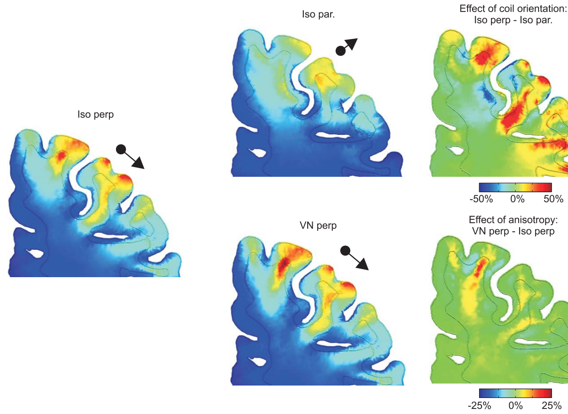
## Results

Currents that are approximately perpendicular to the local gyral orientation significantly enhance the field strength both in GM and WM. The spatial distribution of this effect differs distinctly for these two tissues. While the field in GM is selectively enhanced at the gyral crowns and lips, high field strengths can still occur rather deep in WM. Taking the WM anisotropy into account generally boosts this effect in WM, but not in GM (Fig 2). The differences in the electric field can be explained by the effective conductivity (conductivity in field direction) (Fig 3). The influence of coil orientation and anisotropy on the field strength and depth of the field differ markedly between WM and GM (Fig 4). Results of the activating function indicates that stimulation might also occur in WM regions. Furthermore stimulation is dependent on the location of the tract in the gyrus (Fig 5).

**Effects of conductivity anisotropy and coil orientation**

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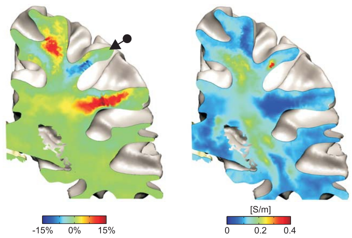
**Differences in field strength explained by effective conductivity**




Difference in field strength    Effective conductivity

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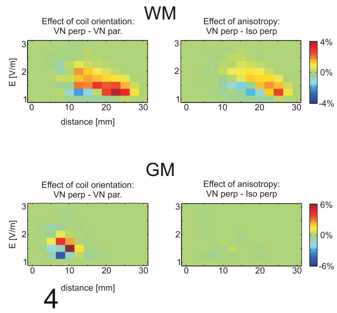
**Effects on Field distribution differ markedly between WM and GM**

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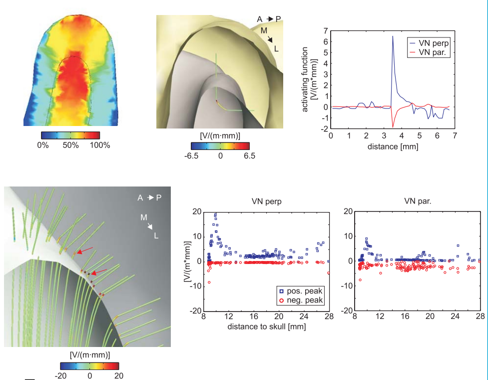
**Activating function**

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**Conclusion and future work:**

Our results show a marked influence of the local gyral orientation on the induced field, with notably different patterns for gray and white matter. WM anisotropy influences the field distribution in WM, but only weakly in neighbouring GM. The results for the nerve activating function highlight the future importance of using realistic nerve models to improve estimates of the effect of TMS on WM structures. Simulation software will be made publicly and freely available as SimNIBS (Simulation of Non-invasive Brain Stimulation).

www.simnibs.org