

<u>Artefact Correction In Diffusion MRI</u> ACID SPM toolbox

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www.diffusiontools.com



SPM-ACID Toolbox DTI, DKI, & NODDI-DTI



Open-Access: www.diffusiontools.com

Questions/queries to Siawoosh Mohammadi s.mohammadi@uke.de

Preprocessing:

- Eddy current and motion
- HySCO (EPI distortions)
- msPOAS (adaptive smoothing)
- Vibration Artifacts (DTI model)
- Spinal Cord Branch in prep
- Rican Noise Bias Correction in prep.

Signal Models:

- DTI (ols, wols, robust fitting)
- Diffusion Kurtosis Imaging
- NODDI-DTI



Artefact Correction In Diffusion MRI ACID SPM toolbox



NODDI-DTI

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- 30-60 min intro to ACID toolbox
- hands-on application:
 - Installation,
 - ECMOCO,
 - msPOAS,
 - HySCO,
 - Tensor fitting
- Open discussion



- One main goal of our group: "In-vivo histology using MRI"
- Standard DTI is sensitive to microstructure but unspecific
- Advanced diffusion MRI might improve specificity
- Diffusion MRI suffers from various artifacts
- Advanced diffusion MRI requires correcting artifacts

• ACID toolbox provides *principled, model-based, and peerreviewed correction methods* to correct artifacts and thus enable advanced diffusion MRI



- Diffusion MRI: why, how, and what does it mean?
- Pre-processing steps
 - Eddy current and motion correction
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- Diffusion models
 - Weighted Ordinary Least Squares, Robust Tensor Fitting
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Outline

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Why is diffusion more interesting than standard structural imaging?



Histology

T1w image



Diffusion MRI reveals microstructural information



Histology

T1w image

DTI index map



Main features of fibers in the white matter



Fieremans, ESMRMB, 2015



Aligned axons in fiber pathways





Diffusion weighted images









Diffusion weighted images





What do we need for diffusion MRI?

Shell 1 (b-value e.g 1000 s/mm²)

Shell 0 (b-value e.g 0 or 100 s/mm²)

n DW images



m reference images



Model



The general linear model framework for diffusion MRI





Diffusion MRI : interpreting fractional anisotropy

Fractional anisotropy - FA



CSF: Isotropic diffusion

0





0

Diffusion MRI : interpreting fractional anisotropy

Fractional anisotropy - FA





WM: Anisotropic diffusion





Diffusion MRI reveals orientation information







Diffusion MRI reveals orientation information







For tractography in SPM contact Marco Reisert:

https://www.uniklinik-freiburg.de/mren/members/current/reisert/



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EC and Motion correction

Single spin echo







Stejskal & Tanner, JCP, 1965



Mohammadi et al., Frontiers, 2015



Whole-brain eddy current distortions



Mohammadi et al., MRM, 2010



Eddy current and motion correction toolbox

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Eddy current and motion correction toolbox

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Vibration artifacts and its correction



Correction of Vibration Artifacts in DTI Using Phase-Encoding Reversal (COVIPER)

Mohammadi et al., MRM, 2012



Correction of vibration artefacts in DTI using phase-encoding reversal (COVIPER)



Mohammadi et al., MRM, 2012

FA



ACID-COVIPER tool Vibration artefacts

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ACID-COVIPER tool Vibration artefacts

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What is adaptive denoising?





What is adaptive denoising?





Position-orientation adaptive smoothing (POAS)





Multi-shell position-orientation adaptive smoothing (msPOAS)



WIAS – Hamburg: Becker et al., 2014; Tabelow/Mohammadi et al., 2015



Multi-shell position-orientation adaptive smoothing (msPOAS)



WIAS – Hamburg: Becker et al., 2014; Tabelow/Mohammadi et al., 2015



msPOAS in cortex DWI



- Multi-shell dMRI
- @1.2 x 1.2 x 1.2 mm³
- @ 3T clinical scanner

Becker et al., MIA, 2012, Becker et al., 2014



msPOAS in cortex DWI and across brain



Becker et al., MIA, 2012, Becker et al., 2014



ACID toolbox – msPOAS NODDI: Intracellular compartment



Original



msPOAS

Mohammadi et al., Frontiers in Neuroscience, 2015



Denoising: multi-shell orientationposition adaptive smoothing (msPOAS)



Tabelow/Mohammadi et al., Neuroinformatics, 2015



Denoising: multi-shell orientationposition adaptive smoothing (msPOAS)

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Tabelow/Mohammadi et al., Neuroinformatics, 2015



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DTI images Select high- and low-b-value images.

Universitätsklinikum Hamburg-Eppendorf

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Most important

Diffusoin Data

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- b-values
- b-vectors



What are the outputs?



{M} = method:

- ols: ordinary least square
- wls: weighted ordinary least square
- robust: robust fitting
- More details here:
 - Mohammadi et al., MRM, 2012;
 - Mohammadi et al., NI, 2013

More advanced:

- Tensor fit error: RES_{M}
- Eigenvalues and Eigenvectors
- Output for Freiburg Fibertools (Tractography – contact Marco Reisert / Volkmar Glauche)

Learn more about the DTI metrics:

Basser et al. 1996; Diffusion MRI..., Ed: H Johansen-Berg & TEJ Behrens, 200?



Robust tensor fitting for spinal cord DTI

Based on Zwiers, NI, 2010

$$y = X d + \varepsilon$$



Mohammadi et al., MRM, 2012 Mohammadi et al., NI, 2013



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What is the DKI switch?

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Most important

- Diffusoin Data
- b-values (multi-shell)
- b-vectors

DKI switch



$$\ln\left[\frac{S(\mathbf{n},b)}{S_0}\right] = -b\sum_{i=1}^3 \sum_{j=1}^3 n_i n_j D_{ij} \qquad \text{diffusion tensor}$$
$$+\frac{1}{6}b^2 \overline{D}^2 \sum_{i=1}^3 \sum_{j=1}^3 \sum_{k=1}^3 \sum_{l=1}^3 n_i n_j n_k n_l W_{ijkl},$$
kurtosis tensor

The kurtosis tensor is fitted using the constrained least square model suggested by Tabesh et al., 2011. For implementation into ACID, see Mohammadi et al., Frontiers in Neurosci., 2015



What are the outputs?



Maps

- MK mean kurtosis
- AWF axonal water fraction

Learn more about MK and AWF:

- Jensen et al., 2010 (review about DKI);
- Fieremans et al., 2011 (biophysical model of AWF)
- Jelescu et al., 2015 (comparison to NODDI)



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Zhang, OHBM, 2014 Fieremans, ESMRMB, 2015

Biophysical model of the diffusion signal







Biophysical model of the diffusion signal



Zhang, OHBM, 2014



Fieremans, ESMRMB, 2015

Biophysical model of the diffusion signal

Fiber dispersion "" [a. u.]



Fiber density " τ " [a. u.]





Zhang, OHBM, 2014



Universitätsklinikum Hamburg-Eppendorf **NODDI-DTI:**

fiber density " ν "

mean diffusivity "MD"



Edwards et al., 2017





$$\nu = 1 - \sqrt{\frac{1}{2} \left(\frac{3\text{MD}}{d} - 1\right)}$$

Edwards et al., 2017



Universitätsklinikum Hamburg-Eppendorf **NODDI-DTI:**

fiber dispersion " τ "

mean diffusivity "MD" & fractional anisotropy "FA"

$$\tau = \frac{1}{3} \left(1 + \frac{4}{|d - MD|} \frac{MD \times FA}{\sqrt{3 - 2FA^2}} \right)$$





Contributers





Karsten Tabelow & Jörg Polzehl, WIAS, Berlin (msPOAS and DKI)

Lars Ruthotto, Emroy University (HySCO and DKI)

- Volkmar Glauche, Universität Freiburg (FA-VBS)
- Luke Edward, MPI-CBS, Leipzig (NODDI-DTI)
- Gergely David, University Zürich (spinal cord branch *in prep.*)