k-space and q-space: Combining Ultra-High Spatial and Angular Resolution in Diffusion Imaging using ZOOPPA at 7T

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Introduction: Recently, a combination of reduced FOV acquisition (zoomed imaging) and partially parallel acquisition (PPA), given the name ZOOPPA, has been used for isotropic high resolution diffusion-weighted imaging (DWI) at ultra-high field strength [1]. With ZOOPPA it is possible to perform DWI at 7T with 1 mm isotropic resolution [2]. In the current study, the protocol parameter were optimized for high SNR, while at the same time the number of averages was reduced by the use of a novel noise cleaning procedure [3]. The acquired DWI data have sufficient SNR to resolve fibre crossings at this spatial resolution in the white matter. The diffusion signal in the cortex shows clear radial anisotropy and the high spatial resolution allows the detection of subcomponents of white matter fibre bundles which are difficult to observe with MRI.

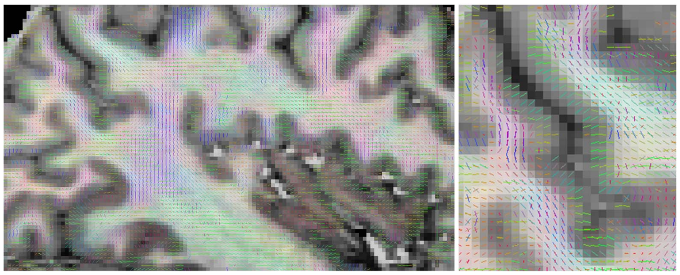

Fig 1: Sagittal view of the main fibre orientations. Enlarged section shows radial anisotropy in the transoccipital sulcus. Most white matter voxels shows a significant signal contribution of 2 fibre compartments.

Methods: Imaging was performed on a human whole-body 7T MR scanner (MAGNETOM 7T, Siemens Healthcare, Erlangen, Germany) equipped with a 24-element phased array head coil (Nova Medical, Wilmington, MA, USA). Informed consent was obtained before each study. The single-shot DW EPI with ZOOPPA was performed as described in [2] with the following image protocol: TR 10500ms, TE 82ms, BW 980Hz/Pixel, FOV 144x150mm^2, partial Fourier 5/8, isotropic resolution 1.0mm^3, 71 axial slices with 10% overlap, DW with b = 1000 s/mm^2, 60 directions and 4 averages. A total acceleration factor (AF) of 4.2 was achieved with AF_{GRAPPA}= 3 and AF_{ZOOM} = 1.39. The total acquisition time was 48 min. A fat suppression method was used, which is well suited to ultra-high field DWI [4]. The DW images were noise cleaned with the help of a two-stage hybrid image restoration procedure as described in [3], followed by a correction for subject motion, and linear registration to a T_1-weighted anatomical scan (0.9 mm resolution). In each voxel, multiple fibre orientations (f-value > 0.05) [4] and the fibre orientation distribution (FOD) was computed by constrained spherical deconvolution [5] followed by whole-brain fibre-tracking using *MRtrix* [6].

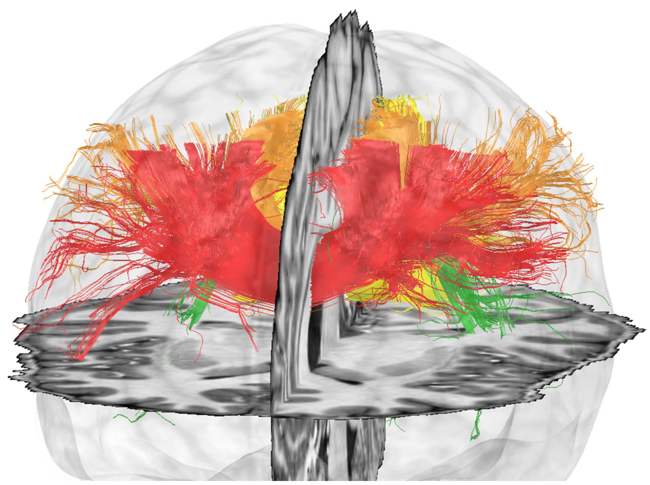

Fig. 2: Lateral connections of the corpus callosum to the precentral (red) and postcentral (orange) gyrus, the occipital (yellow) and temporal (green) lobe.

Results and Discussion: The main fibre orientations in each voxel are shown in a sagittal view in Fig. 1 overlaid on the T_1 anatomy. The enlarged section highlights radial anisotropy in the cortex of the transoccipital sulcus and good spatial correspondence (no distortions). The high spatial resolution improved fibre tracking significantly over previously published results. This is illustrated by the abounding lateral connections of the corpus callosum to the precentral and postcentral gyrus (Fig. 2) computed by streamline tractography. Fig. 3a shows fibre tracks in the superior longitudinal fasciculus (SLF), which can be subdivided into 4 compartments connecting the inferior frontal lobe with the inferior-parietal (pink), lateral-occipital (green), superior- (orange) and middle- (red) temporal lobe. Furthermore, the data quality allows the resolution of small fibre bundles, like a direct connection between the primary auditory and primary visual system (see Fig. 3b) and the transcallosal connection of the visual motion area V5/MT (see Fig. 3c). V5/MT was identified by an fMRI localizer and is overlaid in red colour in Fig. 3c.

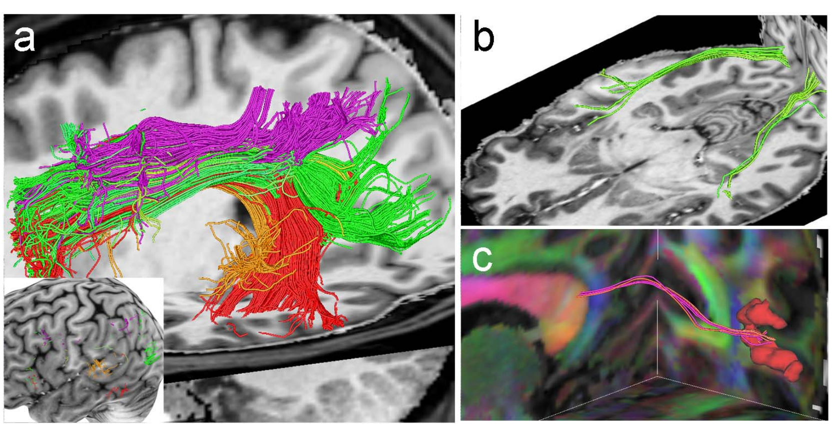

Fig. 3: (a) The superior longitudinal fasciculus can be divided into 4 compartments. (b) Direct connection between. the auditory and the visual system. (c) Transcallosal connection to V5/MT (overlaid in red).

Conclusion: DW EPI with ZOOPPA at ultra-high field strength enables DWI with a very high spatial and angular resolution together with a sufficiently high SNR to resolve crossing fibres.

References: [1] Heidemann, et al. HBM 2009, #254 F-PM. [2] Heidemann, et al. ISMRM 2010, #1610. [3] Lohmann, et al. MRM 2010;64:15-22. . [4] Behrens, et al. Neuroimage 2007:34:144-55. [5] Ivanov, et al. MRM 2010;64:319-26. [6] Tournier, et al. NeuroImage 2007;35:1459-72. [7] http://www.brain.org.au/software